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The effects of assisted and resisted plyometric training on jump height and sprint performance among physically active females

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ABSTRACT

The aim of the present study was to compare the effects of assisted and resisted plyometric jump training on jump height, sprint performance (acceleration (0–20m), maximum speed (30–40m) and 40m sprint time) among physically active females. Fifty-six participants (age: 21.1 ± 1.7 years; body mass: 64.2 ± 7.0 kg; height: 168.0 ± 5.6 cm) were randomly allocated to either an assisted (*n* = 16) or resisted training group (*n* = 17), or a control group (*n* = 14). Nine participants dropped out during the intervention. The training sessions consisted of three different plyometric jump exercises over an eight-week period, while the control group continued their normal training routine. The results revealed a significant between-group difference in jump height and maximal speed. The resisted training group achieved a significantly greater improvement in jump height compared to the active control group (*p* = .04, ES=1.06), and a significantly greater improvement in maximal speed (*p* = .02, ES = 0.93) when compared to the assisted training group. No other group differences were observed for jump height, acceleration or in maximal speed (*p* = .31–.53). The resisted training group improved jump height (*p* = .01, ES = 0.62) and maximum speed (*p* = .03, ES = 0.48) from pre- to post-test, while the control group improved maximal speed (*p* = .04, ES = 0.37) and acceleration (*p* = .01, ES = 0.68). All three groups improved their 40m sprint time from pre- to post-test (*p* = .01–.04, ES = 0.38–0.45). In conclusion, resisted plyometric training was more effective than assisted plyometric training for improving the maximal speed and more effective than the active control condition for increasing jump height.

KEYWORDS

Countermovement jump; acceleration; maximal running velocity; overspeed; overload

Introduction

Optimizing jumping qualities, acceleration and maximal speed is considered fundamental for successful performance in many sports (Bobbert, 1990; Matavulj et al., 2001; Nealer et al., 2017). These qualities are influenced by force production and contraction velocity, where the product of force and velocity is defined as power output (Knuttgen & Kraemer, 1987). Several researchers have stated that plyometric training is the preferred training method for enhancing power output in the lower extremities (Ebben & Blackard, 2001; Ebben, Carroll, & Simenz, 2004; Markovic et al., 2007). Plyometric training is synonymous with exercises involving the stretch-shortening cycle (SSC) which is defined as the transition between high velocity eccentric muscle action, immediately followed by a powerful concentric muscle contraction (Komi, 1984; Kubo, Kawakami, & Fukunaga, 1999). Plyometric training programmes typically includes bilateral jumping movements (vertical and horizontal) (Argus, Gill, Keogh, Blazevich, & Hopkins, 2011; Harris, Cronin, Hopkins, & Hansen, 2008; Markovic, Mirkov, Knezevic, & Jaric, 2013; Markovic, Vuk, & Jaric, 2011; McBride et al., 2002). Furthermore, it has been demonstrated that plyometric training with body weight can enhance sprint performance through neurological as well as mechanical factors such as changes in muscle activity (McBride et al., 2002), increased rate of force-development (RFD) (Häkkinen et al., 1990; Winchester et al., 2008), maximal power output (Harris et al., 2008; McBride et al., 2002) and elastic tendon properties (Davies, Riemann, & Manske, 2015).

More recently, plyometric training with assistance (reduced load) or resistance (increased load) have gained increased interest (Argus et al., 2011; Khodaei, Mohammadi, & Badri, 2017; Markovic et al., 2011; Markovic et al., 2013; Stien, Strate, Andersen, & Saeterbakken,

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2020). Theoretically, by adding assistance or resistance to the athletes' body mass, faster muscle contractions or a greater initial force than normally can be achieved (Markovic et al., 2011; Sheppard et al., 2011). Assisted plyometric training could therefore lead to greater performance on high velocity movements, while resisted plyometric training primarily enhances performance through increased muscle force for lower velocity movements (Argus et al., 2011; Sheppard et al., 2011). Previous studies comparing the two modalities have focused on jump performance and reported similar effects (Argus et al., 2011; Markovic et al., 2011; Markovic et al., 2013). However, one study, Khodaei et al. (2017), examined on sprint performance after four weeks of either assisted or resisted plyometric training. Both modalities improved more than common plyometric exercises (control) on 10–20m and 20–30m sprint time. Furthermore, the resisted group improved more than the assisted group on 0–10m and 0–30m sprint time. Importantly, all of the abovementioned studies only included vertical exercises (and not combined both vertical and horizontal PT exercises). To the authors' best knowledge, only one study has compared both training approaches in the same study using both vertical and horizontal exercises (Stien et al., 2020). Stien et al (2020) compared the effect of assisted and resisted plyometric training on jump height and showed no difference between the groups. Importantly, jump height was measured using the squat jump which is less specific to both sport specific movement and plyometric training.

