Perceptual, Mechanical, And Electromyographic Responses To Different Relative Loads In The Parallel Squat

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Abstract

The effectiveness of the OMNI-RES (0–10) Scale and the electromyographic signal for monitoring changes in the movement velocity were examined during a set to muscular failure using different percentages of 1 repetition maximum (1RM) in the parallel squat exercise (PSQ). Twelve men (26.3 ± 5.8 years) were evaluated on 8 separate days with 48 hours of rest between sessions. After determining the 1RM value, participants underwent 7 tests until achieving muscular failure with the following percentage ranges: 30 to <40%, 40 to <50%, 50 to <60%, 60 to <70%, 70 to <80%, 80 to <90%, and >90%. An optical rotary encoder measured mean accelerative velocity (MAV), and the OMNI-RES (0–10) Scale was used to express the rating of perceived exertion (RPE) after every repetition of each set. In addition, the normalized root mean square signal of the surface electromyography (N-EMG) was calculated for the vastus medialis muscle. The RPE expressed after the first repetition and when the maximum value of MAV was achieved along the sets was lower ($p < 0.001$, $d > 0.8$) than the RPE that corresponded to a 10% drop in MAV and at failure. In addition, the initial RPE was useful to distinguish different loading zones by anchoring the OMNI-RES value to the magnitude of the relative load (<60%, 60 to <70% or ≤70% 1RM). Similar patterns were observed using the N-EMG. In conclusion, apart from differentiating between relative loads during a set to failure in the PSQ, the RPE and the N-EMG can both reflect changes associated with the initial, maximal, 10% drop in movement velocity and the muscular failure.

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PERCEPTUAL, MECHANICAL, AND ELECTROMYOGRAPHIC RESPONSES TO DIFFERENT RELATIVE LOADS IN THE PARALLEL SQUAT

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ABSTRACT

Chapman, M, Larumbe-Zabala, E, Gosss-Sampson, M, Colpus, M, Triplett, NT, and Naclerio, F. Perceptual, mechanical, and electromyographic responses to different relative loads in the parallel squat. *J Strength Cond Res* 33(1): 8–16, 2019—The effectiveness of the OMNI-RES (0–10) Scale and the electromyographic signal for monitoring changes in the movement velocity were examined during a set to muscular failure using different percentages of 1 repetition maximum (1RM) in the parallel squat exercise (PSQ). Twelve men (26.3 ± 5.8 years) were evaluated on 8 separate days with 48 hours of rest between sessions. After determining the 1RM value, participants underwent 7 tests until achieving muscular failure with the following percentage ranges: 30 to <40%, 40 to <50%, 50 to <60%, 60 to <70%, 70 to <80%, 80 to <90%, and >90%. An optical rotary encoder measured mean accelerative velocity (MAV), and the OMNI-RES (0–10) Scale was used to express the rating of perceived exertion (RPE) after every repetition of each set. In addition, the normalized root mean square signal of the surface electromyography (N-EMG) was calculated for the vastus medialis muscle. The RPE expressed after the first repetition and when the maximum value of MAV was achieved along the sets was lower ($p < 0.001$, $d > 0.8$) than the RPE that corresponded to a 10% drop in MAV and at failure. In addition, the initial RPE was useful to distinguish different loading zones by anchoring the OMNI-RES value to the magnitude of the relative load (<60%, 60 to <70% or ≤70% 1RM). Similar patterns were observed using the N-EMG. In conclusion, apart from differentiating between relative loads during a set to failure in the PSQ, the RPE and the N-EMG can both reflect changes associated with the initial, maximal, 10% drop in movement velocity and the muscular failure.

KEY WORDS RPE, OMNI-RES (0–10) scale, accelerative velocity, muscular failure, EMG, neuromuscular activity

INTRODUCTION

The use of different rating of perceived exertion (RPE) scales to monitor the progression of fatigue and changes in velocity during resistance exercises has been analyzed in several investigations (6,12,27,29). A limited number of studies have examined the relationship between the mechanical (15) or muscular activation (9,17,25) responses and the RPE. Although the level of muscular activation seems not to be related to changes in the RPE when training with constant loads (17), some studies reported significant correlations between the intensity and the level of elicited muscular activity expressed after performing upper- (25) and lower-body (9) resistance exercises. Increases in muscular activity are a direct result of motor efferent commands, which, in turn, cause an increase in the number of corollary signals toward the sensory cortex that may regulate the perception of exertion (24). The aforementioned neurological and perceptual effects would be determined by an increase in exercise intensity (25) or the number of repetitions performed per set or over a whole training session (29). Furthermore, the ability of perception to reflect the level of fatigue in terms of power output (15) or movement velocity (27) using different percentages of the maximal weight that can be lifted in 1 repetition maximum (1RM) has been previously demonstrated. The aforementioned studies support the use of perception scales to monitor the variation of the velocity to stop the set before a decline in velocity below a desirable level occurs as a consequence of fatigue. Two of the most important variables affecting the performance outcomes of resistance training are the relative load (% 1RM) and the movement velocity (28). Although light (<60%), moderate (>60–80%), and heavy (>80%) loads have been traditionally associated with endurance, hypertrophy, and maximal strength training outcomes, respectively (1), when training for power, the resistance must be moved at the highest possible velocity (29). A decrease greater than 10% of the maximal velocity, for a given relative load, has been associated with a change from power toward more endurance-oriented strength (32). This drop in the mechanical performance would be attributable to a selective fatigue of fast motor units along with a progressive activation of the slow motor unit (8). In addition, some linear models have successfully correlated changes in electromyographic (EMG) signal and power loss to assess acute changes in the capability to apply force during resistance exercises (20,21). To the best of the authors' knowledge, the sensitivity of both the perceived exertion and the electromyographic signal to differentiate specific moments within the set where the movement velocity peaks, drops below 10% from the maximum, or where the set approaches muscular failure still needs to be properly investigated.

