# NEW TOOL TO CONTROL AND MONITOR WEIGHTED VEST TRAINING LOAD FOR SPRINTING AND JUMPING IN SOCCER

**JORGE CARLOS-VIVAS,[1] TOMÁS T. FREITAS,[1] MIGUEL CUESTA,[1] JORGE PEREZ-GOMEZ,[2] MOISÉS DE HOYO,[3,4] AND PEDRO E. ALCARAZ[1,5]**

AU1 *[1]UCAM Research Center for High Performance Sport, Catholic University of Murcia, Murcia, Spain; [2]Faculty of Sport Sciences, University of Extremadura, Caceres, Spain; [3]Department of Physical Education and Sport, University of Sevilla,*
AU2 *Sevilla, Spain; [4]Fitness Section, Levante UD, Valencia, Spain; and [5]Faculty of Sport Sciences, UCAM, Catholic University of Murcia, Murcia, Spain*

## ABSTRACT

Carlos-Vivas, J, Freitas, TT, Cuesta, M, Perez-Gomez, J, De Hoyo, M, and Alcaraz, PE. New tool to control and monitor weighted vest training load for sprinting and jumping in soccer. *J Strength Cond Res* XX(X): 000–000, 2018—The purpose of this study was to develop 2 regression equations that accurately describe the relationship between weighted vest loads and performance indicators in sprinting (i.e., maximum velocity, Vmax) and jumping (i.e., maximum height, Hmax). Also, this study aimed to investigate the effects of increasing the load on spatio-temporal variables and power development in soccer players and to determine the "optimal load" for sprinting and jumping. Twenty-five semiprofessional soccer players performed the sprint test, whereas a total of 46 completed the vertical jump test. Two different regression equations were developed for calculating the load for each exercise. The following equations were obtained: % body mass (BM) $= -2.0762 \cdot \%\text{Vmax} + 207.99$ for the sprint and % BM $= -0.7156 \cdot \%\text{Hmax} + 71.588$ for the vertical jump. For both sprinting and jumping, when the load increased, Vmax and Hmax decreased. The "optimal load" for resisted training using weighted vest was unclear for sprinting and close to BM for vertical jump. This study presents a new tool to individualize the training load for resisted sprinting and jumping using weighted vest in soccer players and to develop the whole force-velocity spectrum according to the objectives of the different periods of the season.

**KEY WORDS** speed, strength, power output, performance, football, training prescription

---

Address correspondence to Jorge Carlos-Vivas, jcarlos@ucam.edu.

*00(00)/1–9*

*Journal of Strength and Conditioning Research*

## INTRODUCTION

Sprinting and jumping are high-intensity actions crucial in soccer, e.g., when scoring a goal or to be better positioned to win the ball (17). The success in such actions has been related to the athlete's capacity for maximizing power output (45), which is determined by the force-velocity (F-V) relationship. This relationship dictates that the amount of force generated decreases as the velocity of movement increases (23) and that maximal power output (Pmax) is achieved at compromised levels of force and velocity (25). Thus, Pmax may be improved by increasing the ability to develop high levels of force at low velocities and/or by enhancing movement AU3 velocity (11,31). Theoretically, the use of low-load maximum-velocity movements can affect the high-velocity area of the F-V curve, whereas heavier loads enhance the high-force segment. In this regard, mixed methods have been shown to result in a higher increase in Pmax because of a more well-rounded development of the F-V relationship (11).

A widely used and very fashionable approach to develop power output today is the "optimal load" training, which consists of using the load that elicits Pmax in a specific movement (10,25). In fact, it has been suggested that training with the OL is effective for improving power output (11,31) because it provides an adequate load-specific stimulus to elicit increases in Pmax (31). Several investigations have shown greater improvements in Pmax when the OL was used rather than other load conditions over short-term interventions lasting 8–12 weeks (11,31). However, the load that maximizes power in multi-joint, sports-specific movements differs significantly across different exercises because of the nature of the movement involved (20).

There are different training methods to improve performance on abilities such as sprint or vertical jump (2,16,19,38). These methods can increase athletes' strength and power levels in its vertical and horizontal components (11), depending on the sport needs. Most research has

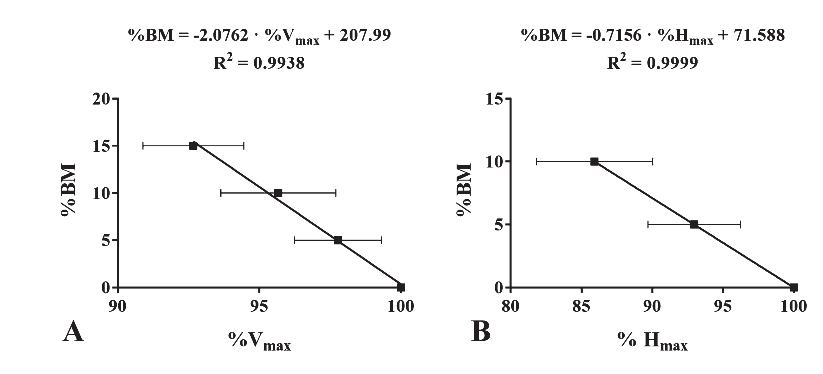

**Figure 1.** Effect of increase in load on (A) Vmax for sprint and (B) Hmax for countermovement jumps.

focused on identifying which are the most appropriate training methods that could translate the strength and power training gains to an increased performance of sports-specific movements (11,27).

