

1 **Visual feedback attenuates mean concentric barbell velocity loss, and improves**
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3 **motivation, competitiveness, and perceived workload in male adolescent athletes**
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1 **ABSTRACT**

2 It is unknown whether instantaneous visual feedback of resistance training outcomes can
3 enhance barbell velocity in younger athletes. Therefore, the purpose of this study was to
4 quantify the effects of visual feedback on mean concentric barbell velocity in the back squat,
5 and to identify changes in motivation, competitiveness, and perceived workload. In a
6 randomised-crossover design (Feedback vs. Control) feedback of mean concentric barbell
7 velocity was or was not provided throughout a set of 10 repetitions in the barbell back squat.
8 Magnitude-based inferences were used to assess changes between conditions, with *almost*
9 *certainly* greater differences in mean concentric velocity between the Feedback (0.70 ± 0.04
10 $\text{m}\cdot\text{s}^{-1}$) and Control ($0.65 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$) observed. Additionally, individual repetition mean
11 concentric velocity ranged from *possibly* (repetition number two: 0.79 ± 0.04 vs. 0.78 ± 0.04
12 $\text{m}\cdot\text{s}^{-1}$) to *almost certainly* (repetition number 10: 0.58 ± 0.05 vs. $0.49 \pm 0.05 \text{ m}\cdot\text{s}^{-1}$) greater
13 when provided feedback, while *almost certain* differences were observed in motivation,
14 competitiveness, and perceived workload, respectively. Providing adolescent male athletes
15 with visual kinematic information while completing resistance training is beneficial for the
16 maintenance of barbell velocity during a training set, potentially enhancing physical
17 performance. Moreover, these improvements were observed alongside increases in
18 motivation, competitiveness and perceived workload providing insight into the underlying
19 mechanisms responsible for the performance gains observed. Given the observed
20 maintenance of barbell velocity during a training set, practitioners can use this technique to
21 manipulate training outcomes during resistance training.

22
23 **Keywords:** Kinematic feedback, back squat, resistance training
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1 INTRODUCTION

2 Adolescent athletes participating in sport are typically exposed to strength and conditioning
3 programmes (9, 39, 42). In particular, strength and conditioning interventions often
4 incorporate resistance training, which is safe and effective for adolescent athletes (25), and
5 demonstrates favourable developments in muscle size, force, and power (25, 26). Resistance
6 training programmes are developed by manipulating numerous variables (i.e. exercise type,
7 order, intensity, volume of repetitions and sets, allotted rest, and movement velocity), to alter
8 the physiological response and adaptation (7). Given the importance of these variables,
9 substantial research has been placed upon their implementation and outcomes, typically
10 focusing on exercise intensity and volume (7, 11).

11
12 More recently, the role of repetition velocity ($\text{m}\cdot\text{s}^{-1}$) within a resistance training programme
13 has received increased attention (29). This is likely due to advances in portable technology
14 (e.g. linear position transducers) which have the ability to monitor this training variable.

15 Research has demonstrated the importance of barbell velocity for the enhancement of
16 muscular strength and power (29). For example, Pareja-Blanco and colleagues (29)
17 established superior adaptations in lower body strength (effect size (ES): 0.94 vs. 0.54) and
18 power (ES: 0.63 vs. 0.15) when physically active males completed resistance training with
19 maximal intended velocities compared to sub-maximal. As such, strategies to manipulate
20 repetition velocity may be advantageous when prescribing resistance training programmes to
21 improve physical adaptations in adolescent athletes.

22
23 It is also acknowledged that athletic development would benefit from a multidisciplinary
24 approach (24), although this is rarely presented within the literature. Previous research (2, 31)
25 has suggested that utilising strategies (e.g. verbal feedback) can enhance motivation and/or

1 competitiveness, consequently improving acute resistance training performance (i.e. velocity,
2 power, force). While these studies provide an insight into the potential benefits of feedback
3 during resistance training, neither study has assessed the psychological responses or the
4 potential changes in perceived mental workload. With the relationship between motivation
5 and competitiveness known to help drive sporting outcomes and adherence (13), it is
6 important that these variables are quantified. Furthermore, it is unknown whether these
7 improvements in kinematic outcomes occur alongside increases in perceived workload (2,
8 31).

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10 Changes in resistance training performance due to visual kinematic feedback have not been
11 investigated in adolescent athletes. Additionally, while improvements and increases in
12 psychological characteristics have been suggested (i.e. motivation, competitiveness, and
13 workload) (2, 31), these outcomes have not been substantiated. Therefore, the aim of this
14 study was to assess the effects of visual kinematic feedback on mean concentric barbell
15 velocity during the back squat in adolescent athletes. In addition, the effect of kinematic
16 feedback on motivation, competitiveness, and perceived workload was also assessed.