The present study aimed to investigate the effects following eight weeks of assisted or resisted plyometric jump training on counter movement jump (CMJ) performance, sprint performance in the acceleration phase (0–20 m) and in the maximum speed phase (30–40 m). Training effects in the intervention groups were compared with changes in a control group who continued their usual training routines. Based on earlier studies (Argus et al., 2011; Markovic et al., 2011; Rimmer & Sleivert, 2000), it was hypothesized that; (A) both plyometric training groups would increase CMJ performance, but the assisted training group will achieve greater change than the resisted group, (B) comparing the training groups, the resisted training group would achieve a greater improvement in the acceleration phase whereas the assisted group would achieve a greater improvement in maximum speed phase, and (C) both plyometric training groups would achieve greater improvements in CMJ, acceleration and maximum speed phases of a sprint than the control group.

Table 1. Subject characteristics and estimated weekly training volume at pre-test.

	Assisted (*N* = 16)	Resisted (*N* = 17)	Control (*N* = 14)	*p*
Age (years)	21.3 ± 1.3	20.9 ± 1.9	21.1 ± 1.8	.77
Height (cm)	168.2 ± 6.5	167.1 ± 5.5	168.6 ± 4.8	.75
Body mass (kg)	62.1 ± 7.1	63.3 ± 6.1	67.5 ± 7.1	.09
Training (h)	5.5 ± 3.6	6.3 ± 4.8	8.3 ± 5.6	.27

Results are given as mean ± SD. h, hours estimated weekly training volume; *p*, *p*-value between groups.

Methods

Experimental design

To determine the potential differences between assisted or resisted plyometric training on CMJ, acceleration and maximum speed, a randomized controlled trial was conducted. The tests used in this study included anthropometric measurements, CMJ and 40 m sprint performance. After all pre-tests were completed, the participants were randomly allocated to either an assisted or a resisted training group, or to a control group (Table 1). Participants in the two training groups were scheduled to complete twenty training sessions over eight weeks.

Participants

A total of 56 physically active female students between 19 and 26 years volunteered to participate in the study. The included subjects were either physical education students who participated in various physical activities throughout their academic curriculum, active within individual training, fitness or team sports, or a combination of these. The following inclusion criteria were met; all participants (A) were regularly physically active and were familiar with jumping and sprinting, (B) did not suffer from any medical conditions that could influence the training or test-results, (C) did not practice any systematic plyometric training or sprint training in the last six months and (D) had to be able to sprint 40 m in less than seven seconds. Due to ethical reasons, the last inclusion criterion was not given to participants. Instead, participants who did not meet these criteria completed the intervention but were excluded from the analyses.

All participants (including the active control group) were instructed to continue their regular training routines during the intervention. As none of the participants performed any systematic plyometric or sprint training in their regular training routines before participating, they were instructed to refrain from this during the intervention. The participants' estimated weekly training volume, outside the intervention, was controlled via a questionnaire at pre- and post-test. Data from nine participants was excluded due to one of the following reasons; (A) injuries not related to the study (2), (B) failed to achieve the required number (> 80%) of training sessions (3), (C) personal reasons (2), (D) or failed to perform 40 m sprint in less than seven seconds (2). This left a total of forty-seven participants to be included in the analysis.

Prior to the commencement of the study, all participants were fully informed orally and in writing, of the nature of the testing as well as the potential risks and benefits. A written consent form was signed by each participant before the pre-test. The study was approved by the Norwegian Centre for Research Data (56489/3/HJT) and the research was conducted ethically according to the standards described by the European Journal of Sport Science and the latest version of the Helsinki Declaration.