Regarding sprinting, resisted sprint training is one of the most used methods because it provides a mechanical overload specific to sports movements and allows the athlete to reproduce the technical gestures with an additional external load (13). There are different resisted sprint training modalities that require different equipments used to add external resistance: sled towing, weighted vest, parachutes, running uphill, or running on sand surface (1). The direction of the resultant ground reaction force (GRF) vector, in response to the force applied by the athlete, will have a different direction according to the sport and the conditions in which it happens; therefore, depending on the task, the work should focus more on vertical or horizontal forces. Thus, recent studies have analyzed sprint mechanics in elite athletes (33,37) and have shown typical manifestations of instantaneous vertical, anteroposterior, and lateral component of GRFs. Data showed that the GRF vertical component is greater than the horizontal during full sprint, except in the first steps when the sprint starts from a 4-point stance static position (33,37). Furthermore, vertical GRF increases while the horizontal component decreases as velocity increases (33,37). Based on these findings and knowing that, in soccer, most sprints begin in motion (42) with the body in a more straight position (2-point stance), training with a vertical component resistance could be effective in improving performance in soccer. Furthermore, weighted vest resisted training (WVT) is a method in which resistance has a greater vertical component on the athlete's center of mass (36), thus providing a more specific stimulus for soccer players. However, there is no scientific evidence on this matter, and the few studies that have included weighted vest as a resistance device have assessed only the effects on kinematics, using loads from 7 to 20% of the body mass (BM) (4,6,9,12,14,39).

With respect to vertical jump, among nonconventional power training methods, WVT has demonstrated excellent results, showing improvements of ≥10% with 3–10-week interventions in trained athletes (5–7). In addition, WVT use significantly increases the vertical jump performance using loads from 7 to 13% BM when compared with conventional power training (5–7). In the vertical jump, the athlete must overcome his/her BM, and the resultant force is completely vertical, acting on his/her center of mass, where the resultant GRF is equal to the product between the player's mass and the acceleration of gravity (26).

Therefore, WVT may be a good training method for soccer because it allows multidirectional training that is essential to this sport (21). Likewise, WVT allows athletes to reproduce the real actions found in competition while adding an external load closer to their center of mass. Despite the importance given to other resisted training methods (i.e., sled towing) in the past, less is known regarding the F-V relationship with weighted vest. Moreover, it would be interesting to know the power output generated when the load increases to properly prescribe the OL training. Thus, the first objective of this study was to develop 2 regression equations that accurately describe the relationship between weight vest loads and performance indicators in sprinting (i.e., maximum velocity, Vmax) and jumping (i.e., Hmax). In addition, this study aimed to describe how the increase of the load affects spatio-temporal variables and power development in soccer players and to determine the OL in sprinting and jumping.

## METHODS

### Experimental Approach to the Problem

A cross-sectional study design was used. Testing was conducted in the midseason after 2 days of rest to avoid possible interferences caused by fatigue. All measures were taken in a single testing session. Participants performed eight 30-m sprints and 6 countermovement jumps (CMJs) while wearing a weighted vest (Kettler, Germany) with different loads to determine changes in spatio-temporal variables. Sprints were performed unloaded and using a weighted vest with an additional load corresponding to each participant's 5, 10, and 15% BM (2 trials per load). The same loads were used for CMJs up to 10% BM. These loads were selected based on the few studies that included weighted vest as a resistance device for both sprinting (4,6,9,12,14,39) and jumping (5–7).

**Table 1.** Relative differences and qualitative outcomes between different loads used according to percentages of BM.*†

| | Mean ± *SD* | Comparative assessment (% BM) | Changes (%) (90% CL) | Chances (%) | Qualitative assessment |
|---|---|---|---|---|---|
| Vmax | 0%: 8.41 ± 0.47 | 0 vs. 5% | −2.2 (−2.8 to −1.7) | 0/0/100% | Almost certainly poorer |
| | 5%: 8.22 ± 0.44 | 0 vs. 10% | −4.3 (−5.0 to −3.6) | 0/0/100% | Almost certainly poorer |
| | 10%: 8.04 ± 0.43 | 0 vs. 15% | −7.3 (−8.0 to −6.7) | 0/0/100% | Almost certainly poorer |
| | 15%: 7.80 ± 0.48 | 5 vs. 10% | −2.2 (−2.6 to −1.7) | 0/0/100% | Almost certainly poorer |
| | | 5 vs. 15% | −5.2 (−5.8 to −4.6) | 0/0/100% | Almost certainly poorer |
| | | 10 vs. 15% | −3.1 (−3.6 to −2.6) | 0/0/100% | Almost certainly poorer |
| $P_h$ | 0%: 13.65 ± 1.95 | 0 vs. 5% | −4.3 (−9.9 to 1.6) | 2/32/66% | Possibly poorer |
| | 5%: 13.04 ± 1.75 | 0 vs. 10% | −2.0 (−7.8 to 4.1) | 8/52/40% | Unclear |
| | 10%: 13.50 ± 2.68 | 0 vs. 15% | −4.6 (−11.9 to 3.3) | 6/30/64% | Unclear |
| | 15%: 13.21 ± 3.01 | 5 vs. 10% | 2.4 (−5.0 to 10.4) | 47/40/13% | Unclear |
| | | 5 vs. 15% | −0.3 (−7.6 to 7.6) | 25/45/30% | Unclear |
| | | 10 vs. 15% | −2.6 (−10.0 to 5.4) | 8/55/37% | Unclear |
| Hmax | 0%: 34.10 ± 4.30 | 0 vs. 5% | −7.2 (−8.0 to −6.4) | 0/0/100% | Almost certainly poorer |
| | 5%: 31.70 ± 4.47 | 0 vs. 10% | −14.3 (−15.3 to −13.3) | 0/0/100% | Almost certainly poorer |
| | 10%: 29.27 ± 4.30 | 5 vs. 10% | −7.6 (−8.6 to −6.7) | 0/0/100% | Almost certainly poorer |
| Pmax | 0%: 54.25 ± 5.05 | 0 vs. 5% | −5,9 (−6,8 to −5.0) | 0/0/100% | Almost certainly poorer |
| | 5%: 51.12 ± 5.59 | 0 vs. 10% | −10.5 (−11.4 to −9.6) | 0/0/100% | Almost certainly poorer |
| | 10%: 48.61 ± 5.26 | 5 vs. 10% | −4.9 (−5.7 to −4.0) | 0/0/100% | Almost certainly poorer |