Consequently, the aim of this study was to explore the perception of effort and neuromuscular activity where the movement velocity peaks, decreases 10% with respect to the maximum, and at muscular failure during a continuous set, using different percentages of the 1RM in the free weight parallel squat exercise (PSQ). Furthermore, the ability of the RPE and the neuromuscular activity to discriminate between relative loads across a wide range, from 30 to 100%, divided by 10% incremental slots was also investigated. To reach these objectives, the following hypotheses were formulated: (a) the RPE and the electromyographic signal at the end of the repetition will show significant differences between specific moments within the set where the velocity concomitantly reduced as the set approaches muscular failure; and (b) the RPE and the electromyographic signal measured at the beginning of each set will differentiate relative loads (as a percentage of 1RM) used.

METHODS

Experimental Approach to the Problem

This study was designed to examine the applicability of the RPE and the electromyographic signal as methods for discriminating the relative load and reflecting changes in the movement velocity during a continuous repetition set until muscular failure using different percentages of 1RM in PSQ. After determining the individuals' 1RM values, participants were evaluated on 7 occasions until achieving muscular failure with the following 1RM percentage ranges: 30 to <40%, 40 to <50%, 50 to <60%, 60 to <70%, 70 to <80%, 80 to <90%, and >90%. The mean accelerative velocity (MAV), the OMNI-RES (0–10) Scale value, as a measure of the RPE, and the root mean square (RMS) surface electromyography signal (amplitude EMG) were obtained for all the repetitions of each set. The study assessed whether the instances where the movement velocity peaks, drops 10% from the maximum, or reaches muscular failure show different values of the subjective perception of effort and the neuromuscular activation measured over a set using 7% ranges (30–100% of 1RM) in PSQ.

Subjects

Twelve recreationally resistance-trained men (mean ± *SD*: age 26.3 ± 5.8 years; body mass 81.1 ± 13.6 kg; and height 178.1 ± 4.5 cm), with a minimum of 2 years of experience performing squatting exercises volunteered to take part in this study. Before participation, all participants read and signed an informed consent previously approved by the University of Greenwich Ethics Committee.

Procedures

Before the beginning of the study, all the participants underwent 2 familiarization sessions. During these sessions, standard instructions, and RPE OMNI-RES (0–10) Scale anchored procedures were explained to the participants to properly reflect the RPE for the whole body (31) after performing each singular repetition of the different resistance exercises including the PSQ.

The OMNI Perceived Exertion Scale for Resistance Exercise (OMNI-RES) developed and validated by Robertson et al. (31) includes both verbal and mode-specific pictorial descriptors distributed along a comparatively narrow response range of 0–10 (Figure 1). These characteristics make the OMNI-RES Scale a useful methodology to control the intensity of resistance exercises over other previously published scales.

Exercise. The PSQ was performed using free weights and a squat rack. Participants were instructed to start the exercise from standing, feet parallel and shoulder width apart with toes pointing slightly outward. The bar was either centered across the shoulders just below the spinous process of the C7 vertebra (high-bar position) (33). Participants were instructed to squat down with a controlled velocity until their posterior thigh was positioned parallel to the floor. After a minimum pause (less than 1 second), participants performed the concentric squatting phase with the maximal possible velocity. One qualified instructor (a certified strength and conditioning

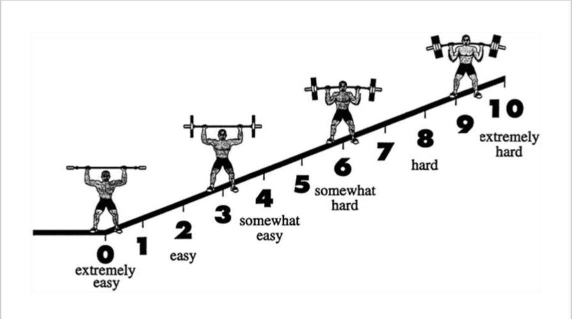

Figure 1. OMNI-RES (0–10) proposed by Robertson et al. (31).

coach, CSCS or UK Strength and Conditioning Association) monitored the appropriate range of motion.

Evaluation Sessions. The 1RM PSQ was determined in the first session. After 48-hour rest and based on the 1RM results, participants performed seven-assessment sessions separated by 48 hours of rest. Each session comprised only 1 repetition to failure (RTF) test using the following 1RM percentages: 30; 40; 50; 60; 70; 80, and 90%. As the availability of the free weight equipment (20 kg Olympic bar, 1.25, 2.5, 5, 10, 15, and 20 kg disks) did not always permit obtaining the exact amount of kilograms representing the aforementioned percentages, the nearest amount of kilograms provided it being equal or up to a maximum of 10% greater than the reference was considered for the test. Therefore, the following 7% evaluation ranges were determined: 30 to <40%, 40 to <50%, 50 to <60%, 60 to <70%, 70 to <80%, 80 to <90%, and >90%. To minimize the accumulated fatigue effect, sequencing of the RTF tests was randomized. Furthermore, participants were asked to abstain from any unaccustomed or hard exercise and refrain from caffeine intake, while maintaining similar sleeping hours and daily activities during the testing period.

