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Perception of changes in bar velocity as a resistance training monitoring tool for athletes

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A B S T R A C T

Purpose: To investigate if perception of changes in bar velocity (PCV) can be used as a substitute for velocity tracking devices commonly used to monitor resistance-exercises.

Methods: Twenty-one professional male soccer athletes (21±4 years) first went through a load-power profile assessment to determine their optimal power load in the back-squat. In the next three experimental sessions, athletes completed four sets of six repetitions loaded with optimal power load. Starting from the second repetition, athletes reported their PCV of each repetition as a percentage of the first repetition. Accuracy of PCV was calculated as the absolute difference between PCV and the actual percentage change from the first repetition in bar velocity measured with a linear-encoder. The second and fourth sessions served as the pre- and post-intervention sessions, in which athletes received no feedback about their PCV accuracy. The third session served as the intervention session, in which athletes received verbal and visual feedback about their PCV accuracy levels after each set.

Results: The estimated accuracy of PCV decreased from an average error of 7% in the pre-intervention to an average error of 4.7% in the post-intervention session (95% confidence levels of difference: 1.5, 3.0).

Conclusion: Athletes with velocity based training experience begin with a reasonable PCV accuracy rates which can be meaningfully improved after a single session that includes accuracy feedback. When velocity tracking devices are impractical or absent, PCV can be implemented as a resistance training monitoring tool.

1. Introduction

Velocity-based training (VBT) is a method used to prescribe and monitor resistance training programs based on repetition velocity outputs during different exercises [1-4]. VBT has a number of benefits. First, the velocity loss observed across repetitions provides an indication of neuromuscular fatigue [5] and the number of repetitions left before one reaches task-failure [6]. Second, a number of longitudinal studies found that terminating sets at certain velocity loss thresholds (e.g., 5–30% relative to first repetition) can induce a range of neuromuscular adaptations [7-9]. These benefits allow to individualize and thus optimize the training process by adjusting the number of repetitions performed per exercise. However, in order to implement VBT methodologies, velocity measuring devices are required (e.g., linear position transducers [LPT [10]]). While the costs of these devices have decreased in recent years, they are not affordable to many [11]. Furthermore, using these devices with large groups of athletes can be a challenging task. Hence, in cases that velocity measuring devices are inaccessible or impractical, trainee's perception of movement velocity, or changes in movement velocity, can be used as a possible substitute. Assuming acceptable accuracy levels, applying VBT methodologies based on trainee's perception can be advantageous given its simple and free to use.

Recently, Sindiani et al. [12] examined the accuracy levels of trainee's perception of changes in bar velocity (PCV) in comparison to actual bar velocity (ACV) measured with an LPT. Twenty resistance-trained subjects completed three sessions composed of four sets of eight repetitions in the squat and bench-press exercises. In two sessions, subjects lifted loads corresponding to 60% of one Repetition-Maximum (1RM), and in one session the loads corresponded to 70% of 1RM. Starting from the second repetition of each set, subjects rated their PCV as a percentage of the first repetition, which was preset to be 100% (i.e., the reference point), irrespective if it was the fastest repetition or not. To illustrate, if the third repetition was perceived to be 10% slower than the first repetition, then the person should have rated it

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as 90%. Using this approach, two types of errors were analyzed. First, the absolute error, defined as the difference between PCV and the actual changes in bar velocity (ACV). Second, the directional error, defined as the likelihood of over- or underestimating ACV.