*CL = confidence limits; % Difference = percentage difference; Chances = percentage chance of having better/similar/poorer values; Vmax = maximum sprint velocity; 0% = without extra load; 5%: extra load of 5% BM; 10%: extra load of 10% BM; 15%: extra load of 15% BM; $P_h$ = maximum horizontal sprint power output; Hmax = maximum CMJ height; Pmax = CMJ peak power.

†Data are mean ± *SD*.

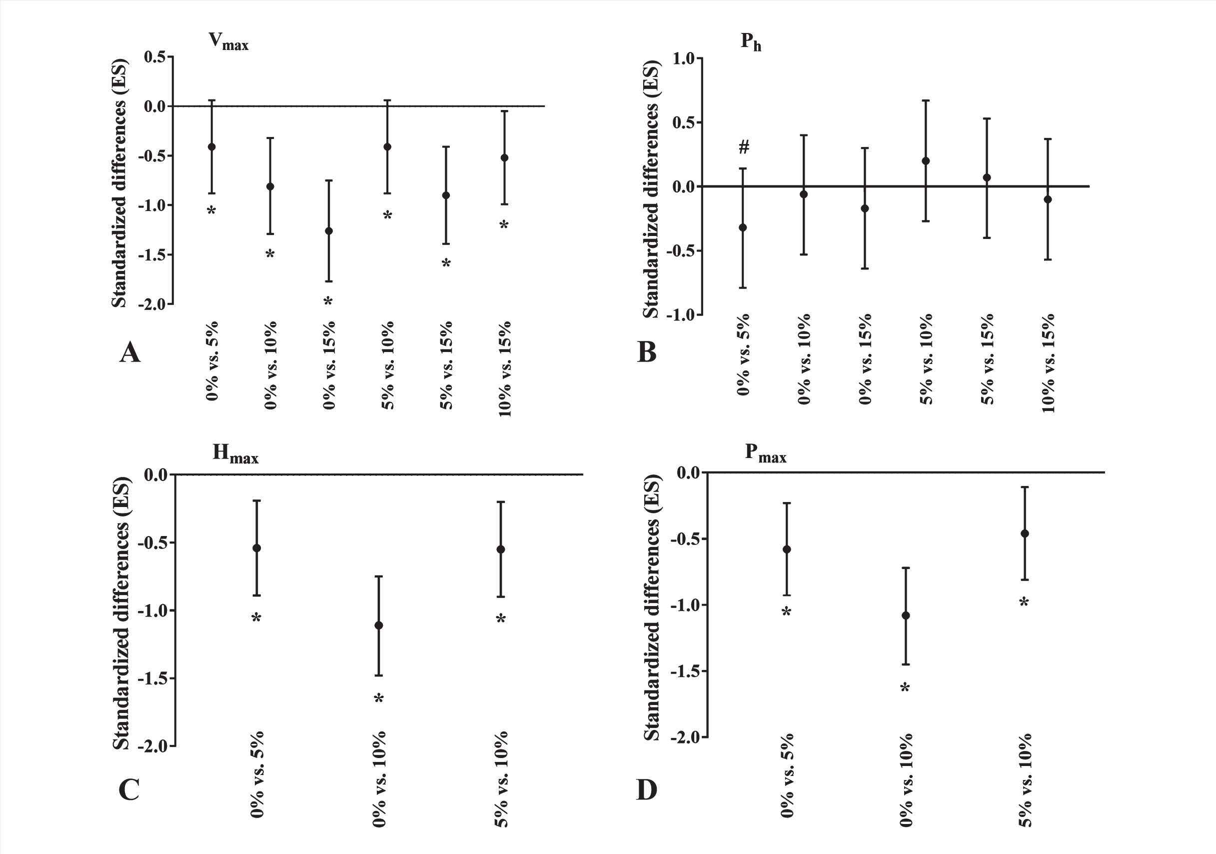

**Figure 2.** Effect size comparison in (A) maximum speed developed in 30-m sprint test between different additional loads used, (B) peak power developed in 30-m sprint test, (C) countermovement jump height and, (D) countermovement jump power. Bars indicate uncertainty in the true mean changes with 90% confidence intervals. Qualitative assessment: # = possibly; * = almost certainly.