Measurement of Velocity. An optical rotary encoder (model WLEN01; Winlaborat, Buenos Aires, Argentina) with a minimum lower position register of 1 mm connected to proprietary software Real Speed Version 4.20 was used for measuring the position and calculating the velocity (v) in $\mathrm{m \cdot s^{-1}}$ achieved during each repetition of the PSQ. The cable of the encoder was connected to the bar in such a way that the exercise could be performed freely, which enabled the cable to move in either vertical direction of the movement. To avoid underestimation of the neuromuscular performance, the mean accelerative velocity (MAV) calculated from the accelerative portion of the concentric phase, during which the acceleration of the barbell was $\geq -9.81\ \mathrm{m \cdot s^{-2}}$, was used for estimating changes in movement velocity (13).

The analysis of the MAV achieved during the RTF test was based on 4 specific events determined at (a) the first repetition (MAV-1); (b) the repetition where the maximum value of MAV was achieved along the corresponding set (MAV-max); (c) the repetition where a drop of 10% in the MAV with respect to the MAV-max was identified (MAV-10%); and (d) the MAV measured during the last repetition (MAV-F), just before the muscular failure on the last repetition of each set. A 10% drop in the MAV was selected because a decline of such magnitude when performing explosive resistance exercises has been associated with selective fast-twitch fibres' fatigue and a loss of movement speed which is not recommended for power development in athletes (19). The criterion analysis to determine the time point associated with the MAV-10% was the performance of 2 continuous repetitions with a 10% reduction from the MAV-max.

Control of the Rating of Perceived Exertion. During the familiarization sessions and the RFT tests, the participants were instructed to verbally report the RPE value indicating a number of the OMNI-RES (0–10) scale that reflects their overall muscular effort at the end of each repetition of the PSQ. The investigators used the same question before starting the first set of each exercise during the familiarization sessions and immediately before each of the 7 RTF tests: "how hard do you feel your muscles are working during the exercise?" (30). A rating of 0 was associated with no effort (seating or resting), and a rating of 1 corresponded to the perception of effort while performing an extremely easy effort (26). A rating of 10 was considered to be maximal effort and associated with the most stressful exercise ever performed (23). The OMNI-RES (0–10) scale was in full view of participants at all times during the procedures.

Electromyography Data Collection. The dominant limb was selected for data collection. Before electrode placement, the skin was shaved, abraded, and cleaned with isopropyl alcohol. Differential bipolar (10 mm center to center) surface electrodes (DE-2.1; Delsys, Boston, MA, USA) were then placed over the vastus medialis of the quadriceps muscle in accordance with SENIAM guidelines (16). A single reference electrode was placed on the C7 vertebra, and all leads connected to the electrodes were secured with tape to avoid artifacts from limb movements. Electromyographic signals were amplified (1 k gain) via a Delsys Myomonitor system with EMGworks software 3.1 (Delsys Inc) with a bandwidth of 20–450 Hz. Root mean square analysis was performed on each repetition using Python programming language version 3.4.1. (Python Software Foundation, Wilmington, DE, USA). Data were collected throughout the entire RTF test for all the 7 evaluated ranges. As the vertical displacement during the concentric phase (ascending movement) was recorded by the rotary encoder and time synchronized with the EMG signal, only the EMG data relating to the concentric phase of each repetition were analyzed. As this study was focused on identifying changes in the accelerative velocity at 4 specific moments along each continuous set, the RMS signal was considered as the primary data for the analysis. The RMS value is the standard method for defining the effective amplitude of a time-varying, alternating signal, providing a meaningful representation of muscle activation at each of the analyzed time points (18).

Maximum Voluntary Isometric Contraction Test. For normalization purposes, each participant completed a 5-second maximal voluntary isometric contraction (MVIC) maintaining a squat position keeping the trunk erect and the knee joint angle at 90° (anatomical angle). The exercise was performed on a rack that was secured to avoid any movement of the resistance. This knee joint angle was selected based on previous observations, which demonstrated that peak acceleration force occurred near this point in the range of motion immediately after overcoming the sticking region during the concentric movement in squat (10). The muscle activity of the vastus medialis was recorded and considered the reference value for normalizing the RMS signal (N-EMG) measured during the RTF tests. To avoid potential sources of error by moving or reapplying electrodes, the MVIC was performed at the beginning of every RTF test after the electrodes were applied.

The reliability of the RTF test used in this study has been demonstrated in previous pilot and published studies (29) of our research group that found test-retest intraclass correlation coefficients to be >0.92 for both the MAV and the RPE values obtained from the OMNI-RES (0–10) scale.

Dependent Variables. Three main dependent variables (MAV, RPE, and N-EMG) were analyzed for each of the RTF tests. Furthermore, to assess the electromyographic signal and the perceived exertion to reflect changes in mechanical performance over a set to failure, the previously identified 4 consecutive time points for the MAV (MAV-1, MAV-max, MAV-10%, and MAV-F) were also used to determine the corresponding values of RPE and N-EMG. Table 1 depicts the main 3 variables and the 4 different points identified for each of the 7 RTF tests.