17 18 **METHODS**

19 **Experimental approach to the Problem**

20 To assess the effects of visual feedback on mean concentric velocity, motivation,
21 competitiveness, and perceived global workload during the back squat, 15 sub-elite
22 adolescent rugby players performed the back squat exercise with and without visual
23 kinematic feedback on two separate occasions in a randomised crossover design. Each trial
24 (Feedback and Control) was separated by 7 days. Before and after the exercise, subjects were
25 provided a questionnaire which assessed motivation levels at that moment in time. In

1 addition, after the exercise subjects completed a questionnaire regarding levels of
2 competitiveness and overall perceived workload that they experienced during the task.

4 **Subjects**

5 15 male sub-elite adolescent rugby union players (mean \pm SD age; 17.1 ± 0.5 years, height
6 1.81 ± 0.07 m, body mass 85.1 ± 9.4 kg, three repetition maximum (3RM) back squat $88.8 \pm$
7 18.8 kg) from an independent school in the United Kingdom volunteered to participate in this
8 study. Testing took place in February (which is within the second half of the school boy
9 rugby playing calendar). Each subject had regularly used the back squat exercise in resistance
10 training programmes and had at least six months of resistance training experience (41). All
11 subjects were informed of the risks and benefits of this study, and signed a consent document
12 prior to commencement. Experimental procedures were approved by the institutional ethics
13 committee, while assent and parental consent were provided along with permission from the
14 school.

16 **Experimental Procedures**

17 All testing was conducted at the same time of day one week apart, with 72 hours' rest
18 occurring prior to procedures. Subjects were instructed to maintain normal dietary habits in
19 the 24 hours prior to testing, with caffeine not being consumed in the 12 hours before. All
20 subjects completed a baseline session including anthropometric and 3RM back squat strength
21 assessments. Two testing sessions (i.e. Feedback and Control) were then completed in a
22 randomised crossover design with group designation decided by computer-generated random
23 numbering (36). Both sessions consisted of a standardised warm-up and one set of 10
24 repetitions of the back squat at 65% of 3RM (3). The Feedback condition consisted of
25 participants completing 10 repetitions with an iPad (iPad Pro, Apple Inc., Cupertino,

1 California, USA) directly in front of them at standing eye level. The iPad in the Feedback
2 condition displayed mean concentric barbell velocity upon the completion of each repetition
3 of the back squat. The Control condition consisted of the subjects completing the 10
4 repetitions without any visual feedback. Mean concentric velocity was assessed via the back
5 squat due to its common use in resistance training programmes (16, 34) and ability to develop
6 lower body strength and power in similar cohorts (42). Questionnaires, which assessed
7 motivation, competitiveness, and perceived workload, were completed 10 minutes before and
8 after the completion of the back squat exercise in both conditions.

10 *Lower-body Strength Assessment*

11 In the week prior to completing the Feedback or Control trials, the 3RM back squat was
12 assessed as previously used in similar cohorts (38, 39). With the bar resting on the upper
13 trapezius, subjects lowered themselves so that the top of their thigh was parallel with the
14 floor. The eccentric portion of the squat was two seconds with a one second pause at the
15 bottom of the exercise. The concentric portion of the exercise was instructed to be as
16 “forceful and powerful” as possible. Instructions were maintained during both the Feedback
17 and Control trials. Upon completion of testing, 65% of each subject's 3RM maximal back
18 squat was calculated.

20 *Experimental Trials*

21 Following a standardised warm up, all subjects completed one set of 10 repetitions of the
22 back squat at 65% of 3RM. All repetitions in both the Feedback and Control trials were
23 required to be completed in the same manner as the lower-body strength assessment with the
24 concentric phase again instructed to be as “forceful and powerful” as possible. Mean
25 concentric velocity ($\text{m}\cdot\text{s}^{-1}$) was obtained through utilising a GymAware (Kinetic Performance

1 Technology, Canberra, Australia) optical encoder which sampled at 50-Hz with no data
2 smoothing or filtering. The numerical value of each individual repetition was visually
3 provided to the participant in the Feedback condition at the completion of each repetition. No
4 visual feedback was provided to subjects in the Control condition. No other verbal feedback
5 or communication was provided throughout the set and until the completion of the
6 questionnaires in either condition.

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8 The GymAware consists of a spring-powered retractable cord, with one end of the cord
9 attached to a barbell and the other end attached to a pulley system that is coupled with an
10 optical encoder. The velocity of the barbell is calculated from the spinning of the pulley as
11 the cord extends and retracts, with high levels of validity and reliability (coefficient of
12 variation = <5%) (4, 20). The GymAware provides one pulse approximately every three
13 millimetres of barbell displacement, with the displacement time-stamped with a one
14 millisecond resolution (2, 10).