AU4 **Subjects**

AU6 AU5 Healthy, semiprofessional soccer players, competing in the Spanish National Divisions, were recruited for this study. All players had experience with WVT. Twenty-five participants performed the sprint test (height: 1.79 ± 0.05 m, and BM: 72.2 ± 6.7 kg), whereas a total of 46 completed the jump test (height: 1.78 ± 0.06 m, and BM: 72.3 ± 7.2 kg). Normal team practice and competition schedule, consisting of at least 4 training sessions and 1 match per week, were maintained during the investigation period. Only players who had no recent injuries or no medical condition that might have prevented maximal exertion were included in the study. The Ethics Committee of the Catholic University San Antonio of Murcia, in accordance with the Declaration of Helsinki (2008), approved the study. Participants were informed of the protocol and procedures before their involvement, and their written consent was obtained before their participation.

**Procedures**

Sprints were completed on an outdoor artificial turf 3 G soccer field, and CMJs were performed on a rigid surface in the same sports center. Participants used their own athletic wear for the tests: sports shoes for jumping and football boots for sprinting. Before starting the tests, height and BM were measured to determine the relative loads needed for the weighted vest (5, 10, and 15% BM). All participants performed a standardized specific warm-up, consisting of 8-minute low-intensity running, 5 minutes of active dynamic stretching, 3–4 submaximal CMJs, and 3–4 submaximal sprints over 30 m, increasing progressively the intensity until Vmax and with 90-second rest between trials. Afterward, all players performed the CMJ test first and, after 10 minutes of rest, they completed the sprint test. Two trials were performed for each load, and the order of the trials was randomized for each participant.

*Sprint Test.* Players performed a total of eight all-out sprints over 30 m (2 trials for each load condition). A 5-minute rest period was given between trials to minimize fatigue effects on performance. Participants were encouraged to perform each trial as fast as possible. A radar device (Stalker ATS II; Applied Concepts, TX, USA), placed on a tripod 5 m behind AU7

**Table 2.** Load (kg) required for WVT of sprint, depending on individual BM.*

| | % Vmax | | | |
|---|---|---|---|---|
| BM (kg) | 90% kg | 92.5% kg | 95% kg | 97.5% kg |
| 100 | 21.1 | 15.9 | 10.8 | 5.6 |
| 95 | 20.1 | 15.1 | 10.2 | 5.3 |
| 90 | 19.0 | 14.3 | 9.7 | 5.0 |
| 85 | 18.0 | 13.6 | 9.1 | 4.7 |
| 80 | 16.9 | 12.8 | 8.6 | 4.4 |
| 75 | 15.8 | 12.0 | 8.1 | 4.2 |
| 70 | 14.8 | 11.2 | 7.5 | 3.9 |
| 65 | 13.7 | 10.4 | 7.0 | 3.6 |
| 60 | 12.7 | 9.6 | 6.5 | 3.3 |
| 55 | 11.6 | 8.8 | 5.9 | 3.1 |
| 50 | 10.6 | 8.0 | 5.4 | 2.8 |
| %BM | ~21.1% | ~15.9% | ~10.8% | ~5.6% |

*WVT = weighted vest resisted training; BM = body mass; Vmax = maximum sprint velocity; %BM = percentage of body mass.

**Table 3.** Load (kg) required for WVT of vertical jump, depending on individual BM.*

| | % Hmax | | | |
|---|---|---|---|---|
| BM (kg) | 90% kg | 92.5% kg | 95% kg | 97.5% kg |
| 100 | 7.2 | 5.4 | 3.6 | 1.8 |
| 95 | 6.8 | 5.1 | 3.4 | 1.7 |
| 90 | 6.5 | 4.9 | 3.2 | 1.6 |
| 85 | 6.1 | 4.6 | 3.1 | 1.5 |
| 80 | 5.7 | 4.3 | 2.9 | 1.5 |
| 75 | 5.4 | 4.0 | 2.7 | 1.4 |
| 70 | 5.0 | 3.8 | 2.5 | 1.3 |
| 65 | 4.7 | 3.5 | 2.3 | 1.2 |
| 60 | 4.3 | 3.2 | 2.2 | 1.1 |
| 55 | 4.0 | 3.0 | 2.0 | 1.0 |
| 50 | 3.6 | 2.7 | 1.8 | 0.9 |
| %BM | ~7.2% | ~5.4% | ~3.6% | ~1.8% |

*WVT = weighted vest resisted training; BM = body mass; Hmax = maximum CMJ height; %BM = percentage of body mass.

the starting line and at a height of 1 m corresponding approximately to the height of subjects' center of mass, was used to measure sprint instantaneous velocity using a sampling frequency of 47 Hz. In addition, sprint time was measured with wireless photocells from Microgate's WITTY System (Microgate, Bolzano, Italy) that were placed on the starting and finish line. Only those sprints in which the velocity curve achieved a plateau zone were considered, indicating that Vmax was reached. The best sprint time for each load condition was selected for analysis, and the Vmax was used to obtain the sprint equation.