Statistical Analyses

Mean values and *SD*s were determined for all the variables analyzed during the 1RM and RTF tests. Mauchly's test of sphericity was used for testing the normality of the difference data between all possible pairs of within-subject conditions. For each 7 tested percentage range data, 1-way repeated measures analysis of variance (ANOVA) was applied to detect differences between the 4 time points identified for each dependent variable (MAV, RPE, and N-EMG). Repeated measures ANOVAs were also performed to determine differences between percentage ranges among each time point data for each variable. Bonferroni-adjusted post hoc analyses were performed as appropriate for pairwise comparisons. Generalized eta-squared (η^2_G) and Cohen's d values were reported to provide an estimate of standardized effect size (small $d = 0.2$, $\eta^2_G = 0.01$; moderate $d = 0.5$, $\eta^2_G = 0.06$; and large $d = 0.8$, $\eta^2_G = 0.14$). To provide useful information for controlling the load estimate, changes in movement velocity through the perception of effort the confidence intervals (CIs) (95%) of the RPE variables were calculated. Average values are reported as mean ± *SD* unless stated otherwise. Statistical power for the evaluations ranged from 0.85 to 1.00. The significance level was set at 0.05.

RESULTS

The 1RM mean value was 128.3 ± 26.3 kg (1.6 ± 0.3 kg body weight^{-1}). The average relative load values and the total number of repetitions performed in each of the 7 ranges were as follows: (a) 31.04 ± 0.71% and 50.9 ± 10.7 repetitions; (b) 41.04 ± 0.90% and 34.3.1 ± 4.7 repetitions; (c) 50.9 ± 0.27% and 30.7 ± 5.3; repetitions; (d) 60.68 ± 0.57% and 19.6 ± 2 repetitions; (e) 71.98 ± 0.51% and 14.7 ± 2.5 repetitions; (f) 80.92 ± 0.61% and 9.2 ± 1.4 repetitions;

TABLE 1. Variables and corresponding time points measured during the maximal repetition to failure tests.

Variable	Description
MAV (m·s^{-1})	Mean accelerative velocity
MAV-1	Maximal mean accelerative velocity achieved during the first repetitions of the corresponding set
MAV-max	Maximal mean accelerative velocity achieved during the corresponding set
MAV-10%	Mean accelerative velocity measured when a 10% decrease was determined during each corresponding set
MAV-F	Mean accelerative velocity measured during the last repetition completed during each corresponding set
RPE	Rate of perceived exertion (OMNI-RES 0–10 Scale)
RPE-1	OMNI-RES Scale value of the first repetitions of each corresponding set
RPE-max	OMNI-RES Scale value measured where the maximal mean accelerative velocity was measured for each corresponding set
RPE-10%	OMNI-RES Scale value produced when a 10% drop in maximal accelerative velocity was determined for each corresponding set
RPE-F	OMNI-RES Scale value measured immediately after the end of each corresponding set
N-EMG (%)	Normalized root mean square signal
N-EMG-1	Normalized signal achieved during the first repetitions of the corresponding set
N-EMG-max	Normalized signal achieved during the repetition where the MAV was measured for each corresponding set
N-EMG-10%	Normalized signal achieved during the repetition where a 10% drop of the MAV was determined for each corresponding set
N-EMG-F	Normalized signal determined for the last completed repetition for each corresponding set

TABLE 2. Mean (*SD*) for the 3 outcomes and the analyzed time points within the sets and across the 7 ranges evaluated.*

	Percentage ranges							
Variables	30 to <40%	40 to <50%	50 to <60%	60 to <70%	70 to <80%	80 to <90%	>90%	One-way ANOVA (7 assessments)
MAV ($m \cdot s^{-1}$)	†	†	†	‡	§	§	§	
MAV-1	0.71 (0.07)‖	0.67 (0.08)‖	0.61 (0.07)‖	0.58 (0.07)¶	0.51 (0.05)	0.44 (0.07)	0.38 (0.08)	F(6,66) = 57.2, $p <$ 0.001 $\eta^2 = 0.84$
MAV-max	0.84 (0.09)	0.75 (0.08)	0.71 (0.07)	0.62 (0.07)	0.53 (0.06)	0.46 (0.07)	0.38 (0.08)	F(6,66) = 145.8, $p <$ 0.001 $\eta^2 = 0.93$
MAV-10%	0.72 (0.11)	0.64 (0.05)	0.59 (0.07)	0.55 (0.07)	0.45 (0.05)	0.40 (0.07)	0.31 (0.09)	F(6,66) = 98.2, $p <$ 0.001 $\eta^2 = 0.90$
MAV-F	0.35 (0.18)#	0.32 (0.17)	0.33 (0.15)**	0.27 (0.15)	0.26 (0.13)	0.23 (0.10)	0.22 (0.09)	F(6,66) = 6.98, $p <$ 0.001 $\eta^2 = 0.39$
One-way ANOVA (4 time points)	F(3,33) = 43.6, $p < 0.001$, $\eta_G^2 = 0.80$	F(3,33) = 56.7, $p < 0.001$, $\eta_G^2 = 0.84$	F(3,33) = 45.3, $p < 0.001$, $\eta_G^2 = 0.80$	F(3,33) = 56.3, $p < 0.001$, $\eta_G^2 = 0.84$	F(3,30) = 38.3, $p < 0.001$, $\eta_G^2 = 0.79$	F(3,33) = 55.3, $p < 0.001$, $\eta_G^2 = 0.83$	F(3,33) = 41.8, $p <$ 0.001 $\eta_G^2 =$ 0.79	
RPE (0–10)	††	††	††	††	††	††	††	
RPE-1	1.5 (0.80)‡‡	2.17 (1.34)‡‡	3.33 (1.30)‡‡	3.83 (1.27)§§	5 08 (1.30)	6.5 (0.80)	7.75 (1.29)	F(6,60) = 80.6, $p <$ 0.001 $\eta^2 = 0.89$
RPE-max	1.83 (1.34)	3.08 (2.07)	4.25 (1.91)	4.58 (1.44)	5.36 (1.38)	6.92 (0.79)	7.92 (1.16)	F(6,60) = 28.8, $p <$ 0.001 $\eta^2 = 0.74$
RPE-10%	6.58 (1.78)	6.83 (1.70)	7.42 (1.31)	6.83 (1.34)	7.64 (0.81)	8.33 (0.78)	8.75 (0.87)	F(6,60) = 4.2, $p =$ 0.002 $\eta^2 = 0.29$
RPE-F	10	10	10	10	10	10	10	
One-way ANOVA (4 time points)	F(3,33) = 175.9, $p <$ 0.001, $\eta_G^2 =$ 0.94	F(3,33) = 104.9, $p <$ 0.001, $\eta_G^2 =$ 0.91	F(3,33) = 110.6, $p <$ 0.001, $\eta_G^2 =$ 0.91	F(3,33) = 102.3, $p <$ 0.001, $\eta_G^2 =$ 0.90	F(3,30) = 106.6, $p <$ 0.001, $\eta_G^2 =$ 0.91	F(3,33) = 99.1, $p < 0.001$, $\eta_G^2 = 0.90$	F(3,33) = 26.7, $p <$ 0.001 $\eta_G^2 =$ 0.71	
N-EMG (%)		‖‖	‖‖¶¶			##	##	
N-EMG-1	99.8 (43.8)	159.6 (93.5)	157.1 (66.4)	136.2 (53.2)	150.9 (85.0)	154.3 (70.3)	200.0 (142.5)	F(6,66) = 1.7, $p =$ 0.136 $\eta^2 = 0.13$
N-EMG-max	85.9 (10.4)***	118.4 (16.4)†††	115.1 (18.8)†††	108.8 (15.8)	122.6 (54.8)	100.4 (6.4)	100.2 (0.63)	F(6,66) = 3.25, $p =$ 0.007 $\eta^2 = 0.23$
N-EMG-10%	92.7 (19.1)‡‡‡	111.1 (12.9)	111.9 (12.6)	106.2 (11.3)	111.2 (16.7)	104.3 (13.8)	98.3 (15.5)‡‡‡	F(6,66) = 3.16, $p =$ 0.009 $\eta^2 = 0.22$
N-EMG-F	103.5 (17.0)	95.3 (13.6)	101.7 (14.9)	92.5 (26.6)	95.3 (17.6)	98.5 (9.6)	110.8 (22.4)	F(6,66) = 1.43, $p =$ 0.217 $\eta^2 = 0.12$

