Manuscript title: Use of visual feedback during jump-squat training aids improvement in sport-specific tests in athletes

Abstract

This study investigated the effects of instantaneous performance feedback during the jump-squat exercise over a 6-week training period. Twenty-five strength-trained athletes were randomly divided into an instant feedback (n = 13, half-squat 3-RM/body weight = 2.38 ± 0.19) or a non-feedback (n = 12, half-squat 3-RM/body weight = 2.03 ± 0.44) group. Both groups performed the same training program (3×week), consisting of 4 sets of 8 repetitions (weeks 1-3) and 8 sets of 4 repetitions (weeks 4-6) using a barbell with a load that maximized the average concentric power output (Pmax) of each athlete. Subjects in the instant feedback group were given real-time data after each repetition. Pre-, mid-, and post-training testing consisted of maximum 20m, 30m and 50m running speed, 3-RM back half-squat load, Pmax and the load that maximized average concentric power output (Pmax load), countermovement (CMJ) and squat jump (SJ) height. Results revealed that the feedback group significantly improved all selected tests versus non-feedback (time×group interaction, $p<0.01$). Significant improvements post-training for 20m, 30m, 50m, 3-RM load, Pmax load, CMJ and SJ were observed in the feedback group only ($p<0.01$). Training without instant feedback did not lead to significant performance improvements, this group actually demonstrated significant decreases in SJ and Pmax (W) and Pmax load ($p<0.05$). The results of this study indicate that the use of instant feedback during jump-squat training in athletes was beneficial for improving multiple performance tasks over 6-weeks of training. Instant feedback is an important element of power training to maximize adaptations when training strength-trained athletes.

Key words: squat, power, sprint running, maximum strength, linear position transducer, vertical jump

INTRODUCTION

The demand for elite athletes to maximize performance from competition to competition is constantly increasing. Hence, sport scientists and practitioners constantly manipulate training variables and try different training modalities to optimize improvements. One strategy used in modern training is to provide instant feedback upon completion of each repetition so that each and every effort is maximized, and appropriate adjustments can be made if necessary. In recent years, the abundance of commercial linear position transducers available has enabled athletes to perform strength or power training using instant feedback regarding power production during the exercise.

Instant feedback is now commonly used in athletic training to facilitate achievement of goals and to motivate the athletes to consistently improve performance (20). From a motor learning standpoint, it has been stated that instant feedback during exercise can have a substantial contribution to athletic performance (15). In this regard, many studies have investigated the effectiveness of instant feedback to maximize performance during the exercise itself (1, 2, 7, 12, 16, 27).

For instance, Hopper et al. (12) examined the influence of power production feedback during the leg press exercise in elite field-hockey players, where two groups of players were tested for peak power during a both feedback and non-feedback condition Results show that both groups had higher power production during the feedback condition (group 1: No-feedback = 685.4 ± 65.7 W and Feedback = 698.8 ± 64.8 W, group 2: No-feedback = 743.3 ± 103.5 W and Feedback = 756.0 ± 110.6 W, $p = 0.027$). Favorable findings for the use of feedback have also been demonstrated when comparing muscle activation and strength during concentric and eccentric muscle actions via EMG feedback (7).

However, the aforementioned studies have only assessed the impact of instant feedback on performance of the training-specific exercise, but they have not tested possible transfer to other (sport-specific) performance. To our knowledge, only one study has investigated the effects of instant performance feedback on other sport-specific tests (23). In this study, professional rugby players were assigned into feedback (n = 7) and non-feedback (n = 6) training groups (23). The results (percentage probabilities) revealed that the use of feedback during the training was beneficial for improving performance in horizontal jump (83%), vertical jump (45%), 10m (49%), 20m (49%), and 30m sprint time (99%). These results provide evidence that training with instant feedback can potentially augment gains in multiple sport-specific tasks. Nevertheless, these findings should be verified by further studies.