Sindiani et al. [12] observed three key findings. First, across sessions and sets, the absolute error was ~5.8 percentage-points in both exercises in the second repetition and increased to 13.2 and 16.7 percentage-points by the eighth repetition in the bench-press and squat, respectively. The increments in error followed a linear pattern, increasing by 1.2 and 1.8, percentage-points with consecutive repetitions in the bench-press and squat, respectively. Second, as a whole, subjects improved their accuracy in the second 60%1RM session compared to the first by ~1.7 percentage-points in both exercises. Finally, subjects were 4.2 times more likely to underestimate bar velocity, as reported relative to the first repetition of the set (i.e., reported PCV values being lower than ACV values), in the squat compared to the bench-press. Based on these results, the authors proposed a number of future research directions, two of which are relevant to the present study. First, there is a need to investigate PCV accuracy levels among different populations. Specifically, while subjects in Sindiani's study were experienced in resistance training, none were accustomed to VBT. It may be that prior experience with VBT is associated with reduced absolute and directional errors. Second, there is a need to investigate to what extent accuracy levels can be improved. The fact that subjects reduced the absolute error in the second 60%1RM session in the study by Sindiani et al. [12] suggests that practice can enhance accuracy levels. Importantly, the observed improvement occurred despite the fact that subjects were not provided with feedback on ACV. It is thus of interest to examine to what extent accuracy levels can be improved when subjects are presented with feedback on ACV.

Therefore, the purpose of the present study was to complement and expand upon Sindiani's work by: (i) investigating PCV accuracy rates during the barbell squat exercise among competitive athletes experienced with VBT; (ii) Investigate if, and to what extent, PCV accuracy rates can be improved among this cohort when receiving augmented feedback concerning the extent and direction of error.

2. Materials and methods

2.1. Participants

A convenience sample of 21 male national-level professional soccer players volunteered to participate in the study (age: 21.1 ± 4.3 years; height: 178.3 ± 5.8 cm; body mass: 72.9 ± 6.2 kg; optimum power load (OPL): 51.7 ± 6.7% of 1RM). Whereas all 21 completed the first two sessions, only 16 completed the final session due to the COVID-19 outbreak. All athletes had at least 12 years (range: 12–27) of soccer training and three years (range: 3–9) of resistance training experience, and at least one year (range: 1–7) of resistance training experience involving VBT methodologies. Specifically, ten athletes had approximately one year of VBT experience, and 11 athletes had 3–7 years of VBT experience. This difference mostly stemmed from the age in which athletes entered the professional senior teams. Written informed consent was obtained after athletes received an oral explanation of the purpose, benefits, and potential risks of the study. All procedures were conducted in accordance with the Helsinki Declaration and approved by the Institution's Ethics Committee.

2.2. Procedure

A pre-post within-subject design was used to investigate (i) the accuracy levels of PCV in the barbell squat exercise performed in a Smith-Machine (Technogym Equipment, Barcelona, Spain) among professional soccer players familiar with VBT; (ii) examine if, and to what extent, PCV accuracy can be improved among this cohort when receiving augmented feedback on the extent and direction of their errors. Whereas in Sindiani et al. [12] participants lifted fixed training loads (e.g., 60% and 70% of 1RM), in the present study athletes lifted their individual OPL. This decision was based on the fact that the recruited athletes routinely performed the squat exercise loaded with OPL while following a similar training volume configuration (i.e., sets × repetitions). Accordingly, the professional staff preferred that we use OPL in this study given that it is more aligned with the athletes normal testing and training routines.

Athletes reported to the laboratory on four occasions separated by a minimum of three and a maximum of six days. In the first session, participants were assessed to determine the individual OPL in the barbell squat and were familiarized with the experimental procedures. In the three subsequent experimental sessions, participants followed the exact same procedures, consisting of four sets of six repetitions of squats using the individual OPL, with three minutes of rest between the sets. Starting from the second repetition, participants verbally reported their PCV of each repetition which was recorded via a tie-microphone attached to their shirts. ACV was measured with an LPT. While the second and forth sessions were identical, serving as the pre and post-intervention session, in the third session athletes received both verbal and visual feedback concerning their accuracy after each set. All testing sessions were conducted by a single experimenter (G.Y.V), between 15:00–17:00, before to the team's soccer training sessions, during the second part of the competitive season (January-February). Athletes were instructed to avoid a heavy meal two hours prior to the sessions and to otherwise maintain their normal dietary habits during the study's duration.