15 16 *Assessment of motivation, competitiveness, and perceived workload*

17 Motivation to complete the exercise was assessed using the motivation subscale from the
18 Dundee Stress State Questionnaire (DSSQ) with this subscale previously reporting acceptable
19 reliability ($\alpha = 0.78$) (27). All items were scored on 10-point Likert scales.

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21 Competitiveness was measured using an adapted version of the 4-item competitiveness scale
22 from Anderson and Carnagey (1) which has previously reported acceptable levels of internal
23 reliability ($\alpha = 0.84$).

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25 The National Aeronautics and Space Administration Task Load Index (NASA-TLX) (17)

1 was used to gauge subjective task-related workload during the trial due to its high level of
2 validity and reliability ($r = 0.94$) and ability to objectively evaluate cognitive load during
3 exercise (18, 19). The NASA-TLX is composed of six items that measure mental demand,
4 perceived physical demand, temporal demand, performance, effort, and frustration. The six
5 items were aggregated together to produce an overall ‘global workload’ score.

7 **Statistical Analyses**

8 Data are presented as mean \pm standard deviation (SD). Prior to analysis, all data were log-
9 transformed to reduce bias arising from non-uniformity error, and then analysed for practical
10 significance using magnitude-based inferences (5). The chance of the mean concentric
11 velocity or the psychological characteristic being lower, similar, or greater than the smallest
12 worthwhile change (i.e. 0.2 x between participant difference) was calculated using an online
13 spreadsheet (21). The probability that the magnitude of the change was greater than the
14 smallest worthwhile change was rated as <0.5%, *almost certainly not*; 0.5-5%, *very unlikely*;
15 5-25%, *unlikely*; 25-75%, *possibly*; 75-95%, *likely*; 95-99.5%, *very likely*; >99.5% *almost*
16 *certainly*. Differences less than the smallest worthwhile change were described as *trivial*. In
17 cases where the 90% CI crossed the lower and upper boundary of the smallest worthwhile
18 change, the magnitude of the difference was described as *unclear* (22).

21 **RESULTS**

22 Figure 1 shows the mean concentric velocity for the Feedback and Control conditions across
23 the 10 repetitions of the back squat exercise. The mean (\pm SD) concentric velocity for all
24 participants for the Feedback condition was $0.70 \text{ m}\cdot\text{s}^{-1}$ (± 0.04), while the mean concentric
25 velocity for the Control condition was $0.65 \text{ m}\cdot\text{s}^{-1}$ (± 0.05). *Almost certainly* greater mean

1 concentric velocity for the Feedback condition was reported, with inferences for each
2 individual repetition ranging from *possibly* to *almost certainly* greater.

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17 8 Pre- and post-motivation, competitiveness, and perceived workload were all found to be
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19 9 *almost certainly* greater in the Feedback protocol (Figure 2). Of the six items which compose
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21 10 the NASA-TLX questionnaire, the Feedback condition reported *almost certainly* greater
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23 11 values on the 10-pt Likert scale in mental demand (7.87 ± 0.92 vs. 6.13 ± 1.30), perceived
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25 12 physical demand (7.13 ± 0.99 vs. 5.40 ± 0.91), temporal demand (7.40 ± 1.45 vs. $6.27 \pm$
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27 13 1.16), performance demand (7.47 ± 1.30 vs. 6.07 ± 0.70), and effort (8.07 ± 0.80 vs. $7.33 \pm$
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29 14 0.82). The final item in the NASA-TLX scale, frustration, was reported to be *almost*
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31 15 *certainly* greater in the Control condition (1.60 ± 1.12 vs. 4.60 ± 1.18).
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48 **DISCUSSION**

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51 22 The purpose of this investigation was to determine the acute effects of visual feedback of
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53 23 mean concentric velocity on back squat performance and psychological outcomes in sub-elite
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55 24 male adolescent athletes. *Almost certainly* greater concentric velocity was observed across the
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57 25 set when visual feedback was provided, with individual repetitions showing *possible* to
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1 *almost certainly* greater mean concentric velocity across the 10 repetitions. Furthermore,
2 subjects reported increased motivation, competitiveness and perceived workload when
3 feedback was supplied. These results provide an improved understanding of adolescent
4 performance and the intricate link between psychological factors and physical outcomes.