The jump-squat exercise appears to be a good candidate to examine the influence of instant feedback on multiple sport-specific performances. It has been shown to simultaneously influence concentric power output, running speed, maximal isometric force and vertical jump performance in physical active populations (18, 19, 29). One important aspect that should be considered when manipulating training variables is the level of training experience of the individual. Whereas novice athletes will have large performance gains after a relatively short training time, experienced athletes will make small strength/performance gains over a long period of time (10). Therefore, it is perhaps advisable to investigate the use of instant feedback in already-trained individuals.

Consequently, the present study investigated the efficacy of jump-squat training with instant concentric power feedback compared to training without feedback in already strength-trained individuals. It was hypothesized that the training gains of several sport-specific tests in the group with visual instant feedback will be larger compared to the non-feedback group.

METHODS

Experimental Approach to the Problem

Strength-trained men were pair-matched based on the load that yielded maximum concentric power (Pmax) and randomly divided into instant feedback (displayed concentric power output after each repetition) or non-feedback groups. Muscular power is considered as one of the main determinants of performance during maximal sprinting, jumping and throwing. It has been shown that training with the load that maximizes power output can enhance various athletic tasks, including sprinting, maximum strength and jumping (19, 29). From that standpoint, it was important to maintain similar training loads between the groups. Both groups performed the jump-squat exercise 3×week over a 6-week period. Performance tests included maximum running speed, highest average concentric power, 3-RM load and vertical jump performance pre-, mid- (after 3 weeks) and post-training.

Subjects

Twenty-five strength-trained men from different sports (martial arts, weightlifting, soccer players, track and field athletes) agreed to participate in this research. Subjects were placed into an instant feedback group (n = 13, age = 22.9 ± 2.2 years, height = 182.9 ± 3.6 cm, weight = 81.6 ± 5.7 kg, 3-RM = 194.6 ± 19.8 kg) or non-feedback group (n = 12, age = 23 ± 2 years, height = 182 ± 4.9 cm, weight = 80.4 ± 6.9 kg, 3-RM = 163.3 ± 36.9 kg). The instant feedback group was composed of 2 university weightlifters, 3 former track and field athletes (100 and 200 m), 5 soccer players (regional competition), 1 judoka, 1 karate and 1 boxer. In the non-feedback group were 2 university weightlifters, 5 soccer players (regional competition), 2 karate, 2 judokas and 1 Thai boxer. All subjects had a minimum of 4 years of resistance training experience. Subjects were fully informed about the study design and all procedures were explained along with possible risks prior to providing signed informed content. The study was approved by the local University Ethics Committee and conformed to the Declaration of Helsinki.

Figure 1 about here

Procedures

Diagnostic series – determination of the load that maximized average power output

A diagnostic series was carried out as previously reported (28, 29). Before the start of the experiment, subjects underwent a series of jump-squat trials. A linear position transducer (FiTRODyne Premium, Bratislava, Slovakia) was used to record average concentric power during each repetition throughout the study. The FiTRODyne's cord was attached to an Olympic barbell perpendicular to the floor. The system´s sensor unit was connected to a computer with built-in software that displayed average concentric power data. It has been shown to be a reliable device to measure power (14). Foam cubes were individually adjusted to each subject by measuring the knee joint angle using a handheld goniometer. The depth of the squat was to a knee-angle of approx. 90°. All subjects were instructed to "squat down in a controlled manner and then immediately jump up as quickly as possible". The series began with an Olympic barbell (20kg) and the test was interrupted upon reaching a plateau or decrease in average concentric power output (Pmax). Each subject had two attempts with each load, which was then increased in 10 kg steps if average concentric power continued to increase. Three minutes of rest was included after the 2 trials and before further increments. To confirm that the plateau in power output had been obtained, each subject performed a further 2 trials (+20 kg). The same procedure to evaluate Pmax and the load that maximized Pmax was chosen during pre-, mid-, and post-training testing.