2.3. OPL test and familiarization (session 1)

Anthropometric measurements were taken and followed by an assessment of the required squat depth corresponding to a 90° knee angle measured with a hand-held goniometer. To ensure similar depth across sessions, a box with adjustable height was placed underneath the participants to which they were required to gently squat onto. Athletes then performed a structured warm-up protocol consisting of dynamic stretching and calisthenics, followed by five minutes of a self-selected warm-up. This warm-up protocol was identical in all sessions. Thereafter, athletes completed a load-power profile assessment to determine the individual OPL in the barbell squat using a Smith-machine. The OPLs were determined following the protocol described by Loturco et al. [13] and identified as the absolute load resulting in the highest mean propulsive power values measured during progressively loaded trials. Briefly, the protocol consisted of consecutive sets of squats starting with 36 kg and 10–20 kg increments per set. Athletes performed three repetitions at maximum velocity for each progressive load until a clear decrement (observed over at least two loads) in power output was detected. This equated to approximately 5 testing sets. Two to three minutes of rest were provided between attempts. The individual OPLs were calculated via a dedicated software (Chronojump, Barcelona, Spain), and then used for the three experimental sessions.

Following the OPL assessment, participants were familiarized with the procedure of the experimental sessions by performing two sets of 8–12 repetitions with an unloaded barbell. Specifically, athletes were asked to verbally report their PCV starting from the second repetition and onward as a percent of the first repetition. That is, the first repetition was always considered 100% (i.e., the reference point) irrespective if the actual velocity resulted in the fastest repetition or not. Then, starting from the second repetition, participants reported percent values in relation to the first repetition. Participants were asked to execute the concentric phase of each repetition as fast as possible. After each completed repetition, participants were asked to verbally state their PCV.

2.4. Experimental sessions (sessions 2–4)

Following a standard warm-up, athletes completed a squat specific warm-up consisting of sets with progressive loads until reaching their respective OPL. After two minutes of rest, athletes completed four sets of six repetitions with the OPL in all three sessions. Whereas the second and forth session were identical and served as the pre- and post-intervention sessions, in which no velocity feedback was provided, in the third session athletes received augmented feedback after each set concerning their accuracy rates. Specifically, within ~30 s after each set the experimenter prepared an Excel graph illustrating both PCV and AVC velocity data points of each repetition (Fig. 1). The experimenter showed the graph to each athlete during the rest period between sets and pointed out the extent and direction of the errors. These graphs were subsequently sent to each athlete and also used during a short, five-minute face-to-face meeting between the third and the fourth session, in which the experimenter went over the graphs with each athlete, highlighting their common errors. All sessions were performed at the same facility, ran by the same experimenter at approximately the same time of the day (±2 h). Athletes were asked to refrain from intense training 24 h prior to testing days and to avoid muscular fatigue and soreness.

2.5. Bar velocity data collection

The mean propulsive velocity of bar movement during the concentric phase for each repetition was collected. For this purpose, an LPT (Chronojump, Barcelona, Spain) sampling at 1000 Hz, was fixed to the bar of the Smith machine at a perpendicular angle to the floor, and the commercial software provided by the manufacturer in conjunction with the device, was used to record the bar velocity outcomes. According to the software specifications, instantaneous velocity was smoothed with a fourth-order low-pass Butterworth filter, with a cut-off frequency of 10 Hz.

2.6. Statistical analysis

We descriptively inspected the data points by plotting the raw percentage point differences between the PCV and ACV in all repetitions, relative to the first repetition. To inferentially analyze the absolute differences between PCV and ACV we used the following within subject fixed effects model:

$$|PCV - ACV|_{it} = \beta_0 + \beta_1 session_{it} + \beta_{2-4} set_{it} + \beta_5 repetition_{it} + \beta_k z_{it} + a_i + \varepsilon_{it}$$

where inaccuracy $scores_{it}$ is the percentage point difference between PCV and ACV of subject i at repetition t; β_k represents the 4 coefficients of the two-way interactions between session (post-intervention=1) on the one hand and sets and repetitions on the other. Finally, a_i is a subject specific deviation from the grand mean of the inaccuracy scores.

In contrast to Sindiani et al.'s study [12] in which an analysis of the propensity of a unidirectional error (i.e., either under- or over-estimating the bar velocity) was reported in the main text, in the current study we decided to present this analysis as supplementary material because we did not find any theoretical or practical value of this analysis to the field (see online supplement).