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6 Providing visual feedback *almost certainly* improved mean concentric velocity of a resistance
7 training set in the barbell back squat exercise in sub-elite adolescent athletes. Additionally,
8 when inferences of individual repetitions are observed across the set it appears that changes
9 become more certain. These findings suggest that providing feedback for male adolescent
10 athletes throughout resistance training sessions could be highly beneficial in improving
11 training session quality, particularly as fatigue develops. While this study is over an acute
12 time-frame (i.e., 1 set), by improving training quality it is postulated that superior training
13 adaptations may occur, as has previously been observed in velocity based training research
14 (31). Furthermore, when placed in context with the relatively small changes in power that
15 professional athletes incur across prolonged training periods (35), improvements of 7.6% in
16 mean set velocity suggests this is a worthwhile finding for the development of adolescent
17 athletes.

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19 The effects of visual feedback were considerably larger than those demonstrated in previous
20 research (2). Argus et al. (2) demonstrated improvements of 1.3% in mean peak concentric
21 velocity in the bench throw exercise when similar kinematic information was verbally
22 provided. It is hypothesised that these differences may be due to the training experience of
23 the participants involved and the resistance training movement (i.e. the back squat rather than
24 the bench throw) utilised. It is commonly accepted that well trained athletes are able to recruit
25 a larger percentage of motor units than their lesser trained counterparts (14, 40). With

1 participants in the current study having only 12-24 months' resistance training experience,
2 previous speculation that feedback improves motor unit recruitment may assist in explaining
3 the larger improvements observed in this younger, relatively inexperienced cohort, who may
4 have more room for improvement of muscle activation (2). Additionally, due to the larger
5 proportion of muscle mass in the lower body compared to the upper body, there may have
6 been an increased scope for greater recruitment to occur (6). Coaches therefore may show
7 preferential application of instantaneous feedback to movements of the full or lower body
8 compared to the upper body, however future research is still required to investigate these
9 mechanisms.

11 This study also provides the novel aspect of being the first to explore the underlying
12 psychological mechanisms associated with feedback and resistance training performance.

13 Previous research has speculated that improvements in velocity, force, and power in response
14 to instantaneous feedback while resistance training, may be due to improved motivation and
15 competitiveness (2, 31). However, neither these factors or any other psychological factors
16 were assessed in their research (or any other similar research, to the authors' knowledge).

17 This study assessed the impact of instantaneous feedback on motivation, competitiveness,
18 and perceived workload, and found that all three were greater when feedback was provided
19 relative to a no-feedback control. Therefore, it seems reasonable that the improvements in
20 performance were due to improvements in motivation and competitiveness, which were in
21 turn a result of the immediate feedback. Strength and conditioning staff should therefore be
22 aware of the potential impact that immediate feedback can have on the adolescent
23 psychological state and how this may improve physical performance and outcomes.

25 With the increase in mean set concentric velocity, motivation, and competitiveness however,

1 came an increase in perceived workload. This suggests an increase in cognitive load which
2 may impact upon physical fatigue (28). As stated earlier, global workload was measured by
3 aggregating scores from the six subscales of the NASA-TLX scale (17). We note that
4 participants reported higher scores in the feedback condition for five of the six subscales:
5 perceived physical demand, mental demand, temporal demand, performance, and effort. This
6 is to be expected given the performance improvements that were concurrently observed in the
7 feedback condition. Notably, participants reported considerably lower frustration levels (the
8 remaining subscale) for the feedback condition relative to the control condition. This
9 reduction in frustration may therefore positively influence training outcomes such as
10 adherence and wellbeing. While previous research assessing the implications of feedback on
11 performance have not addressed workload measures (2, 31), it has been shown that
12 adolescent athletes complete greater resistance training volumes and intensities over
13 prolonged periods when external motivating factors are present (8, 34). It is unknown
14 whether this increase in global workload could have an accumulative effect on an athlete
15 (12), however, this should be considered during the planning of resistance training
16 programmes. Furthermore, research is required to assess the impact, if any, of objective
17 instantaneous feedback on total training load over a training cycle.

18
19 Finally, it should be stated that the provision of feedback and the corresponding improvement
20 of motivation and competitiveness appears to mitigate the acute effects of fatigue on
21 resistance training across a set (Figure 1). This may assist the athlete who is wishing to not
22 only improve strength or power, but also muscular hypertrophy. It is known that terminal
23 mean velocity of the back squat is $\sim 0.35 \text{ m}\cdot\text{s}^{-1}$ (15, 23, 32), and that by being able to maintain
24 higher velocities throughout a set, an athlete may be able to complete larger volumes prior to
25 reaching this terminal point. These increased training volumes could potentially lead to

1 improved muscular development (32, 33). Indeed, recent research has suggested that
2 increasing volume through the monitoring of velocity loss in the back squat can induce
3 increased cross sectional area of the quadriceps (30). Therefore, future research should
4 consider investigating whether increased motivation and competition through objective visual
5 feedback could improve resistance training volume and physical characteristic change.