Maximal running speed testing

Subjects completed 2 trials of a 50m maximal sprint running test. Split times were recorded at 30m and between 30m and 50m to evaluate 20m flying start. Each subject started volitionally from a stationary, standing start. The front foot was placed approx. 50 cm behind the dualbeam timing gate (FiTRO Light Gates, Bratislava, Slovakia) to avoid spontaneous triggering. The best time of the 2 trials was recorded for further analysis. A two-minute rest period was included between trials.

3-RM half-squat testing

3-RM back half-squat strength was performed using an Olympic barbell and free weight according to procedures of Crewther et al. (6), but modified to the back half-squat (90° knee-angle). A loaded barbell was positioned across the shoulders. Feet were placed slightly wider than shoulder width apart. On both sides of the barbell were experienced instructors who watched for subjects' safety and were available to take the bar if something unpredictable happened or the attempt failed. Subjects squatted down in a controlled manner until a knee angle of 90° (controlled by foam blocks as above) before returning to the fully extended (start) position without assistance. The load started at 40-60% of subject-estimated 3-RM for 4-8 repetitions. The load was then increased, in 10 kg steps, until 3-RM was unsuccessfully performed. Once the subject failed, the load was decreased by 5 kg and a further attempt was made. Hence, the final 3-RM was determined with an accuracy of 5 kg and always within 3-5 sets. Rest intervals between trials were 3-4 minutes. 3-RM testing has a high degree of reliability in trained men (5).

Vertical jump testing

CMJ and SJ measurements were performed with the subjects' feet placed shoulder-width apart. Maximal height of each vertical jump was recorded on a Myotest accelerometer system (Myotest® Performance Measuring system, Sion, Switzerland), which was positioned on a stick and held on the shoulders (similar to barbell jump-squats). The device calculates jump height through the change in position in the vertical plane (2D accelerometer with a sampling frequency of 500 Hz). The Myotest has been shown to be valid and reliable device to measure countermovement (CMJ) and squat jump (SJ) height (3). All subjects were instructed to jump as high as possible and to avoid involuntary movement that could affect results. During the testing session, subjects performed 2 trials of the squat and countermovement vertical jump. The best height was recorded for further analysis. When performing the SJ, subjects were instructed to avoid any countermovement in the base position (90° knee-angle). During the CMJ, subjects were instructed to perform the test to a self-selected depth. Rest intervals between trials were between 30-60 seconds.

Jump-squat training

Both groups trained 3 times per week for 6 weeks. During the first 3 weeks, subjects in both groups performed 4 sets of 8 repetitions with an absolute load 20% below Pmax load and the last 3 weeks were performed with 8 sets of 4 repetitions with the absolute load that maximizes average power. In our previous study (29) we conducted pilot measurements where a sub-set of the subjects were randomly selected to perform 1 set with Pmax load and 1 set with a load corresponding to 90% of maximum power (which is approx. 20% below Pmax load-identified by the diagnostic series). From these measurements we determined that subjects were able to perform 4.4 ± 1.5 repetitions with Pmax load, and 8.3 ± 2.8 repetitions with lighter load (20% below Pmax load) while maintaining average concentric power above a threshold of 90 % of the measured maximum power (29). During training, all subjects were instructed to squat down until they touched the foam cubes (approx. 90° knee angle) and then immediately jump as high as possible. Both groups were verbally encouraged to jump as high as possible during all training sessions, but only the feedback group received (visual) real-time data from the each repetition (Figure 1). These standardized instructions were maintained throughout the study. Three minutes rest was allowed between sets. The subjects were instructed to avoid any other heavy or power-type strength training during the 6-week period, but they were allowed to continue their normal off-season technical training sessions. Subjects completed 18 jump-squat training sessions in total. Differences between training loads used were non-significant (feedback: 85±11 kg, 43.6±5 % of 3RM; non-feedback: 79±14 kg, 49.6 % of 3RM; p=0.295).