Procedures

Before the commencement of the study, all participants were instructed not to perform any leg training two days before testing. Pre-test took place over three separate days and was separated by a minimum of 48 hours. Day one included anthropometric measurements, while day two consisted of CMJ measurement. Day three involved a 40 m sprint with split-time on an indoor running track. As the subjects were physically active and had previous experience with activities which involves both jumping and running, no familiarization session was performed. Instead, a minimum of three attempts for CMJ and 40 m sprint was given to ensure that their maximum performance was achieved. If the third attempt was the best, additional attempts were given until the performance stagnated. The result from the best attempt was used for further analysis. Post-tests were conducted identical to the pre-test protocol as described above.

Measurements

CMJ height was measured on a force plate (Ergotest Innovation A/S, Porsgrunn, Norway) connected to a PC with the software Musclelab (v. 10.4.37.4073, Ergotest Innovation A/S, Porsgrunn, Norway). Calibration of the force plate was done according to the manufacturer's specifications before each test day. A standardized warm-up routine consisting of two series with five CMJ and five squat jumps (SJ) with maximal effort was carried out prior to testing (Andrade et al., 2015). Participants performed the CMJ with approximately 90 degrees knee angle during the testing. All participants were instructed to perform the jumps with maximum effort and their hands placed akimbo throughout the entire jump phase. The jump was disallowed if the hands left the hip at any point. The participants were given a 90-second rest period between each test trial.

The warm-up protocol in advance of the 40 m sprint test consisted of 400 metres of jogging, 4 × 40 m running drills (inward rotation, outward rotation, high knees, back kicks) and 2 × 40 m sprints gradually accelerating to maximal effort. The information about participants' split times was collected at 0, 20, 30 and 40 metres using four pairs of photocells (Ergotest Innovation A/S, Porsgrunn, Norway) connected to a PC with the software Musclelab (v. 10.4.37.4073, Ergotest Innovation A/S, Porsgrunn, Norway). The acceleration phase was defined as the time between 0 and 20 m (m/s), while the maximal speed phase was defined as the time between 30 and 40 m (m/s). To avoid accidental timer activation or reaction time as a factor in the initial start, a 30 cm flying start was used to activate the first photocell, and the participants could therefore initiate the start when they were ready (Loturco et al., 2018). Between each test trial, an active rest period between four and five minutes was given and all participants were instructed to run with maximum effort throughout the race.

Training

Before each training session, a standardized warm-up routine was completed. The routine consisted of two sets of ten body weight squats followed by two sets of five CMJ performed with maximal effort separated by one-minute rest in between the sets (Argus et al., 2011). During the eight-week training intervention, rubber bands were used to provide either assistance or resistance to the participants (Figure 1).

The training consisted of three different exercises: vertical jumps, Bulgarian squat jumps, and broad jumps for both experimental groups (Figure 1). All vertical jumps within one set were performed consecutively without rest between the repetitions. For the broad jumps, the participants immediately had to move back to their starting position after landing to perform their next repetition with as little rest as possible between repetitions. The rest-period between each set was a minimum of three minutes (Argus et al., 2011), and all participants were instructed to perform all exercises with maximal effort and as explosively as possible. Arm swing was allowed in the broad jump-exercise.

To simulate an increase or decrease of the participants body mass for the vertical jumps, rubber bands were attached to a chain above the subjects in the assisted group and below the subjects in the resisted group. For the assisted group, the rubber bands were placed under the participants arms during the vertical

Figure 1. *Resisted exercises:* Two-legged vertical jump (a), Bulgarian squat jump (b) and broad jump (c). *Assisted exercises:* Two-legged vertical jump (d), Bulgarian squat jump (e) and broad jump (f).

jumps (Figure 1(d, e)). Based on the participants height, the rubber bands were attached to an individual link on the chain to achieve the desired assistance/resistance. The resisted group used a modified climber's harness to attach the rubber bands to the floor (Figure 1(a, b)). During the broad jumps, the rubber bands were attached in front of the participants in the assisted group (Figure 1(f)) and behind the subjects in the resisted group (Figure 1(c)). The broad jumps were performed with their feet placed behind a line on the floor to achieve the intended assistance/ resistance provided by the rubber band.