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7 While this study is the first to assess the role of instantaneous feedback on physical and
8 psychological measures, it is not without its limitations that might reduce its application to
9 real life practice. Firstly, due to the current study being across an acute time frame (i.e. a
10 single set), it is unknown whether effects are diminished or augmented with prolonged use of
11 visual feedback. Randell et al. (31) previously demonstrated the beneficial effects of feedback
12 on physical adaptations in adults, however these findings may not be replicated in
13 adolescents. Secondly, the psychological outcomes demonstrated in the current study may
14 have been enlarged due to the novel application of visual feedback. It is feasible that
15 motivation and competitiveness may diminish over time, therefore future research may need
16 to assess not only long term physical adaptations, but also psychological responses. Finally,
17 the current study was completed in sub-elite adolescent male athletes aged between 16-18
18 years. Because of this selective use of participants, it is unknown whether findings may differ
19 between varying cohorts. Male and female adolescents are known to have differing
20 motivating factors and perceptions towards exercise (37), and it would be imprudent to
21 assume psychological and physical responses are identical across individuals of varying
22 demographics.

23
24 In conclusion, this study presents the effects of instantaneous visual feedback in the back
25 squat on mean concentric velocity in sub-elite male adolescent athletes. Furthermore, this

1 study has been the first to investigate the psychological mechanisms associated with
2 improved performance outcomes from feedback in this context. The findings demonstrate
3 that visual feedback throughout a set of the back squat can promote *almost certain*
4 improvements in mean concentric velocity in sub-elite male adolescent athletes. Additionally,
5 it was established that motivation and competitiveness are closely associated with these
6 improvements, and it is possible that these psychological factors are responsible for the
7 improvement in performance through instantaneous feedback. This feedback appears to also
8 increase perceived workload however, which is something that should be noted when
9 considering longer-term use of feedback in this context. This study suggests that
10 instantaneous objective feedback should be utilised when completing resistance training to
11 increase motivation and competitiveness and improve performance. However, future research
12 is required to assess how these improvements in velocity affect cumulative training load and
13 adaptation.

14 15 **PRACTICAL APPLICATIONS**

16 Based on the current findings, providing augmented feedback through knowledge of
17 performance to male adolescent athletes improves motivation and competitiveness which
18 manifests in improved training quality. Therefore, it is suggested that visual feedback of
19 kinematic outcomes is supplied when training quality is of importance (e.g. during periods of
20 power development). Alternatively, the practitioner may choose to provide visual feedback
21 during resistance training sessions that require high training volumes. This feedback may
22 mitigate the effects of fatigue on mean concentric barbell velocity as a set progresses.
23 Moreover, by providing kinematic feedback, the practitioner may have a smaller time
24 commitment supervising and generating motivation within athletes. Finally, the practitioner
25 can also utilise feedback during periods of low athlete motivation. Provision of feedback can

1 enhance motivation and improve effort when completing resistance training.