Sprint mechanical horizontal power output was computed using a valid and reliable computation method based on a macroscopic inverse dynamics analysis of the center of mass motion (40). Raw velocity-time data were fitted with an exponential function to obtain the instantaneous theoretical velocity, which was then derived to calculate the net horizontal antero-posterior GRF and the horizontal mechanical power output ($P_h$) using the equations proposed by Samozino et al. (40). The load added was taking in account to determine these variables. $P_h$ is presented relative to total system mass (i.e., BM plus the added external weighted vest load). This model presents a coefficient of variation (CV) of 2.93 and 1.87% for maximum horizontal force and $P_h$, respectively (40).

*Countermovement Jump Test.* Countermovement jumps were assessed using a portable force platform (Kistler 9286BA; Winterthur, Switzerland), with a sampling rate of 1,000 Hz. A total of 6 maximum trials (2 trials for each load condition) were performed, with 90-second rest between them. Players stood over the center of the force platform with their feet placed shoulder width apart, their hands were kept on the hips throughout the execution of the jump, and the depth of the countermovement (i.e., knee flexion angle) was self-selected. They were instructed to jump as high as possible with a rapid countermovement and to land close to the point of take-off (18). The Hmax and the maximum CMJ power (Pmax) were calculated using the take-off velocity through a customized macro for RStudio software (R-Tools Technology, Inc., Boston, MA, USA). The highest jump for each load was taken as the best trial and used to calculate the jump equation. The CMJ test is characterized by a low variability between trials (CV = 3.0%) (29) and high test-retest reliability (intraclass correlation coefficient = 0.98) (8).

### Statistical Analyses

Statistical analyses were performed using SPSS 21.0 for Windows. Descriptive statistics summarized all demographic characteristics and outcomes. Data are presented as mean ± *SD*. All data were log-transformed for analysis to reduce bias arising from nonuniformity error and then analyzed for practical significance using magnitude-based inferences (24). The effect size (ES, 90% confidence limit) in the selected variables was calculated using the *SD*. Threshold values for Cohen's ES statistics were as follows: >0.2 small, >0.6 moderate, and >1.2 large (24). The chance that any difference was better/greater (i.e., greater than the smallest worthwhile change, SWC [0.2 multiplied by the between-subject *SD*, based on Cohen's *d* principle, ES]) or similar or worse/smaller than the other group, was subsequently calculated (24). Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: <1%, almost certainly not; >1–5%, very unlikely; >5–25%, unlikely; >25–75%, possible; >75–95%, likely; >95–99%, very likely; and >99%, almost certain. If the chance of having beneficial/better or detrimental/poorer was <5%, the true difference was considered unclear (43). If the chance was >75%, data were considered substantially different.

## RESULTS

All velocities and jump heights were converted to percentage of Vmax over 30 m and percentage of Hmax, respectively. These data were plotted against each other to produce a regression equation for sprinting (equation 1, Figure 1A) and for jumping (equation 2, Figure 1B). The $R^2$ value was 0.99 for both sprint and CMJ equations. The regression equations obtained are listed below:

$$\%\mathrm{BM} = -2.0762 \cdot \%\mathrm{Vmax} + 207.99 \qquad (1)$$

$$\%\mathrm{BM} = -0.7156 \cdot \%\mathrm{Hmax} + 71.588 \qquad (2)$$

Relative differences and qualitative outcomes resulting from the within-loads analyses are shown in Table 1, and the comparison of ESs between different tests and external load conditions for all variables measured are illustrated in Figure 2. As expected, there was a reduction in Vmax during the 30-m sprint tests as the load increased. Sprinting data showed an almost certainly poorer Vmax with 15% BM compared with 0% (ES = 1.26), with 10% compared with 0% BM (ES = 0.81), and when 15% was compared with 5% BM (ES = 0.90). An almost certainly poorer Vmax was also obtained with 5% BM with respect to 0% BM (ES = 0.41), with 10% BM compared with 5% BM (ES = 0.41) and when comparing 15–10% BM (ES = 0.52) (Figure 2A). The $P_h$ data showed a possibly poorer performance with 5% BM compared with 0% BM (ES = 0.32), whereas the qualitative outcome was unclear when the other loads were compared (Figure 2B). These results do not clarify which is the OL for sprinting, although 0% BM is the load that produces the highest $P_h$.

Regarding the jump test, the unloaded condition (0% BM) showed a higher Hmax than with additional loads of 5% (ES = 0.54) and 10% BM (ES = 1.11). Moreover, an additional load of 5% BM showed a greater Hmax than 10% BM (ES = 0.55) (Figure 2C). The Pmax data exhibited an almost certainly poorer output with 10% BM compared with 0% BM (ES = 1.08), with 5% in comparison with 0% BM (ES = 0.58), and when 10% BM was compared with 5% BM (ES = 0.46) (Figure 2D). These results seem to indicate that the OL is closer to the own BM for jumping.

## DISCUSSION

Weighted vest resisted training is a very popular resisted training modality designed to develop strength and power of the lower limbs in many sports where sprinting and jumping are key factors such as soccer. However, the number of studies on this topic is limited because most of the knowledge in this area has been obtained from the practical experience of coaches and strength and conditioning professionals. To our knowledge, this is the first study to develop 2 regression equations that accurately describe the relationship between weighted vest loads and the Vmax in a 30-m sprint and Hmax of a CMJ in semiprofessional soccer players. Moreover, this research shows the load-velocity relationship for resisted sprint training and load-height relationship for resisted jump training using weighted vest. In addition, power output and the effects of the different loads on Vmax and Hmax for sprinting and jumping, respectively, were examined. Finally, the OL for maximizing power production in soccer players under the conditions described in this study was also obtained.