The training period was divided into two similar blocks, each lasting four weeks. To ensure progression between the blocks, the applied loading was increased from the first to the second block. To control the loading a force sensor (Ergotest Innovation A/S, Porsgrunn, Norway) was used during one full set in each block, for each participant. Since rubber bands vary their loading throughout the movement, the force was measured in the position with highest resistance (upper position, Figure 1(a–c)) or assistance (lower position, Figure 1(d–f)). In the first block the force was set to 200 Newton in the bilateral exercises and 100 Newton in the unilateral exercise. In the second block the force was increased to 300 Newton and 150 Newton, respectively. The loading was identical for all participants. Furthermore, the rubber bands were measured daily and replaced if they did not provide the correct loading at the correct length. To ensure progression within each block the training volume was increased between the second and third week (Table 2).

Statistical analyses

Visual inspection of Q-Q plots revealed no violations of normality between groups. To identify potential differences between groups, the pre-post change was analysed using one-way analysis of variance (ANOVA) with Tukey post hoc tests. Significant differences between pre- and post-values within each group were identified by performing paired sample t-tests. Cohen`s d was used to determine effect size (ES) if differences were observed. An ES of < 0.2, 0.2–0.5, 0.5–0.8 and > 0.8 were considered as trivial, small, moderate, and large effects, respectively (Cohen, 1988). The criterion alpha level was set at $p \leq .05$, and all statistical analyses were performed using the statistical software SPSS (Version 25, SPSS, Inc., Chicago, Illinois, USA). All analysed data are presented as means ± 95% confidence intervals while descriptive data are presented as means ± standard deviation.

Results

Baseline data

There were no significant differences in any of the performance variables between the groups at pre-test ($p = .08$–$.58$). A mean training attendance of 90% was reached for both training groups.

Effects of training intervention

Counter movement jump

A significant difference in change between the groups was observed for jump height (F = 3.256, $p = .05$). Post hoc comparisons demonstrated that the resisted training group achieved greater improvement in jump height compared to the active control group ($p = .04$, ES = 1.06; table 3), while no other differences were found between groups ($p = .31$–$.53$). From pre to post, the resisted group achieved a significant mean improvement of 3.58 cm ($p = .01$, supplementary Figure 1), while no significant changes occurred for the assisted group ($p = .10$) or the control group ($p = .94$).

Table 2. Training progression, and volume characteristics.

	Block 1		Block 2	
Week	1–2	3–4	5–6	7–8
Sessions per week	2	3	2	3
Sets × reps	4 × 5	5 × 5	4 × 5	5 × 5
Exercises	3	3	3	3
Training volume (reps per session)	60	75	60	75

Sprint performance

A significant difference between the groups was found for the maximal speed phase (F = 4.053, $p = .02$), but not for the acceleration phase (F = 1.120, $p = .34$) or the total sprint time (F = 0.912, $p = .41$). While the resisted training group improved their maximal speed by 0.30 m/s ($p = .03$, supplementary figure 2), the assisted group demonstrated a non-significant decline by −0.10 m/s ($p = .29$) from pre- to post test. The control group significantly improved their maximal speed by 0.21 m/s ($p = .04$). Post hoc comparisons demonstrated that the resisted training group achieved a greater improvement in the maximum speed phase compared to the assisted training group ($p = .02$, ES = 0.93), while no other differences were found between groups ($p = .39$–$.42$).

None of the intervention groups increased their acceleration phase from pre- to post-test ($p = .09$–$.11$, supplementary figure 3). However, the control group increased their speed in the acceleration phase by 0.17 m/s ($p = .01$). All groups reduced their total 40m sprint time from the start to the end of the intervention ($p = .01$–$.04$, supplementary figure 4).

Other training

None of the groups changes their estimated weekly training volume significantly during the intervention (Δ resisted; 0.4 ± 3.1 hours, Δ assisted; −0.6 ± 2.5 hours, Δ control; −0.3 ± 2.8 hours, $p = .34$–$.67$) and there was no significant difference in change between the groups (F = 0.591, $p = .56$).

Discussion

The main findings of the present study were that resisted plyometric training improved the maximal speed phase more than assisted plyometric training and jump height more than the active control group. Furthermore, the resisted training group improved jump height and maximum speed phase from pre- to post-test, while the control group improved their maximal speed phase and acceleration phase. All three groups improved their 40m sprint time from pre- to post-test.