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1 REFERENCES

- 2 1. Anderson CA and Carnagey NL. Causal effects of violent sports video games on
3 3 aggression: Is it competitiveness or violent content? *J Exp Soc Psychol* 45: 731-739,
4 4 2009.
- 5 5 2. Argus CK, Gill ND, Keogh JW, and Hopkins WG. Acute effects of verbal feedback
6 6 on upper-body performance in elite athletes. *J Strength Cond Res* 25: 3282-3287,
7 7 2011.
- 8 8 3. Baechle TR, Earle RW, Strength N, and Association C. *Essentials of Strength
9 9 Training and Conditioning*. Human Kinetics, 2008.
- 10 10 4. Banyard HG, Nosaka K, Sato K, and Haff GG. Validity of Various Methods for
11 11 Determining Velocity, Force and Power in the Back Squat. *Int J Sports Physiol
12 12 Perform*: 1-25, 2017.
- 13 13 5. Batterham AM and Hopkins WG. Making meaningful inferences about magnitudes.
14 14 *Int J Sports Physiol Perform* 1: 50-57, 2006.
- 15 15 6. Behm DG. Neuromuscular implications and applications of resistance training. *J
16 16 Strength Cond Res* 9: 264-274, 1995.
- 17 17 7. Bird SP, Tarpenning KM, and Marino FE. Designing Resistance Training
18 18 Programmes to Enhance Muscular Fitness. *Sports Med* 35: 841-851, 2005.
- 19 19 8. Coutts AJ, Murphy AJ, and Dascombe BJ. Effect of direct supervision of a strength
20 20 coach on measures of muscular strength and power in young rugby league players. *J
21 21 Strength Cond Res* 18: 316-323, 2004.
- 22 22 9. Darrall-Jones JD, Jones B, and Till K. Anthropometric and Physical Profiles of
23 23 English Academy Rugby Union Players. *J Strength Cond Res* 29: 2086-2096, 2015.
- 24 24 10. Drinkwater EJ, Galna B, McKenna MJ, Hunt PH, and Pyne DB. Validation of an
25 25 optical encoder during free weight resistance movements and analysis of bench press
26 26 sticking point power during fatigue. *J Strength Cond Res* 21: 510-517, 2007.
- 27 27 11. Fleck SJ and Kraemer W. *Designing Resistance Training Programs 4th Edition*.
28 28 Human Kinetics, 2014.
- 29 29 12. Foster C. Monitoring training in athletes with reference to overtraining syndrome.
30 30 *Med Sci Sports Exerc* 30: 1164-1168, 1998.
- 31 31 13. Frederick-Recascino CM and Schuster-Smith H. Competition and intrinsic motivation
32 32 in physical activity: A comparison of two groups. *J Sport Behav* 26: 240, 2003.
- 33 33 14. Gabriel DA, Kamen G, and Frost G. Neural adaptations to resistive exercise. *Sports
34 34 Med* 36: 133-149, 2006.
- 35 35 15. González-Badillo JJ and Sánchez-Medina L. Movement velocity as a measure of
36 36 loading intensity in resistance training. *Int J Sports Med* 31: 347-352, 2010.
- 37 37 16. Harries SK, Lubans DR, and Callister R. Comparison of resistance training
38 38 progression models on maximal strength in sub-elite adolescent rugby union players.
39 39 *J Sci Med Sport* 19: 163-169, 2016.
- 40 40 17. Hart SG and Staveland LE. Development of NASA-TLX (Task Load Index): Results
41 41 of empirical and theoretical research. *Advan Psychol* 52: 139-183, 1988.
- 42 42 18. Hill SG, Iavecchia HP, Byers JC, Bittner Jr AC, Zaklade AL, and Christ RE.
43 43 Comparison of four subjective workload rating scales. *Hum Factors* 34: 429-439,
44 44 1992.
- 45 45 19. Hong J-H, Ramos J, and Dey AK. Understanding physiological responses to stressors
46 46 during physical activity. In: *Proceedings of the 2012 ACM Conference on Ubiquitous
47 47 Computing*. Pittsburgh, Pennsylvania: ACM, 2012, pp 270-279.
- 48 48 20. Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med* 30:
49 49 1-15, 2000.

- 1 21. Hopkins WG. Spreadsheets for analysis of controlled trials with adjustment for a
2 predictor. *Sportssci* 10: 46-50, 2006.
- 3 22. Hopkins WG, Marshall S, Batterham A, and Hanin J. Progressive statistics for studies
4 in sports medicine and exercise science. *Med Sci Sport Ex* 41: 3, 2009.
- 5 23. Izquierdo M, González-Badillo J, Häkkinen K, Ibanez J, Kraemer W, Altadill A,
6 Eslava J, and Gorostiaga EM. Effect of loading on unintentional lifting velocity
7 declines during single sets of repetitions to failure during upper and lower extremity
8 muscle actions. *Int J Sports Med* 27: 718-724, 2006.
- 9 24. Jones B, Till K, Manley A, and McGuigan MR. A multidisciplinary approach to the
10 profiling and interpretation of fitness testing data: a case study example. *J Aus*
11 *Strength Cond* 25: 31-36, 2017.
- 12 25. Lloyd R, Faigenbaum A, Myer G, Stone M, Oliver J, Jeffreys I, and Pierce K.
13 UKSCA position statement: Youth resistance training. *Prof Strength Cond* 26: 26-39,
14 2012.
- 15 26. Lloyd RS, Faigenbaum AD, Stone MH, Oliver JL, Jeffreys I, Moody JA, Brewer C,
16 Pierce KC, McCambridge TM, and Howard R. Position statement on youth resistance
17 training: the 2014 International Consensus. *Br J Sports Med* 48: 498-505, 2014.
- 18 27. Matthews G, Joyner L, Gilliland K, Campbell S, Falconer S, and Huggins J.
19 Validation of a comprehensive stress state questionnaire: Towards a state big three.
20 *Person Psychol Euro* 7: 335-350, 1999.
- 21 28. Mehta RK and Parasuraman R. Effects of mental fatigue on the development of
22 physical fatigue A neuroergonomic approach. *Hum Factors* 56: 645-656, 2013.
- 23 29. Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, Gorostiaga EM, and
24 Gonzalez-Badillo JJ. Effect of movement velocity during resistance training on
25 neuromuscular performance. *Int J Sports Med* 35: 916-924, 2014.
- 26 30. Pareja-Blanco F, Rodriguez-Rosell D, Sanchez-Medina L, Sanchis-Moysi J, Dorado
27 C, Mora-Custodio R, Yanez-Garcia JM, Morales-Alamo D, Perez-Suarez I, Calbet
28 JA, and Gonzalez-Badillo JJ. Effects of velocity loss during resistance training on
29 athletic performance, strength gains and muscle adaptations. *Scand J Med Sci Sports*
30 (ahead of press) DOI 10.1111/sms.12678.
- 31 31. Randell AD, Cronin JB, Keogh JW, Gill ND, and Pedersen MC. Effect of
32 instantaneous performance feedback during 6 weeks of velocity-based resistance
33 training on sport-specific performance tests. *J Strength Cond Res* 25: 87-93, 2011.
- 34 32. Sanchez-Medina L and González-Badillo JJ. Velocity loss as an indicator of
35 neuromuscular fatigue during resistance training. *Med Sci Sports Exerc* 43: 1725-
36 1734, 2011.
- 37 33. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to
38 resistance training. *J Strength Cond Res* 24: 2857-2872, 2010.
- 39 34. Smart DJ and Gill ND. Effects of an off-season conditioning program on the physical
40 characteristics of adolescent rugby union players. *J Strength Cond Res* 27: 708-717,
41 2013.
- 42 35. Smart DJ, Hopkins WG, and Gill ND. Differences and changes in the physical
43 characteristics of professional and amateur rugby union players. *J Strength Cond Res*
44 27: 3033-3044, 2013.
- 45 36. Suresh KP. An overview of randomization techniques: An unbiased assessment of
46 outcome in clinical research. *J Hum Reprod Sci* 4: 8-11, 2011.
- 47 37. Tergerson JL and King KA. Do Perceived Cues, Benefits, and Barriers to Physical
48 Activity Differ Between Male and Female Adolescents? *J Sch Health* 72: 374-380,
49 2002.
- 50 38. Till K, Jones B, Darrall-Jones J, Emmonds S, and Cooke C. Longitudinal