One-way ANOVA (4 time points)	F(3,33) = 1.05, $p = 0.384$, $\eta^2_G = 0.09$	F(3,33) = 3,62, $p = 0.023$, $\eta^2_G = 0.25$	F(3,33) = 5,91, $p = 0.002$, $\eta^2_G = 0.35$	F(3,30) = 3.37, $p = 0.030$, $\eta^2_G = 0.24$	F(3,30) = 1.44, $p = 0.251$, $\eta^2_G = 0.13$	F(3,33) = 6.32, $p = 0.003$ $\eta^2_G = 0.37$	F(3,33) = 5.58, $p =$ 0.005, $\eta^2_G =$ 0.32

*ANOVA = analysis of variance; MAV = mean accelerative velocity; RPE = rate of perceived exertion from OMNI-RES (0–10) Scale; N-EMG = normalized root mean square signal.
†$p < 0.001$ between the 4 assess time points with the exception of MAV-1 vs. MAV-10% (differences within each range: MAV).
‡$p < 0.001$ between the 4 assessed time points (differences within each range: MAV).
§$p < 0.001$ between the 4 assess time points with the exception of MAV-1 vs. MAV-max (differences within each range: MAV).
||$p < 0.001$ from the >30–40; >40–50% and >50–60% to the other ranges (differences across ranges: MAV).
¶$p \leq 0.05$ from >60–70% to the other ranges (differences across ranges: MAV).
#$p \leq 0.05$ from 30–40% to >60–70%, >70–80%, and >80–90% (differences across ranges: MAV).
**$p = 0.034$ from >50–60% to >80–90% (differences across ranges: MAV).
††$p < 0.001$ from RPE-1 and RPE-max to RPE-10% and RPE-F (differences within each range: RPE).
‡‡$p < 0.001$ from the >30–40 >40–50%, and >50–60% to the other ranges (differences across ranges RPE).
§§$p < 0.001$ >60–70% to the other ranges (differences across ranges RPE).
||||$p \leq 0.05$ from N-EMG-max to N-EMG-F (differences within each range: N-EMG).
¶¶$p \leq 0.05$ from N-EMG-1 to N-EMG-F (differences within each range: N-EMG).
##$p \leq 0.05$ from N-EMG-1 to the other 3 time points (differences within each range: N-EMG).
***$p < 0.001$ respect to the other ranges (differences across ranges: N-EMG).
†††$p < 0.01$ compared with 80–90 and >90% (differences across ranges: N-EMG).
‡‡‡$p < 0.01$ to the other ranges but not to >90%; $p \leq 0.05$ to >40–50%, >50–60%, and >70–80% (differences across ranges: N-EMG).

(g) 91.03 ± 0.85% and 4.8 ± 1.0 for 30 to <40%, 40 to <50%, 50 to <60%, 60 to <70%, 70 to <80%, 80 to <90%, and >90% respectively.

Table 2 shows the mean ± *SD* for the 3 main variables (MAV, RPE, and N-EMG) and the corresponding 4 time points analyzed along the RTF test within and across the 7 ranges evaluated.