The regression equations showed a significant inverse linear relationship between load and sprint velocity and between load and jump height ($p \leq 0.001$; Figure 1A, B), respectively. These equations may help strength and conditioning coaches establish the load for WVT, according to the individual characteristics of each athlete. Furthermore, these tools allow determination of the different loads to develop each section of the F-V curve, individually and depending on the aims pursued or the period of the season. In soccer, players have to produce power under both unloaded (activities such as sprinting or jumping, where the athlete mainly overcomes the inertia of their BM) and loaded conditions (activities such as collisions in contact sports or changes of direction where the player must apply even greater forces to change the momentum of the body) (41). Developing the power output across the entire F-V profile may be more beneficial because of the different demands placed on an athlete during competition (41). Thus, both equations can be used to control and prescribe the workload and to quantify the load for WVT based on the athlete's BM.

Regarding sprinting, there are not many studies analyzing the effects of WVT, and the ones that do exist evaluated only the effects on kinematics (4,9,12,14). Therefore, to our knowledge, this is the first study that investigated the load-velocity relationship for WVT for sprinting. Nevertheless, 2 previous studies determined this relationship for resisted sprint training with sled towing (3,28). Lockie et al. (28) presented an equation to calculate the additional load during the acceleration phase in field-sport athletes and Alcaraz et al. (3) during the maximum velocity phase in sprinters. However, these equations cannot be compared with the one obtained in this study because the resisted training modality used was different, hence, the mechanical characteristics and conditions too (e.g., inertia, the direction of the load's vector, friction, and the proximity of the resistance device with the athlete's center of mass).

The equations presented in these previous studies (3,28) showed the same load-velocity relationship found here; i.e., when the load increased, the Vmax decreased. With respect to the OL, our results do not clarify which load could be more effective in maximizing $P_h$ and further research is required. A study by Monte et al. (32), with sprinters, reported that 20% BM was the OL, whereas other studies (3,28) indicated loads around 9 and 13% of BM. However, caution should be taken when comparing the results because in the studies by Lockie et al. (28) and Alcaraz et al. (3), the concept of OL was different because the OL was considered the load that caused a detriment of no more than 10% of Vmax in unloaded conditions. By contrast, a recent study by Cross et al. (15) suggested that heavier loads, between 69 and 96% BM, are more suitable for maximizing power output with sled towing, depending on the friction condition.

Resisted sled training (RST) and its influence on sprinting ability has been, and remains, one of the most studied resisted sprint training topics (2,9,15,16,32). Nevertheless, according to soccer-specific sprint characteristics and key actions, RST has some limitations that could be solved with the use of different devices such as weighted vests. For example, RST does not permit changes of direction nor provides an instantaneous stimulus over decelerating actions. Hence, WVT could be an alternative method in soccer for 2 reasons. First, because this method enables loading change of direction and deceleration drills. Second, because WVT resistance has a greater vertical component (36), it would provide a more specific stimulus for soccer players, as most sprints are fly-sprints (42) and it is well documented that vertical GRF rises while horizontal GRF decreases as velocity increases (33,37). Therefore, the combination of different resisted training modalities might be the ideal solution in soccer.

Concerning vertical jump, the results indicate that when the load increases, the Hmax and Pmax decrease. Therefore, the OL is close to the player's own BM for WVT. Our results are in accordance with previous studies that showed the OL closer to the individual's BM using both assisted and resisted loads (30,34,35,44) and supports the idea that the muscular system of the lower body could be designed to elicit the maximum power output in rapid movements in such conditions (30).

Although our results determined that the OL in both exercises was close to 0% BM, we must consider that the OL may change during the season. Thus, it is important to develop all zones of the F-V spectrum, focusing on each section of the curve, depending on the time of the year (25). Traditionally, in soccer, strength and conditioning coaches prescribe heavier loads during the off-season/preseason period to enhance the high-force section of the F-V curve and to maximize overall muscular strength. In the later part of the preseason and during the competitive phase, low-load high-velocity movements are usually used to improve the high-velocity area (11,22). This highlights the importance of developing the whole curve from the high-force section through the high-velocity segment (22).

The direction of the added resistance's force vector during training is another key aspect that strength and conditioning coaches should consider when applying resisted training methods with their athletes. Particularly in soccer, where horizontal and vertical forces are important, the ideal program should combine exercises that add resistance oriented both horizontally and vertically, depending on the aims pursued in each moment of the season. For instance, the vertical jump should be trained with vertical loads, whereas sprint training should combine horizontal and vertical loading. It is well established that, in sprinting, horizontal forces are higher in the first steps and vertical forces in the remaining meters (33,37) because athletes need to always overcome the force of gravity.

The main limitation in the present study is that testing was conducted only once for each load and we cannot exclude that this had an influence on the results. Future studies are needed to clarify what is the OL in sprinting and determine its resultant power output when WVT is used. Furthermore, it would be of great interest to investigate the effect of WVT on soccer-specific movement mechanics (i.e., changes of direction, jumps, sprints, etc.). Moreover, there is a need to determine whether a WVT intervention is more suitable than other methods to improve speed, jump, and change of direction performance in soccer players. Unpublished pilot data from our research center suggested that $P_h$ was achieved at shorter distances, in the acceleration phase, when using weighted vest in comparison with other equipment, such as sled towing or parachute.