In contrast to the hypothesis, a large between-group effect (ES = 0.97) was found in the maximum speed phase between the resisted and assisted training group, favouring the resisted group. This opposes the belief that training with an emphasis on the velocity aspect of the movements (assisted training) would be

Table 3. Changes (pre-post) in the jump height, maximal speed phase (A), acceleration phase (B) or 40m sprint time (C) for assisted (n = 16), resisted training (n = 17) or control group (n = 14).

	Assisted (N = 16)		Resisted (N = 17)		Control (N = 14)	
	Change	ES	Change	ES	Change	ES
Jump height (cm)	2.10 (−0.47–4.67)	0.32	3.58**# (1.60–5.57)	0.62	−0.06# (−1.68–1.56)	0.01
Maximal speed phase (m/s)	−0.10# (−0.28–0.09)	0.02	0.30*# (0.04–0.55)	0.48	0.21* (0.01–0.40)	0.37
Acceleration phase (m/s)	0.10 (−0.03–0.22)	0.38	0.08 (−0.02–0.18)	0.30	0.17** (0.08–0.27)	0.68
40m sprint time (s)	−0.08* (−0.16–0.00)	0.38	−0.22** (−0.22–0.06)	0.41	−0.13** (−0.20–0.06)	0.41

* = significantly different from pre-test ($p < .05$), ** = significantly different from pre-test ($p < .01$), # = significantly different between the groups ($p < .05$). Results are given as mean (95 CI) and effect sizes (ES).

more beneficial for improving maximal velocity by increasing stride length and/or stride rate during high speed running (Bartolini et al., 2011). Importantly, since the velocity during the plyometric training was not measured, we cannot be certain that the participants in the assisted training group were able to jump with a higher velocity than possible without the assistance. Also, although well trained participants have been able to utilize the assistance to produce a higher velocity (Argus et al., 2011), the same might not be true for the present, less trained population. Further, since using rubber bands as assistance will unload the participants' body mass, the overall load will be reduced. If the reduced load is not compensated by increased acceleration, the force (i.e. training stimuli) on the lower extremities would be sub-optimal. Furthermore, a reduced body mass would also induce a reduced training volume. Therefore, the increased training volume and loading may have led to an increased ability to produce force in the resisted group which have been shown to be important for explosive parameters (Komi, 1984; Markovic et al., 2007).

Only the resisted plyometric training group increased jump performance more than the active control group, which is also in contrast to our hypothesis. Importantly, the reported p-value was at the borderline of the alpha-level ($p = .05$) and the results should therefore be interpreted with caution. Although there was no difference in change between the two interventions, only the resisted group improved from pre to post-test and the effect size of the change is distinctly greater than for the resisted (ES = 0.62) compared to the assisted group (ES = 0.32). This could be explained by the aforementioned arguments, suggesting that the resisted plyometric training produces a more potent stimulus compared to the assisted plyometric training in the present population.

There were no differences in change between the groups in the acceleration phase and 40 m sprint time. The lack of difference was in contrast to our hypothesis and literature stating that resisted plyometric training would be more beneficial for the acceleration phase than the other groups, due to the similar ground reaction forces between resisted plyometric training and the acceleration phase of a sprint (Rimmer & Sleivert, 2000). Resisted plyometric training emphasizes the force aspects of the movements and thereby contribute to increased force applied to the ground per stride resulting in a greater acceleration (Bartolini et al., 2011; Murray et al., 2005). However, due to the low training status of the participants in this study (only familiar with running and sprinting) it is possible that although jumping resembles the eccentric-concentric contraction pattern of sprinting, the biomechanical specificity of the training may not be specific enough for individuals without considerable sprinting experience (Sale & MacDougall, 1981). It could therefore be speculated that assisted or resisted plyometric training is more transferable to the acceleration phase among well trained athletes who are highly familiar with sprinting and have a well developed running technique.