Mean Accelerative Velocity

Comparison of the Four Time Points Within Each Range. Significant main time effects were observed for the 7 ranges. Pairwise comparison revealed that with the exception of 3 lowest ranges (30 to <40%, 40 to <50%, and 50 to <60%) where MAV-1 was similar to MAV-10% and the heavy ranges (70 to <80%, 80 to <90%, and >90%) where MAV-1 was similar to MAV-max, significant differences ($p < 0.001$) and large effect sizes ($d > 0.80$) were determined for all the performed pairwise comparisons (Table 2).

Comparison of Each of the Time Points Across the Ranges. Significant main range effects were observed for the 4 analyzed time points. Pairwise comparison revealed that the MAV-1 was different ($p < 0.001$ $d > 0.8$) when comparing lower (30 to <60%), moderate (60 to <70%), and heavy (80 to <90% and >90%) percentages ranges. In addition, the MAV-max was different ($p < 0.001$, $d > 0.8$) between all the percentages with the exception of the 2 lowest ranges. The MAV-F at 30–40% range was significantly higher ($p \leq 0.05$, $d > 1$) than the MAV-F achieved at moderate-to-heavy ranges (60 to <90%). In addition, the MAV-F at 50 to <60% was higher than the MAV-F measured at ≤80- ($p = 0.034$, $d = 1.20$). No differences were observed between the MAV-10%.

Rating of Perceived Exertion

Comparison of the Four Time Points Within Each Range. Significant main time effects were observed for the 7 ranges. Bonferroni post hoc revealed that the RPE values expressed at RPE-1 and RPE-max were similar and significantly lower ($p < 0.001$, $d > 0.8$) than the RPE-10% and RPE-F for all the evaluated ranges (Table 2).

Comparison of Each of the Time Points Across the Ranges. Significant main range effects were observed for the RPE-1; RPE-max, and RPE-10%. Pairwise comparison revealed that The RPE-1 and RPE-max were significantly different ($p < 0.001$, $d > 0.8$) between lower (30 to <60%), moderate (60 to <70%), heavy (80 to <90%), and maximal (>90%) percentages ranges (Table 2). No differences were observed between the RPE-10% and RPE-F across the 7 range percentages.

Table 3 shows the 95% CI limits for the 4 analyzed RPE variables. The presented data express the potential range of RPE values that could be used for selecting the load and estimate changes in movement velocity while performing

TABLE 3. Mean confidence interval (95%) determined on the RPE main variables determined along the seven-repetition to failure test.*

	RPE-1		RPE-max		RPE-10%		RPE-F	
1 RM ranges	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
30 to 40%	1.05	1.95	1.08	2.59	5.58	7.59	10	10
40 to <50%	1.41	2.92	1.91	4.25	5.87	7.79	10	10
50 to <60%	2.60	4.07	3.17	5.33	6.67	8.16	10	10
60 to <70%	3.12	4.55	3.77	5.40	6.08	7.59	10	10
70 to <80%	4.34	5.83	4.72	6.28	7.23	8.11	10	10
80 to <90%	6.05	6.95	6.47	7.37	7.89	8.77	10	10
>90%	7.02	8.48	7.26	8.58	8.26	9.24	10	10

*1 RM = 1 repetition maximum; RPE = rating of perceived exertion; RPE-1 indicates OMNI-RES Scale value determined after doing the first repetition of each repetition to failure test. RPE-max indicates OMNI-RES Scale value of the repetition where the maximal mean accelerative velocity was reached in each repetition to failure test. RPE-10% indicates OMNI-RES Scale value expressed when a 10% decrease in the mean accelerative velocity was determined along each repetition to failure test. RPE-F indicates the OMNI-RES Scale value expressed after performing the last repetition of each ach repetition to failure test.

continuous sets to failure from light to maximal loads (30 to >90% 1RM) in the PSQ exercise.

Amplitude Electromyography, Normalized Root Mean Square Signal

Comparison of the Four Time Points Within Each Range. Significant main time effects were observed at 40 to <50%, 50 to <60%, 60 to <70%, 80 to <90%, and >90% ranges. No other main time effects were determined. Bonferroni post hoc revealed significant lower N-EMG-F values compared with N-EMG-max at >40–50% ($p = 0.002$, $d = 1.18$) and to N-EMG-1 ($p = 0.013$, $d = 0.85$) at 50–60%. Furthermore, strong trends were observed between N-EMG-F and N-EMG-max at 50 to <60% ($p = 0.08$, $d = 0.54$) and 60 to <70% ($p = 0.069$, $d = 0.58$) as well as from N-EMG-F to N-EMG-1 ($p = 0.063$, $d = 0.60$) at 60 to <70%. The N-EMG-1 showed significant higher values ($p \leq 0.05$, $d > 0.5$) at 80 to <90 and >90% with respect to the other 3 assessed time points. No other differences were observed (Table 2).

Comparison of Each of the Time Points Across the Ranges. Significant main range effects were observed for the N-EMG-max and N-EMG-10%. Pairwise comparison revealed that the N-EMG-max was significantly lower at 30 to <40% compared with the other 6 ranges ($p < 0.001$, $d > 0.80$). In addition, higher N-EMG-max was determined for both 40 to <50% and 50 to <60% compared with the heaviest ranges ($p < 0.01$, $d > 1$) (80 to <90 and >90%).