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development of anthropometric and physical characteristics within academy rugby league players. *J Strength Cond Res* 29: 1713-1722, 2015.

39. Till K, Tester E, Jones B, Emmonds S, Fahey J, and Cooke C. Anthropometric and physical characteristics of English academy rugby league players. *J Strength Cond Res* 28: 319-327, 2014.

40. Van Cutsem M, Duchateau J, and Hainaut K. Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. *J Physiol* 513: 295-305, 1998.

41. Weakley J, Till K, Darrall-Jones J, Roe G, Phibbs P, Read D, and Jones B. The influence of resistance training experience on the between-day reliability of commonly used strength measures in male youth athletes. *J Strength Cond Res* (ahead of press) DOI 10.1519/JSC.0000000000001883.

42. Weakley J, Till K, Roe G, Darrall-Jones J, Phibbs P, Read D, and Jones B. Strength and Conditioning Practices in Adolescent Rugby Players: Relationship with Changes in Physical Qualities. *J Strength Cond Res* (ahead of press) DOI 10.1519/JSC.0000000000001828.

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Figure 1. Mean concentric barbell velocity and inferences of individual repetitions across a single set of the back squat in the Feedback and Control conditions. L = *likely*, P = *possibly*, VL = *very likely*, AC = *almost certain*.

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Figure 2. Mean \pm SD scores and inference of pre- and post-motivation, competitiveness, and perceived workload within respective 10-point Likert scales. AC = *almost certain* differences.