The lack of a clear pattern favouring the intervention groups compared to the control group could be explained by several factors. Since the control group was instructed to continue their normal training routines, it is also possible that this activity contributed to improvements in these parameters. The control group had a non-significant higher average weekly training volume compared to the intervention groups at both pre- and post-test (pre-test; 2.0–2.8 hours per week, post-test; 1.3–3.1 hours per week). Although not reaching significance, it is possible that this difference over time might have affected the between-group results. Further, we can`t exclude the possibility that members of the control group changed their behaviour as a result of being randomized to the control group (John Henry-effect), although all participants were told exclusively to continue their normal training routines. Also, the lack of difference between the intervention groups and the control group could be attributed to the population. Although the participants in this study were regularly physical active, they were not experienced with systematic plyometric training. The effects of plyometric training have been suggested to be more relevant for individuals who already have obtained high levels of strength but lack the ability to utilize their power output or movement velocity (Argus et al., 2011; Sheppard et al., 2011). It is therefore possible that the population included in the present study lacked sufficient levels of strength to optimally utilize the training stimuli from the plyometric training.

The present study is, to the authors' knowledge, the first to compare the effects of assisted or resisted plyometric training on jump and sprint performance in the same study. Comparable studies (Davies et al., 2015; Häkkinen et al., 1990; Stien et al., 2020; Winchester et al., 2008) have only included bilateral vertical jumps in their training protocol or only measured jump performance. In accordance with the present study none of these abovementioned studies reported difference in change in jump height between assisted and resisted plyometric training.

Although a strong study design was used to compare the effects of assisted or resisted plyometric training, there are some limitations that may be considered. The relatively short intervention period and small sample size could lead to a lower statistical power. Further, the present study aimed to investigate these training methods with only the external loading as the independent factor and therefore both training groups performed the same number of jumps per training session. The resisted training group therefore achieved a greater training volume than the assisted group, since unloading the participants body mass reduces the overall training volume. Training outside the intervention may have influenced the results of the study. The participants were instructed to continue their regular training routines, which was controlled for by a questionnaire at pre- and post-test. However, the participants only reported the weekly training volume in hours per week without specifying the type of training. A more specified questionnaire may have brought more insight into the results. Finally, since only physically active females were included in this study, the findings cannot be generalized to other populations.

In conclusion, although both interventions might be beneficial for improving jump and sprint performance, this study indicates that resisted plyometric training can improve the maximal speed phase to a greater extent compared to assisted plyometric training among physically active females. Further, the resisted plyometric training seems like a more potent stimulus for improving jump performance than to continue recreational training. Future research should include well trained individuals with extensive sprinting or jumping experience, and a larger sample size over a longer intervention period to provide a greater understanding of the potential differences between the two training methods.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

Andrade, D., Henriquez-Olguin, C., Beltran, A., Ramirez, M., Labarca, C., Cornejo, M., … Ramirez-Campillo, R. (2015). Effects of general, specific and combined warm-up on explosive muscular performance. *Biology of Sport*, *32*(2), 123–128.

Argus, C. K., Gill, N. D., Keogh, J. W., Blazevich, A. J., & Hopkins, W. G. (2011). Kinetic and training comparisons between assisted, resisted, and free countermovement jumps. *Journal of Strength and Conditioning Research*, *25*(8), 2219–2227.

Bartolini, J. A., Brown, L. E., Coburn, J. W., Judelson, D. A., Spiering, B. A., Aguirre, N. W., … Harris, K. B. (2011). Optimal elastic cord assistance for sprinting in collegiate women soccer players. *Journal of Strength and Conditioning Research*, *25*(5), 1263–1270.

Bobbert, M. F. (1990). Drop jumping as a training method for jumping ability. *Sports Medicine*, *9*(1), 7–22.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences. Vol. 2*. Hillsdale: Lawrence Earlbaum Associates.

Davies, G., Riemann, B. L., & Manske, R. (2015). Current concepts of plyometric exercise. *International Journal of Sports Physical Therapy*, *10*(6), 760–786.

Ebben, W. P., & Blackard, D. O. (2001). Strength and conditioning practices of National Football League strength and conditioning coaches. *Journal of Strength and Conditioning Research*, *15*(1), 48–58.

Ebben, W. P., Carroll, R. M., & Simenz, C. J. (2004). Strength and conditioning practices of National Hockey League strength and conditioning coaches. *Journal of Strength and Conditioning Research*, *18*(4), 889–897.

Häkkinen, K., Pakarinen, A., Kyröläinen, H., Cheng, S., Kim, D., & Komi, P. (1990). Neuromuscular adaptations and serum hormones in females during prolonged power training. *International Journal of Sports Medicine*, *11*(2), 91–98.