## PRACTICAL APPLICATIONS

This study presents new tools for strength and conditioning professionals to control and prescribe the WVT load based on Vmax and Hmax. The 2 equations are highly practical and allow strength and conditioning professionals to calculate the loads for WVT in sprinting and jumping exercises easily in soccer players.

Tables 2 and 3 show the reference values for WVT using the % BM for sprint and vertical jump, respectively. These can serve as a starting point when strength and conditioning coaches want to prescribe the training as a function of the velocity or height loss, as well as for choosing the appropriate weighted vest load for each player (i.e., semiprofessional soccer players). For example, if a 70-kg player wants to work at 90% of their Vmax and Hmax, loads of 14.8 and 5.0 kg should be used, respectively. T2 T3

Finally, according to the results obtained in this study, the OL is not clear for sprinting and is closer to BM for jumping. Nevertheless, we must take into account that the OL may be different at varying points in the season and it would be dependent on the athlete's force level.

## Acknowledgments

The authors thank Alberto Castillo, PhD, and Francisco Javier Toscano, PhD (UCAM, Murcia), for their help in recruiting athletes for the study. The authors also thank Elena Marín-Cascales, PhD, for their assistance with data collection.

## References

1. Alcaraz, PE. Sprint training with resisted sprint training methods. *CCD* 5: 19–26, 2010.
2. Alcaraz, PE, Elvira, JLL, and Palao, JM. Kinematic, strength, and stiffness adaptations after a short- term sled towing training in athletes. *Scand J Med Sci Sports* 24: 279–290, 2014.
3. Alcaraz, PE, Palao, JM, and Elvira, JLL. Determining the optimal load for resisted sprint training with sled towing. *J Strength Cond Res* 23: 480–485, 2009.
4. Alcaraz, PE, Palao, JM, Elvira, JLL, and Linthorne, NP. Effects of three types of resisted sprint training devices on the kinematics of sprinting at maximum velocity. *J Strength Cond Res* 22: 890–897, 2008.
5. Bosco, C. Adaptive response of human skeletal muscle to simulated hypergravity condition. *Acta Physiol Scand* 124: 507–513, 1985.
6. Bosco, C, Rusko, H, and Hirvonen, J. The effect of extra-load conditioning on muscle performance in athletes. *Med Sci Sports Exerc* 18: 415–419, 1986.
7. Bosco, C, Zanon, S, Rusko, H, Dal Monte, A, Bellotti, P, Latteri, F, Candeloro, N, Locatelli, E, Azzaro, E, and Pozzo, R. The influence of extra load on the mechanical behavior of skeletal muscle. *Eur J Appl Physiol Occup Physiol* 53: 149–154, 1984.
8. Carlock, JM, Smith, SL, Hartman, MJ, Morris, RT, Ciroslan, DA, Pierce, KC, Newton, RU, Harman, EA, Sands, WA, and Stone, MH. The relationship between vertical jump power estimates and weightlifting ability: A field-test approach. *J Strength Cond Res* 18: 534–539, 2004.
9. Clark, KP, Stearne, DJ, Walts, CT, and Miller, AD. The longitudinal effects of resisted sprint training using weighted sleds vs weighted vests. *J Strength Cond Res* 24: 3287–3295, 2010.
10. Cormie, P, McCaulley, GO, Triplett, NT, and McBride, JM. Optimal loading for maximal power output during lower-body resistance exercises. *Med Sci Sports Exerc* 39: 340–349, 2007.
11. Cormie, P, McGuigan, MR, and Newton, RU. Developing maximal neuromuscular power part 2-training considerations for improving maximal power production. *Sports Med* 41: 125–146, 2011.
12. Cronin, JB, Hansen, K, Kawamori, N, and McNair, P. Effects of weighted vests and sled towing on sprint kinematics. *Sports Biomech* 7: 160–172, 2008.
13. Cronin, JB and Hansen, KT. Resisted sprint training for the acceleration phase of sprinting. *Strength Cond J* 28: 42–51, 2006.
14. Cross, MR, Brughelli, M, and Cronin, JB. Effects of vest loading on sprint kinetics and kinematics. *J Strength Cond Res* 28: 1867–1874, 2014.
15. Cross, MR, Brughelli, M, Samozino, P, Brown, SR, and Morin, JB. Optimal loading for maximising power during sled-resisted sprinting. *Int J Sports Physiol Perform*: 1–25, 2017. AU11
16. de Hoyo, M, Gonzalo-Skok, O, Sañudo, B, Carrascal, C, Plaza-Armas, JR, Camacho-Candil, F, and Otero-Esquina, C. Comparative effects of in-season full-back squat, resisted sprint training, and plyometric training on explosive performance in U-19 elite soccer players. *J Strength Cond Res* 30: 368–377, 2016.
17. Faude, O, Koch, T, and Meyer, T. Straight sprinting is the most frequent action in goal situations in professional football. *J Sport Sci* 30: 625–631, 2012.
18. Freitas, TT, Calleja-Gonzalez, J, Alarcon, F, and Alcaraz, PE. Acute effects of two different resistance circuit training protocols on performance and perceived exertion in semiprofessional basketball players. *J Strength Cond Res* 30: 407–414, 2016.
19. Freitas, TT, Martinez-Rodriguez, A, Calleja-González, J, and Alcaraz, PE. Short-term adaptations following complex training in team-sports: A meta-analysis. *PLoS One* 12: e0180223, 2017.
20. Giroux, C, Rabita, G, Chollet, D, and Guilhem, G. What is the best method for assessing lower limb force-velocity relationship? *Int J Sports Med* 36: 143–149, 2015.
21. Gregson, W, Drust, B, Atkinson, G, and Salvo, VD. Match-to-match variability of high-speed activities in premier league soccer. *Int J Sports Med* 31: 237–242, 2010.
22. Haff, GG and Nimphius, S. Training principles for power. *Strength Cond J* 34: 2–12, 2012.
23. Hill, A. The heat of shortening and the dynamic constants of muscle. *Proc R Soc Lond B Biol Sci* 126: 136–195, 1938.
24. Hopkins, W, Marshall, S, Batterham, A, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3, 2009.
25. Kawamori, N and Haff, GG. The optimal training load for the development of muscular power. *J Strength Cond Res* 18: 675–684, 2004.
26. Linthorne, NP. Analysis of standing vertical jumps using a force platform. *Am J Phys* 69: 1198–1204, 2001.
27. Lockie, RG, Murphy, AJ, Schultz, AB, Knight, TJ, and Janse de Jonge, XA. The effects of different speed training protocols on sprint acceleration kinematics and muscle strength and power in field sport athletes. *J Strength Cond Res* 26: 1539–1550, 2012.
28. Lockie, RG, Murphy, AJ, and Spinks, CD. Effects of resisted sled towing on sprint kinematics in field-sport athletes. *J Strength Cond Res* 17: 760–767, 2003.
29. Markovic, G, Dizdar, D, Jukic, I, and Cardinale, M. Reliability and factorial validity of squat and countermovement jump tests. *J Strength Cond Res* 18: 551–555, 2004.
30. Markovic, G and Jaric, S. Positive and negative loading and mechanical output in maxmium vertical jumping. *Med Sci Sports Exerc* 39: 1757–1764, 2007.
31. 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.
32. Monte, A, Nardello, F, and Zamparo, P. Sled towing: The optimal overload for peak power production. *Int J Sports Physiol Perform*: 1–24, 2016.
33. Nagahara, R, Mizutani, M, Matsuo, A, Kanehisa, H, and Fukunaga, T. Step-to-step spatiotemporal variables and ground reaction forces of intra-individual fastest sprinting in a single session. *J Sport Sci*: 1–10, 2017.
34. Nuzzo, JL, McBride, JM, Dayne, AM, Israetel, MA, Dumke, CL, and Triplett, NT. Testing of the maximal dynamic output hypothesis in trained and untrained subjects. *J Strength Cond Res* 24: 1269–1276, 2010.
35. Pazin, N, Berjan, B, Nedeljkovic, A, Markovic, G, and Jaric, S. Power output in vertical jumps: Does optimum loading depend on activity profiles? *Eur J Appl Physiol* 113: 577–589, 2013.
36. Puthoff, ML, Darter, BJ, Nielsen, DH, and Yack, HJ. The effect of weighted vest walking on metabolic responses and ground reaction forces. *Med Sci Sports Exerc* 38: 746–752, 2006.
37. Rabita, G, Dorel, S, Slawinski, J, Saez-de-Villarreal, E, Couturier, A, Samozino, P, and Morin, JB. Sprint mechanics in world-class athletes: A new insight into the limits of human locomotion. *Scand J Med Sci Sports* 25: 583–594, 2015.
38. Requena, B, García, I, Requena, F, de Villarreal, ESS, and Cronin, JB. Relationship between traditional and ballistic squat exercise with vertical jumping and maximal sprinting. *J Strength Cond Res* 25: 2193–2204, 2011.