3. Results

3.1. Descriptive statistics

Fig. 2 depicts the absolute data points across sessions and repetitions. As seen in panel A (pre-intervention-absolute), both the average absolute error and the variance increases as repetitions progress. In contrast, after receiving the augmented feedback, in the post-intervention (panel B) we note that the extent of error and its variance remained stable throughout the set.

3.2. Extent of error

Controlling for sets and repetitions, the absolute error was 2.3 percentage points higher in the pre- compared to the post-intervention session ($p<0.001$) (Table 1 and Fig. 3). Controlling for sessions and repetitions, we observed no meaningful differences between sets ($p<0.134$, $0.21<b<0.76$ percentage points), nor an interaction between sets and sessions ($p<0.165$, $-0.65<b<1.41$ percentage points). In contrast, we found a significant effect of repetition, so that each passing repetition within a set added 0.45 percentage points to the absolute error. Moreover, the interaction of repetitions and session was significant ($b=-0.73$, $p = 0.004$). Specifically, while the effect of repetition was highly substantial and significant in the pre-intervention session ($b = 0.76$, $p<0.001$), it was inconsequential in the post-intervention session ($b = 0.03$, $p = 0.874$). It therefore follows that differences in the observed error between the sessions grew larger as the number of repetitions progressed. For instance, in the first set the gap between the sessions in repetition two was non-significant at 1.4 percentage points ($p = 0.126$) but it grew to a significant 4.3 percentage points by the repetition 6 ($p<0.001$).

4. Discussion

The purpose of this study was twofold. The first, to examine the PCV accuracy levels of athletes experienced with VBT in the barbell squat. The second was to examine if and to what extent can PCV accuracy

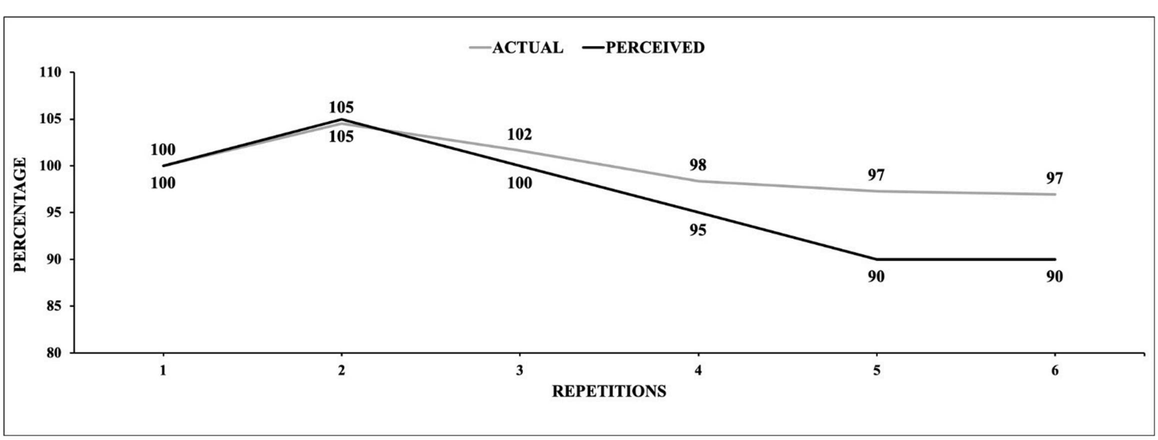

Fig. 1. An example of the individualized graph presented to the athletes as feedback between sets in the intervention session.