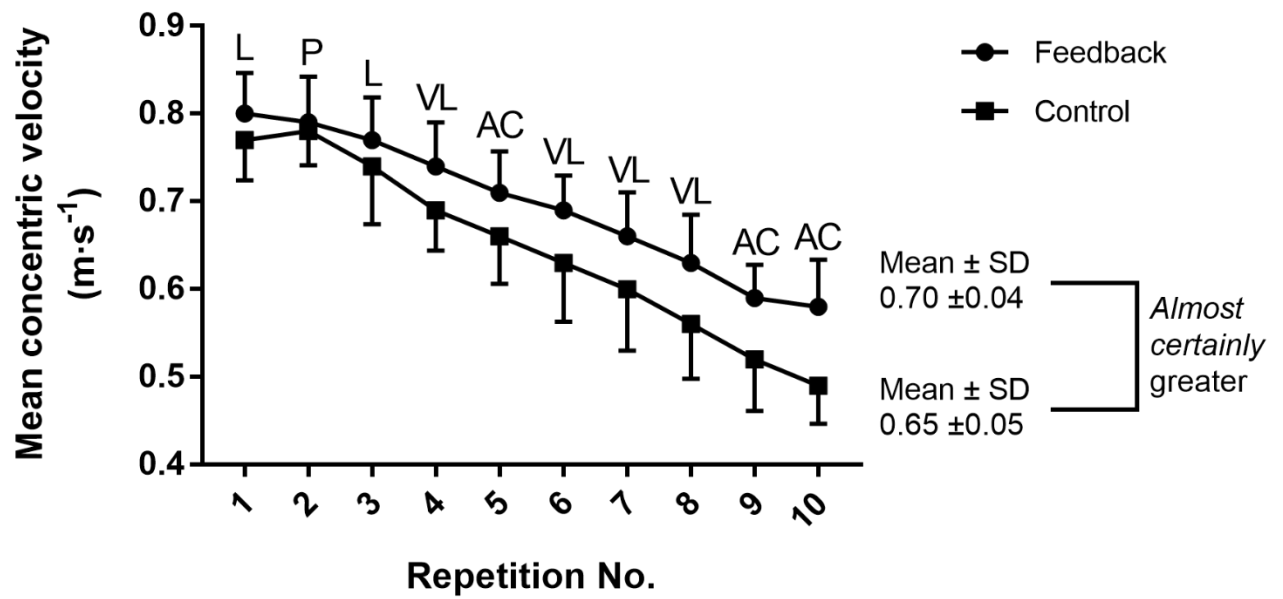


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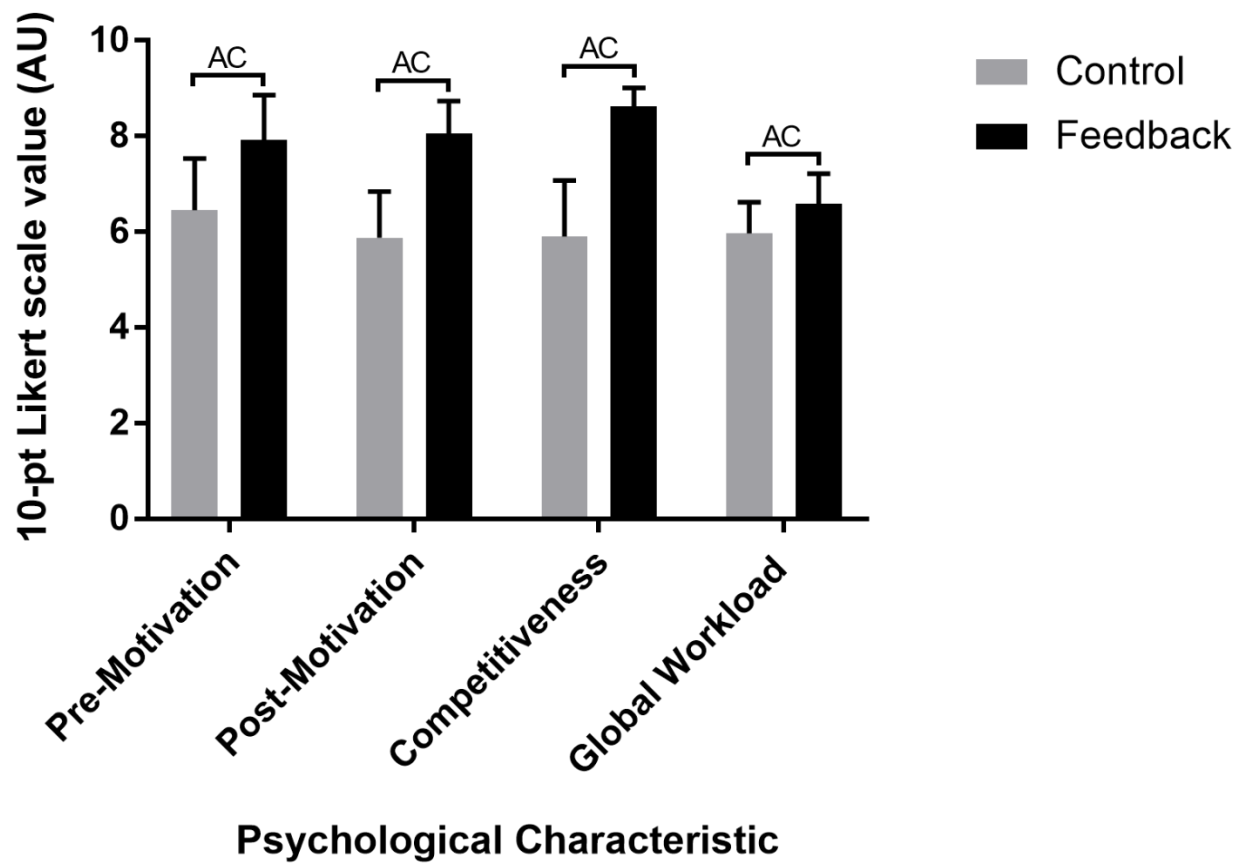


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