39. Rey, E, Padron-Cabo, A, and Fernandez-Penedo, D. Effects of sprint training with and without weighted vest on speed and repeated sprint ability in male soccer players. *J Strength Cond Res*, 2016.

AU12

40. Samozino, P, Rabita, G, Dorel, S, Slawinski, J, Peyrot, N, Saez de Villarreal, E, and Morin, JB. A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. *Scand J Med Sci Sports* 26: 648–658, 2016.

41. Sheppard, JM and Young, WB. Agility literature review: Classifications, training and testing. *J Sport Sci* 24: 919–932, 2006.

42. Stolen, T, Chamari, K, Castagna, C, and Wisloff, U. Physiology of soccer–An update. *Sports Med* 35: 501–536, 2005.

43. Suarez-Arrones, L, Arenas, C, López, G, Requena, B, Terrill, O, and Mendez-Villanueva, A. Positional differences in match running performance and physical collisions in men rugby sevens. *Int J Sports Physiol Perform* 9: 316–323, 2014.

44. Suzovic, D, Markovic, G, Pasic, M, and Jaric, S. Optimum load in various vertical jumps support the maximum dynamic output hypothesis. *Int J Sports Med* 34: 1007–1014, 2013.

45. Swinton, PA, Lloyd, R, Keogh, JW, Agouris, I, and Stewart, AD. Regression models of sprint, vertical jump, and change of direction performance. *J Strength Cond Res* 28: 1839–1848, 2014.