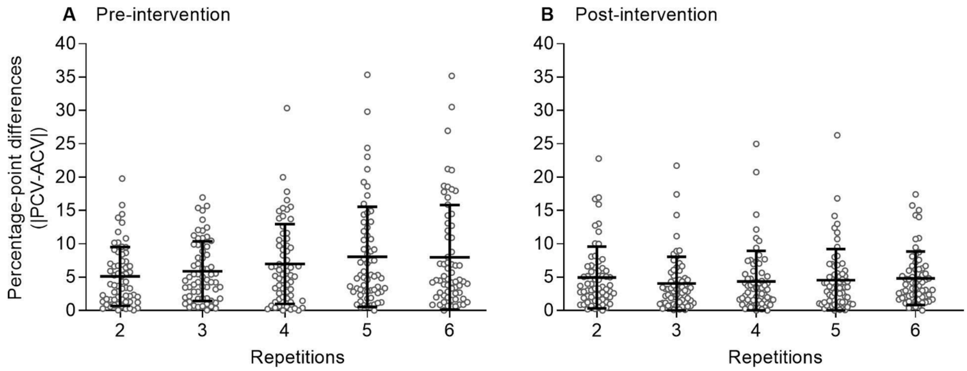

Fig. 2. Data points of percentage-point differences between PCV and ACV in absolute value (|PCV-ACV|) across sets. The mid-horizontal line and error bars represent means and SDs.

Table 1
Fixed effects (within subjects) linear regression of extent of error in velocity.

Fixed	Model 1 b	S.E	Model 2 b	S.E
Constant	5.75***	0.47	5.34***	0.58
Post [Pre]	−2.30***	0.38	−1.36	0.89
[Set 1]				
Set 2	0.76	0.50	0.14	0.66
Set 3	0.20	0.50	−0.37	0.66
Set 4	0.26	0.50	0.54	0.66
Repetition	0.44***	0.12	0.76***	0.16
Post*set 2			1.41	1.01
Post*set 3			1.35	1.01
Post*set 4			−0.64	1.01
Post*Repetition			−0.733**	0.25
N (within 21 subjects)	739		739	

* $p<0.05$;
** $p<0.01$;
*** $p<0.001$.

levels improve among this cohort after a single session of verbal and visual feedback on PCV accuracy. During the pre-intervention session, the absolute error rates increased with consecutive repetitions. In the post-intervention session, after receiving feedback on PCV, athletes improved their accuracy ratings. This consisted of a mitigation of the increment in error associated with each subsequent repetition.

The absolute error in the pre-intervention session followed a similar trend to that observed in Sindiani's study [12], in which the extent of error grew with consecutive repetitions, although it was smaller in the current study. These findings can be explained by the fact that the athletes in the present study had extensive experience with VBT, in contrast to those in Sindiani et al. [12] However, other factors could potentially explain these differences such as the loads lifted and number of repetitions completed across the sets. In the current study, athletes completed six repetitions per set using their individual OPL in the squat, which corresponded to ~52% of estimated 1RM. In contrast, in Sindiani et al. study, individuals completed eight repetitions per set using 60% and 70% of 1RM. It is possible that the heavier lifted loads coupled with the higher number of repetitions may have led to greater neuromuscular fatigue which could partly explain the greater error observed in Sindiani's study [12]. Based on the pre-intervention results, we conclude that athletes with VBT experience begin with reasonable PCV accuracy rates although these progressively worsen with subsequent repetitions. From a practical perspective, it is debatable if the observed error rates can be tolerated by coaches, especially in cases when the more conservative (i.e., 5–20%) velocity loss thresholds are implemented to terminate the training sets. However, PCV may still be used in sessions including velocity loss thresholds of 20–30% to which PCV error rates of 5% and 8%, will likely have a marginal impact on the overall training