Statistical Analyses

Standard statistical methods were used to calculate mean and standard deviations (mean±SD). Normality was assessed by the Kolmogorov-Smirnov test and Levene's test was used to assess homogeneity of variance. Repeated measures Analysis of Covariance (ANCOVA; 2 time × 2 group) with baseline values as covariate was performed to determine significant main effects. Where a significant time×group interaction was detected, Bonferroni post hoc tests were used to determine within-group changes over-time. Calculation of effect size was performed by using Hedge's *g*, where small (<0.3), medium (0.3–0.8) and large (>0.8) effect sizes were used to describe the between-group changes over-time (i.e. Δ pre- to post-training). Alpha was set at 0.05 and all statistics were performed by IBM SPSS statistics 24 software (IBM, Armonk, New York, USA). Test-Retest reliability values were; 30m sprint: 0.961 and 0.7%, 50m sprint: 0.659 and 2.4%, 20m flying sprint: 0.938 and 1.0%, 3-RM: 0.987 and 2.1%, Pmax: 0.459 and 8.4%, Pmax load: 0.659 and 11.1%, CMJ: 0.983 and 1.7%, and SJ: 0.982 and 1.7% for Intra-class correlation coefficient and coefficient of variation %, respectively.

RESULTS

Significant time×group interactions were observed for all variables (Table 1). The group training with instant feedback demonstrated statistically significant (P<0.05) improvements over-time from pre-training to post-training in all variables expect Pmax (Table 1). In particular, the improvements occurred during the last 3 weeks of the training period as demonstrated in the statistically significant differences between mid-training and post-training (Table 1). Significant decreases for the non-feedback group were observed in Pmax, Pmax load and SJ height (Table 1).

Table 1 about here

Effect sizes for the pre- to post-training changes revealed strong effect sizes in favor of the instant feedback group (Figure 2); 30m (*g* = -1.06, 95% confidence interval = -1.89 to -0.22), 50m (*g* = -1.88, 95% confidence interval = -2.82 to -0.94), 20m (*g* = -2.03, 95% confidence interval = -2.99 to -1.06), Pmax (*g* = 1.18, 95% confidence interval = 0.33 to 2.03), 3-RM (*g* = 1.31, 95% confidence interval = 0.44 to 2.17), Pmax load (*g* = 1.74, 95% confidence interval = 0.82 to 2.67), CMJ (*g* = 1.76, 95% confidence interval = 0.84 to 2.69) and SJ (*g* = 2.85, 95% confidence interval = 1.74 to 3.96).

Figure 2 about here

Discussion

The main purpose of this study was to determine the effect of instantaneous power production feedback (after each repetition) on multiple sport-specific tests during a 6-week training period. Significant improvements in all assessed running speed and vertical jump tests were observed in the feedback group only, whereas no improvements occurred in the non-feedback group. The results of the present study support the use of instantaneous feedback during jump-squat training in athletes.

The results of the non-feedback group are not surprising because similar findings in athletes were also recorded in previous jump-squat training studies without feedback (11, 23, 30). This is symptomatic of the difficulty in eliciting gains in already strength-trained individuals. In contrast, some studies using physically active athletes found significant improvements in sprint times over a distance of 5, 10, 20 and 30 m (17) and 50 m, (29) as well as trends toward improved 10 and 20 m sprint time (21). Since the subject's strength level varied from study-to-study, this should be kept in mind when evaluating the literature. While between-study differences may be attributed to training status, we show here that a lack of improvement in maximum strength may not just be due to training history and baseline strength level, but also may depend on how the exercise is performed on a rep-by-rep basis. This interpretation is supported by the divergent adaptations between the feedback and non-feedback groups in the present study.