The N-EMG-10% was significantly lower at 30 to <40% compared with the other percentage ranges ($p < 0.01$, $d > 0.80$) but not with respect to >90%. In addition, the N-EMG-10% measured at >90% was lower than the values obtained at 40 to <50%, 50 to <60%, and 70 to <80% ($p \leq 0.05$, $d > 0.5$). No other main range effects were observed.

DISCUSSION

The main finding of this investigation was that the RPE measured by the OMNI-RES (0–10) scale is a valuable methodology to detect movement velocity fluctuations during a continuous set until volitional failure and to discriminate the relative load used (%1RM) in the PSQ. The proposed approach uses the perception of effort at the beginning (RPE-1), and at different times over a continuous set to monitor mechanical events associated with different strength manifestations (explosive, endurance, or maximal) and the corresponding outcomes. The RPE-1 and RPE-max were similar for all the evaluated ranges but different from RPE-10% and the RPE-F. Thus, controlling the RPE from the beginning and along a set performed with the maximal possible movement velocity would be a suitable method to estimate the moment where a drop of about 10% occurs, and to monitor the progression toward the muscular failure.

Overall, the MAV was different at the 4 evaluated time points for each individual 10% slot. Of interest, at the lightest 3 ranges (30 to <60%), the MAV-1 was similar to MAV-10% and lower than MAV-max. Reaching a maximum movement velocity using light loads may require 2 or 3 previous repetitions to elicit the maximal muscular activation for achieving the highest possible velocity during the ascending phase (4,5). Thus, although further analysis would be necessary for explaining the reason for such as responses, the lower values of MAV-1 may be related to the lack of specific previous neuromuscular preparation. Meanwhile the drop of 10% in the MAV could be associated with a selective fast motor unit disconnection observed during continuous repetitions performed with the maximal possible velocity (32).

Although the N-EMG signal analyzed in this study was unable to accurately reflect small (~10%) fluctuations of the movement velocity, the overall lower values measured at

N-EMG-10% and N-EMG-F for almost all percentage ranges (≥40%) would be in some way associated with the progression of the set after overcoming the repetition anchored to the RPE-10%. The progressive decrease of the N-EMG signal observed in the present study is different from the incremental pattern response reported by Hollander et al. (18) who suggested a rise of the normalized RMS signal as the contraction duration increases between 2, 3, 4, and 5 seconds in the knee extension exercise. Differences in the performed exercises, including mechanics (closed vs. open kinetic chain), the amount of muscle mass (multi-joint vs. single joint exercise), and the mode of execution (explosive vs. controlled) would have influenced these results. Participants of this investigation performed the PSQ exercise with the intention to reach the maximal velocity at the end of concentric phase from the first repetition of each RTF test; meanwhile in the Hollander et al. study, the participants were instructed to complete the knee extension exercise over a 90° range of motion at predetermined 4 contraction durations (2, 3, 4 and 5 seconds). In this study, the available limited time to achieve the full contraction when performing exercises with the maximal possible velocity with light loads would allow the activation of mainly the fast motor units (32) which in turn fatigue at a faster rate (2), disconnecting and influencing the observed descending pattern of the N-EMG signal as the set progresses toward muscular failure.

In summary, the analysis within each range permits the acceptance of the first hypothesis supporting the ability of the RPE and in some way the N-EMG to show changes in the movement velocity during continuous repetitions sets in the PSQ.

The analysis across the ranges indicates that either the RPE-1 or the RPE-max are similar when comparing assessments across the first 3 ranges (>30–60% of 1RM). However, the RPE-1 would be a good indicator for differentiating loads associated with light (≤60% 1RM), moderate (60 to <70% 1RM), and heavy (≥70% 1RM) relative loads. Although N-EMG-1 showed no difference between ranges, N-EMG-max displayed a similar pattern as observed for the RPE with higher values measured at 40 to <60% 1RM compared with the values observed at the highest load (≥80% 1RM). Although the amplitude of EMG signals has been associated with the number of active motor units and their discharge rates, the shape, and propagation velocity of the intracellular action potentials, which is also sensitive to the placement of the electrodes, could be even more influential (2,7) and, therefore, it could be possible that when exercises are performed near or at the maximal levels of voluntary contraction the amplitude decreases (14,22).

The lower levels of N-EMG-max determined for the lightest range (30 to <40%) could be explained by the inability of the participants to produce a maximal neural input when trying to perform explosive movement using very low resistances (<40% 1RM). This capability entails a specific physical conditioning requiring specifically oriented training interventions (3). These results permit the acceptance of the second hypothesis of using the RPE and the neuromuscular signal to differentiate between light, moderate, and heavy loads or 1RM percentages, but not for making a more selective discrimination in 10% incremental loads as used for this study.

Similar to this study, Hollander et al. (18) also reported that relative loads can be clearly delineated by perceived exertion at least in 20% increments (30, 50, and 70%). However, different from this investigation where participants performed a multi-joint exercise (squat) with the maximal possible velocity during the ascending phase, Hollander et al. used a single joint exercise (leg extension) controlling the duration of both concentric and eccentric phases (2, 3, 4, and 5 seconds). It could be possible that if in this study a more controlled slow pattern of contraction had been used, a clearer differentiation of perception of the gradation of the submaximal loads along with a progressive increase in the muscle activation as the load approaches the maximum could have been observed. It is important to note that this study analyzed young, recreationally resistance-trained men performing the PSQ and familiarized with the use of OMNI-RES (0–10) scale. Therefore, these results cannot be applied to other populations such as high performance athletes or other exercises and modalities, especially if there are significant mechanical differences (i.e., a single joint exercise like arm curl, or cyclic total body exercises like running) or use different muscle groups (i.e., upper body like bench press), which have been shown to produce different effort perceptions at the same percentage and repetitions when compared with lower-body exercises (11). Although similar perceptual responses and neurophysiological performance would be observed in women or elderly trained participants, further study is required. Moreover, a limited number of participants ($n = 12$) were studied. The strength of the data, however, was that participants served as their own controls, reducing the variability, and the design involved randomization for assigning different load conditions. In conclusion, results from this study corroborate the functional linkage among 3 main effort markers: performance (MAV), perceptual (RPE), and neuromuscular (EMG response), during resistance exercises, and support the use of the RPE estimated from the OMNI-RES (0–10) Scale to both estimate the relative amount of the load and to control the training zone approached during the strength oriented workouts.