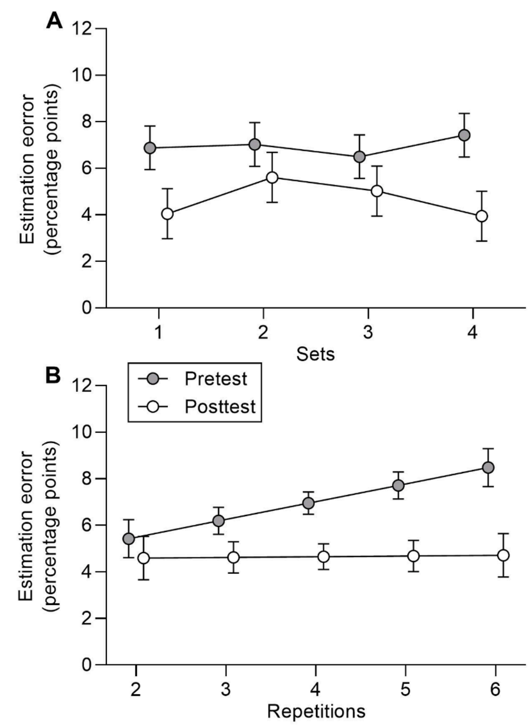

Fig. 3. Estimations of errors (|PCV-ACV|) across sessions and sets (A) or repetitions (B), when all other variables are set to their grand mean. Circles and error bars represent estimations and 95% confidence intervals.

responses.

The post-intervention values indicate that a single session in which verbal and visual feedback were provided on the extent of error considerably improved accuracy rates. More specifically, athletes reduced the absolute error, on average, by 2.3 percentage points from ~7% in the pre-intervention session to ~4.7% in the post-intervention session. While augmented feedback is a known strategy to improve accuracy in motor tasks [14,15], the pattern of improvement observed in this study is interesting and somewhat surprising. Whereas the extent of absolute error of the second repetition was mostly similar to the pre-intervention values (pre: 5%, post: 4.7%), the gradual increments in error were eliminated as the error rates remained approximately constant across repetitions (Fig. 2). Given that different types of feedback are known to influence motor learning [16] and estimation abilities [17] differently, it can be speculated that the provided feedback emphasized error control during sets rather than error reduction of single repetitions. From a practical perspective, the PCV accuracy improvements are encouraging. They indicate that athletes without regular access to velocity tracking devices can improve PCV accuracy after only a single session that includes feedback on the extent of error.

A number of methodological aspects of this study warrant discussion. Due to COVID-19, five athletes did not complete the third and fourth sessions. However, given that these athletes did not differ, significantly or substantially, from the rest of the sample in the extent of error in the pre-intervention session, the attrition does not seem to be related to the dependent variable and thus does not bias the results. Moreover, since we tested a relatively homogenous group of national-level soccer athletes, it is unlikely that attrition bias may have arisen. This study did not include a control group that repeated the same procedure but without receiving any feedback in the third session. The reason we did not include a control group stemmed from our inability to recruit a much larger sample of athletes, but also because our goal was to examine if PCV can be improved, and if so, to what extent. Generating an answer to this question, even absent of the specific causal pathway, was of practical value, and one we were able to answer with the implemented design.

Future studies could inspect if providing slightly types of feedback can reduce the error rates earlier on in a set (e.g., see references [16, 17]). Indeed, it is possible that additional feedback sessions can further reduce the extent of error. We only tested a single exercise among a relatively homogeneous sample with VBT experience. Hence, future studies should compare between different type of exercises and among other populations. Finally, in the present study we inspected the utility of PCV in RT sessions that emphasis power development, in which the number of repetitions is usually limited in order to minimize muscular fatigue. Future studies could inspect if PCV can be used in RT sessions in which sets are taken to task-failure. Assuming PCV reported during various stages of a set can accurately predict the number of repetitions subjects can perform until task-failure, then this may suggest that PCV can be used to achieve other RT related goals.

5. Practical application

Coaches who wish to implement VBT methodologies among athletes with at least a year of VBT experience can do so with reasonable accuracy using athletes PCV as a strategy for set termination. In order to further improve PCV accuracy, it is suggested to have athletes go through at least one session in which athletes receive feedback about their errors. This is expected to improve their accuracy rates, mostly as sets progress. We note that this practical suggestion is limited to athletes with VBT experience in the squat exercise, and to coaches who are willing to accept some degree of error regarding the actual velocity at the point of the set termination.

6. Conclusion

We observed that athletes with VBT experience in the squat exercise begin with reasonable PCV accuracy rates that worsens as the sets progress. When athletes went through a single session that included augmented feedback about their PCV errors, they substantially improved their accuracy rates in the subsequent session, in which feedback was not provided. The pattern of improvement stemmed from the reduction of the progressive worsening of PCV accuracy rates that were present in the pre-intervention session.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.physbeh.2021.113316.

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