The present study's subjects were professional athletes who had several years of experience in strength training, as well as with the jump-squat exercise. Therefore, it may be that jump-squat training as a sole exercise for high-level athletes is not a sufficient stimulus in itself to readily improve sprint and vertical jump performance. If anything, the training stimulus without instant feedback in the present study could be considered insufficient in this population, since the non-feedback group demonstrated reduced jump-squat power and SJ height. Interestingly, the inclusion of instant feedback in the present study shows the importance of this potentially motivating factor to induce performance improvements.

Significant improvements in sprint times were observed in the present study (20 m = 3%, 30 m = 2%, 50 m = 2%, $p \leq 0.05$). This is in-line with previous jump-squat training studies where significant improvements in 20m and 50m sprint time (14.5% and 1.9%, respectively, $p \leq 0.05$) (19, 29) as well as 5m (7.7%, ES=1.68), 10m (5.5%, ES=1.45), 20m (3.6%, ES=1.26) and 30m (3%, ES=0.94) sprinting velocity (17) were observed. With respect to the purpose of the present study, only one study examined the short-term effects of jump-squat training with or without instant (peak velocity) feedback on 30m sprint performance in highly strength-trained rugby players (23). Randell and colleagues (23) observed significant difference in 30 m sprint time (1.4%, ES= -0.46, $p<0.001$) in favor of instant feedback, which the authors explained as a result of greater consistency in peak velocity during the training. A similar effect could have happened in our study where, not velocity but, greater consistency in power output served to enhance sprint performance.

Maximal strength (i.e. 3-RM) improvement was also evident only in the feedback group (pre- to post-training: 7%, $p<0.05$) whereas no significant improvement was observed in the non-feedback group (pre- to post-training: 3%, $p>0.05$). Previous studies have shown mixed results regarding the efficacy of jump-squat training to improve maximum strength, with both significant improvements in recreationally-trained athletes (4, 21, 26) and no improvements in strength-trained athletes (22, 30). One study performed by Harris et al. (9) observed significant increases in 1-RM squat strength after both heavy-load jump-squat training (80% 1-RM, 15%) and light-load load jump-squat training (the load ranged between 20 – 44% of 1-RM to provide Pmax load, 11%) in strength-trained rugby league players. The present training cycle was performed with the load that maximizes average power output and this may allow simultaneous improvement in both maximal strength and sprint performance (29). Improvements in both CMJ and SJ were observed after power training with instant feedback only (pre- to post-training: both 6%, $p<0.05$). The non-feedback group did not improve CMJ or SJ height. Moreover, a significant decrease in SJ height in the non-feedback group was recorded (pre- to post-training: -3%, $p<0.05$). The magnitude of improvements in the feedback group are somewhat lower compared to previous jump-squat studies in only moderately-trained individuals (26, 29). Nevertheless, a similar magnitude of improvement in CMJ compared to the present study was observed by Randell et al. (23) in their feedback group (5%, visual feedback provided was peak velocity). Summarizing the results of the present study and those of Randell et al. (23), it appears that the use of instant feedback leads to (almost) a similar magnitude of training-induced improvement as would be expected in lesser-trained athletes, however, performing jump-squat training without instant feedback leads to a much lower and non-significant change in vertical jump performance.