Harris, N. K., Cronin, J. B., Hopkins, W. G., & Hansen, K. T. (2008). Squat jump training at maximal power loads vs. Heavy loads: Effect on sprint ability. *Journal of Strength and Conditioning Research*, *22*(6), 1742–1749.

Khodaei, K., Mohammadi, A., & Badri, N. (2017). A comparison of assisted, resisted, and common plyometric training modes to enhance sprint and agility performance. *The Journal of Sports Medicine and Physical Fitness*, *57*(10), 1237–1244.

Knuttgen, H., & Kraemer, W. (1987). Terminology and measurement in exercise performance. *Journal of Strength and Conditioning Research*, *1*, 1–10.

Komi, P. V. (1984). Physiological and biomechanical correlates of muscle function: Effects of muscle structure and stretch-shortening cycle on force and speed. *Exercise and Sport Science Reviews*, *12*, 81–121.

Kubo, K., Kawakami, Y., & Fukunaga, T. (1999). Influence of elastic properties of tendon structures on jump performance in humans. *Journal of Applied Physiology*, *87*(6), 2090–2096.

Loturco, I., Contreras, B., Kobal, R., Fernandes, V., Moura, N., Siqueira, F., … Rogan, S. (2018). Vertically and horizontally

directed muscle power exercises: Relationships with top-level sprint performance. *PLoS One*, *13*(7), e0201475–13.
Markovic, G., et al. (2007). Effects of sprint and plyometric training on muscle function and athletic performance. *Journal of Strength and Conditioning Research*, *21*(2), 543–549.
Markovic, G., Vuk, S., & Jaric, S. (2011). Effects of jump training with negative versus positive loading on jumping mechanics. *International Journal of Sports Medicine*, *32*(5), 365–372.
Markovic, S., Mirkov, D. M., Knezevic, O. M., & Jaric, S. (2013). Jump training with different loads: Effects on jumping performance and power output. *European Journal of Applied Physiology*, *113*(10), 2511–2521.
Matavulj, D., et al. (2001). Effects of plyometric training on jumping performance in junior basketball players. *The Journal of Sports Medicine and Physical Fitness*, *41*(2), 159–164.
McBride, J. M., et al. (2002). The effect of heavy- vs. Light-load jump squats on the development of strength, power, and speed. *Journal of Strength and Conditioning Research*, *16*(1), 75–82.
Murray, A., Aitchison, T. C., Ross, G., Sutherland, K., Watt, I., McLean, D., & Grant, S. (2005). The effect of towing a range of relative resistances on sprint performance. *Journal of Sports Sciences*, *23*(9), 927–935.
Nealer, A. L., Dunnick, D. D., Malyszek, K. K., Wong, M. A., Costa, P. B., Coburn, J. W., & Brown, L. E. (2017). Influence of rest intervals after assisted sprinting on bodyweight sprint times in female collegiate soccer players. *Journal of Strength and Conditioning Research*, *31*(1), 88–94.
Rimmer, E., & Sleivert, G. (2000). Effects of a plyometrics intervention program on sprint performance. *Journal of Strength and Conditioning Research*, *14*(3), 295–301.
Sale, D., & MacDougall, D. (1981). Specificity in strength training: A review for the coach and athlete. *Canadian Journal of Applied Sport Sciences*, *6*(2), 87–92.
Sheppard, J. M., Dingley, A. A., Janssen, I., Spratford, W., Chapman, D. W., & Newton, R. U. (2011). The effect of assisted jumping on vertical jump height in high-performance volleyball players. *Journal of Science and Medicine in Sport*, *14*(1), 85–89.
Stien, N., Strate, M., Andersen, V., & Saeterbakken, A. H. (2020). Effects of overspeed or overload plyometric training on jump height and lifting velocity. *Sports Medicine International Open*, *4*(02), E32–E38.
Winchester, J. B., McBride, J. M., Maher, M. A., Mikat, R. P., Allen, B. K., Kline, D. E., & McGuigan, M. R. (2008). Eight weeks of ballistic exercise improves power independently of changes in strength and muscle fiber type expression. *Journal of Strength and Conditioning Research*, *22*, 1728–1734.