Significant improvement in Pmax load was evident only in the feedback group (pre- to post-training: 8%, $p<0.05$) but this plateaued quickly and no significant improvements occurred from mid- to post-training (2%, $p>0.05$). No significant improvements from pre- to post-training or from mid- to post-training were observed in Pmax (pre- to post-training: 6%, $p>0.05$). However, there was trend towards the improvement in Pmax in the feedback group after training (7%, $p=0.063$, $g=1.18$). Conversely, the non-feedback group observed significant decrements in both Pmax load (-15%, $p<0.05$, pre-training to post-training) and Pmax (-4%, $p<0.05$, pre-training to post-training). Our results regarding Pmax in the non-feedback group are in-line with a previous study conducted by Harris et al. (9) who also observed a decrease in power output (with the load at 55% of 1-RM) after two jump-squat training variations (-17%, 80% 1-RM and -6%, 20-44% 1-RM) in elite-level rugby league players. Attributing cause to the findings of the present study and that of Harris and colleagues (9) is complex because of the possible different contributing factors, however, potential reasons include e.g. variation in performance due to fatigue/lack of motivation (despite constant encouragement). Also, possible changes in the force-velocity relationship where maximum strength remained the same but the execution on the jump-squats during the training could be slower compared to their counterparts, or that the training program was not a sufficient stimulus to promote gains in this already highly-adapted group. Nevertheless, as discussed above, the likely candidate may be that the jump-squat exercise alone was not sufficient to maintain maximum strength and power levels in well-trained athletes. In this sense even the addition of feedback only trended to improve Pmax (7%, pre- to post-training, $p=0.063$, $g = 1.18$).

Certainly, it would seem that advanced or highly-trained athletes are more challenging to condition than their less experienced counterparts, and they may require further stimuli of program variables to achieve the desired improvements (8). It has already been shown in previous works that provision of instant feedback led to performance consistency of squat jumps (24, 25) and increased peak velocity of squat jumps (25). Therefore, it seems possible that visual feedback could result in greater consistency of effort and motivate athletes during jump-squat training program to perform high-quality movement repetition-after-repetition. These findings are consistent among studies despite the fact that the feedback provided in the present study was average concentric power (Pmax) compared to peak velocity (23, 24, 25).

The present study has also some important aspects as well as limitations that should be discussed. One important aspect of this study was that the external training load was individually adjusted according to the power-load curve of each subject – and this was monitored throughout the study. The use of individualized loads compared to prescribed (% of 1-RM) may be beneficial, since it has been stated that different neuromuscular characteristics of the subjects may lead to different power-load curves (13). However, one possible confounding factor is that the initial 3-RM strength was different between the groups. The main purpose of our randomization procedure was to match the groups based on training load, but this as an unforeseen consequence of our randomization procedure. Certainly, it would be interesting to conduct the study pair-matched for maximum strength as well as training load. It should be noted that the non-feedback stimulus was not insufficient for all performance tests and within the non-feedback group there were individuals that responded positively to the training. In order to understand the potential inter-individual differences, future studies would need to include a much larger sample size and make detailed assessments of the neuromuscular properties of each individual. Another important consideration of this study was the use of only one exercise (i.e. jump-squat) during the experiment to compare feedback versus no-feedback. While this is of scientific advantage, training sessions in athletic environments are typically composed of several exercises, and so external validity is somewhat compromised here. While other studies have provided feedback in only one exercise, they did include several exercises as part of their training program for athletes (23). Our methods allow us to compare the effects of instant feedback from non-feedback, but the training program itself may not have been optimal or of sufficient volume for the subjects in the present study. Also, the lack of exact mechanisms that are responsible for the performance improvements is as another limitation. Having now confirmed the possible advantage of using instant feedback in training, future studies should aim to determine whether the source of improvement was e.g. neural, muscular or connective tissue in order to understand the phenomena to an even greater extent.

In conclusion, the results of the present study support the use of instantaneous feedback during training sessions to enhance maximal strength, vertical jump and sprint performance in already strength-trained athletes. Therefore, such a procedure can be recommended for practice where further increases in sport performance are required, for instance, when a plateau in already strength-trained athletes has occurred.

Practical Applications

The use of instant (visual) feedback on power production during jump-squat training is an essential component for any athlete/coach. Furthermore, power training of only one exercise in high-level athletes without monitoring has the potential to lead to decrements in performance. Our findings and conclusions are limited to short-term training and in leg extensor muscles/exercise(s), as the present intervention was only 6 weeks in duration. Nevertheless, it might be expected that changing the training stimulus would be recommendable after such a period of power training.

References

1. Anderson, R, Harrison, A and Lyons, GM. Accelerometry-based feedback – Can it improve consistency and performance in rowing? Sports Biomech 4: 179-195, 2005.
2. Argus, CK, Gill, ND, Keogh, JW and Hopkins, WG. Acute effects of verbal feedback on upper-body performance in elite athletes. J Strength Cond Res 25: 3282-3287, 2011.
3. Casartelli, N, Müller, R and Maffiuletti, NA. Validity and reliability of the myotest accelerometric system for the assessment of vertical jump height. J Strength Cond Res 24: 3186-3193, 2010.
4. 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.
5. Coutts, A, Reaburn, P, Piva, TJ and Murphy, A. Changes in selected biochemical, muscular strength, power, and endurance measures during deliberate overreaching and tapering in rugby league players. Int J Sports Med 28: 116-124, 2007.
6. Crewther, BT, Kilduff, LP, Cook, CJ, Middleton, MK, Bunce, PJ and Yang, GZ. The acute potentiating effects of back squats on athlete performance. J Strength Cond Res 25: 3319-3325, 2011.
7. Ekblom, MM and Eriksson, M. Concurrent EMG feedback acutely improves strength and muscle activation. Eur J Appl Physiol 112: 1899-1905, 2012.
8. Harris, NK, Cronin, JB and Keogh, JW. Contraction force specificity and its relationship to functional performance. J Sports Sci 25: 201-212, 2007.
9. Harris, NK, Cronin, JB, Hopkins, WG and Hansen, KT. Squat jump training at maximal power loads vs. heavy loads: effect on sprint ability. J Strength Cond Res 22: 1742-1749, 2008.

10. Hoffman, J. Physiological aspects of sport training and performance. Champaign, IL: Human Kinetics, 2002.
11. Hoffman, JR, Ratamess, NA, Cooper, JJ, Kang, J, Chilakos, A and Faigenbaum, AD. Comparison of loaded and unloaded jump squat training on strength/power performance in college football players. J Strength Cond Res 19: 810-815, 2005.
12. Hopper, MD, Berg, AAM, Andersen, H and Madan, R. The influence of visual feedback on power during leg press on elite women field hockey players. Phys Ther Sport 4: 182-186, 2003.
13. Izquierdo, M, Häkkinen, K, González-Badillo, JJ, Ibáñez, J and Gorostiaga, EM. Effects of long-term training specificity on maximal strength and power of the upper and lower extremities in athletes from different sports. Eur J Appl Physiol 87: 264-271, 2002.
14. Jennings, CL, Viljoen, W, Durandt, J and Lambert, MI. The reliability of the FitroDyne as a measure of muscle power. J Strength Cond Res 19: 859-863, 2005.
15. Kilduski, NC and Rice, MS. Qualitative and quantitative knowledge of results: Effects on motor learning. Am J Occup Ther 57: 329–336, 2003.
16. Limonta, E, Rampichini, S, Cè, E and Esposito, F. Effects of visual feedback absence on force control during isometric contraction. Eur J Appl Physiol 115: 507-519, 2015.
17. Loturco, I, Pereira, LA, Kobal, R, Maldonado, T, Piazzi, AF, Bottino, A, Kitamura, K, Abad, CCC, Arruda, M and Nakamura, FY. Improving sprint performance in soccer: Efectiveness of jump squat and Olympic push press exercises. PLoS One 11: 1-12, 2016.
18. Loturco, I, Pereira, LA, Kobal, R, Zanetti, V, Gil, S, Kitamura, K, Abad, CC and Nakamura, FY. 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.

19. Loturco, I, Ugrinowitsch, C, Roschel, H, Tricoli, V and Gonález-Badillo, J. Training at the optimum power zone produces similar performance improvements to traditional strength training. J Sports Sci Med 12: 109-115, 2013.
20. Magill, RA. Motor Learning. Concepts and Applications, 5th ed., McGraw-Hill, Boston, 1996.
21. 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.
22. Newton, RU, Kraemer, WJ and Häkkinen, K. Effects of ballistic training on preseason preparation of elite volleyball players. Med Sci Sports Exerc 31: 323-330, 1999.
23. Randell, AD, Cronin, JB, Keogh, JW, Gill, ND and Pedersen MC. Effect of instantaneous performance feedback during 6 week of velocity-based resistance training on sport-specific performance tests. J Strength Cond Res 25: 87-93, 2011.
24. Randell, AD, Cronin, JB, Keogh, JWL, Gill, ND and Pedersen, MC. Effect of performance feedback during velocity based resistance training. Sports Biomech 25: 87-93, 2011.
25. Randell, AD, Cronin, JB, Keogh, JWL, Gill, ND and Pedersen, MC. Reliability of velocity measures for jump squats under feedback and non-feedback conditions. J Strength Cond Res 25: 3514-3518, 2011.
26. Smilios, I, Sotiropoulos, K, Christou, M, Douda, H, Spaias, A and Tokmakidis, SP. Maximum power training load determination and its effects on load-power relationship, maximum strength, and vertical jump performance. J Strength Cond Res 27: 1223-1233, 2013.

27. Toumi, A, Jakobi, JM and Simoneau-Buessinger, E. Differential impact of visual feedback on plantar- and dorsi-flexion maximal torque output. Appl Physiol Nutr Metab 41: 557-559, 2016.
28. Vanderka, M, Krčmár, M, Longová, K and Walker, S. Acute effects of loaded half-squat jumps on sprint running speed in track and field athletes and soccer players. J Strength Cond Res 30: 1540-1546, 2016.
29. Vanderka, M, Longová, K, Olasz, D, Krčmár, M and Walker S. 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.
30. Wilson, GJ, Newton, RU, Murphy, AJ and Humphries, BJ. The optimal training load for the development of dynamic athletic performance. Med Sci Sports Exerc 25: 1279-1286, 1993.

Figure legends:

Figure 1 – Subjects performing jump-squat training in the (A) bottom position (approx. 90°) and (B) in a jump position. The figure shows the visual display of average concentric power output provided in real-time between each repetition.

Figure 2 – Effect sizes (Hedge's *g* and 95% confidence intervals) for the between-group changes pre- to post-training. Note that the values for the sprint-time variables have been made positive to maintain directionality within the figure.

Tables

Table 1 – Physical performance (mean±SD) and statistical comparisons between the two groups.

	Feedback group			Non-feedback group			time×group
	Pre-	Mid-	Post-	Pre-	Mid-	Post-	P-value
30m (s)	4.31±0.15	4.28±0.11	4.22±0.14*‡	4.29±0.16	4.26±0.12	4.27±0.16	0.005
50m (s)	6.69±0.23	6.64±0.17	6.52±0.22*‡	6.64±0.25	6.63±0.21	6.64±0.23	<0.001
20m flying (s)	2.37±0.09	2.35±0.08	2.30±0.09*‡	2.35±0.10	2.37±0.10	2.37±0.11	<0.001
3-RM (kg)	195±20	200±18	207±21*‡	163±37§	166±36§	167±36§	0.004
Pmax (W)	1820±173	1878±90	1932±167	1669±188	1635±165§	1600±152*§	0.002
Pmax load (kg)	85±11	90±11	92±12*	79±14	71±14§	68±18*§	<0.001
CMJ (cm)	49.3±4.6	50.9±4.2	52.2±5.1*‡	44.4±6.3§	44.3±6.3§	42.3±6.3§	<0.001
SJ (cm)	44.1±4.2	45.3±4.2	46.8±4.9*‡	40.1±5.9	39.9±5.6§	39.0±5.3*§	<0.001

Within-group differences: *=P<0.05 versus Pre-training, ‡=P<0.05 versus Mid-training.

Between-group differences: §=P<0.05.