PRACTICAL APPLICATIONS

From the practical point of view, the main contribution of this investigation was to show the ability of the RPE to estimate mechanical events occurring at different instances along a set performed to muscular failure with different percentages of the 1RM load. Despite generalizability issues, this approach can help coaches and athletes to distinguish different resistance training zones by anchoring the RPE-1 to the magnitude of the relative load (% 1RM) and the RPE-max and RPE-10% to the moments along the set where the MAV-max and MAV-10% are respectively produced. For instance, to improve explosiveness with light (30 to <50%), moderate (50 to <70), or heavy (70 to <80%) loads, the initial RPE would be around 1–2, >2–3, or 4–5 for the 30 to <50%, 50 to <70%, or 70 to <80% relative loads and never reach values greater than 7 or 8 for the 30 to <50% and 50 to <80% 1RM ranges, respectively. Furthermore, for strength-oriented training where the relative load should be over 80% of 1RM (1), the recommended RPE-1 would be between 6 and 7, increasing suddenly to over 8 when the MAV drops to 10% and approaches the value of 10 at failure.

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REFERENCES

1. ACSM Position Stand. Progression models in resistance training for healthy adults. *Med Sci Sport Exerc* 41: 687–708, 2009.
2. Al-Mulla, MR, Sepulveda, F, and Colley, M. A review of non-invasive techniques to detect and predict localised muscle fatigue. *Sensors (Basel)* 11: 3545–3594, 2011.
3. Baker, D. Acute and long-term power responses to power training: Observations on the training of an elite power athlete. *Strength Cond J* 23: 47–56, 2001.
4. Baker, D, Nance, S, and Moore, M. The load that maximizes the averages mechanical power output during explosive bench press throws in highly trained athletes. *J Strength Cond Res* 15: 20–24, 2001.
5. Baker, D and Newton, RU. Changes in power output across a high-repetition set of bench throws and jump squat in highly trained athletes. *J Strength Cond Res* 21: 1007–1011, 2007.
6. Day, ML, McGuigan, MR, Bice, G, and Foster, C. Monitoring exercise intensity during resistance training using the session RPE scale. *J Strength Cond Res* 18: 353–358, 2004.
7. Dimitrova, NA and Dimitrov, GV. Amplitude-related characteristics of motor unit and M-wave potentials during fatigue. A simulation study using literature data on intracellular potential changes found in vitro. *J Electromyogr Kinesiol* 12: 339–349, 2002.
8. Duchateau, J, Semmler, JG, and Enoka, RM. Training adaptations in the behavior of human motor units. *J Appl Physiol (1985)* 101: 1766–1775, 2006.
9. Duncan, MJ, Al-Nakeeb, Y, and Scurr, J. Perceived exertion is related to muscle activity during leg extension exercise. *Res Sports Med* 14: 179–189, 2006.
10. Escamilla, RF, Fleisig, GS, Lowry, TM, Barrentine, SW, and Andrews, JR. Three dimensional biomechanical analysis of squat during varying stance widths. *Med Sci Sport Exc* 33: 984–998, 2001.
11. Faigenbaum, A, Milliken, LA, and Cloutier, G. Perceived exertion during resistance exercise by children. *Percept Mot Skills* 98: 627–637, 2004.
12. Gearhart, RF Jr, Goss, FL, Lagally, KM, Jakicic, JM, Gallagher, J, Gallagher, KI, and Robertson, RJ. Ratings of perceived exertion in active muscle during high-intensity and low-intensity resistance exercise. *J Strength Cond Res* 16: 87–91, 2002.
13. Gonzalez-Badillo, JJ and Sanchez-Medina, L. Movement velocity as a measure of loading intensity in resistance training. *Int J Sports Med* 31: 347–352, 2010.
14. Gonzalez-Izal, M, Malanda, A, Gorostiaga, E, and Izquierdo, M. Electromyographic models to assess muscle fatigue. *J Electromyogr Kinesiol* 22: 501–512, 2012.
15. Hardee, JP, Lawrence, MM, Utter, AC, Triplett, NT, Zwetsloot, KA, and McBride, JM. Effect of inter-repetition rest on ratings of perceived exertion during multiple sets of the power clean. *Eur J Appl Physiol* 112: 3141–3147, 2012.
16. Hermens, HJ, Freriks, B, Disselhorst-Klug, C, and Rau, G. Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 10: 361–374, 2000.
17. Hiscock, DJ, Dawson, B, Donnelly, CJ, and Peeling, P. Muscle activation, blood lactate, and perceived exertion responses to changing resistance training programming variables. *Eur J Sport Sci* 16: 536–544, 2016.
18. Hollander, DB, Worley, JR, Asoodeh, M, Wakesa, D, Magnuson, M, Dantzler, DK, Didier, JJ, and Kraemer, RR. A comparison of resistance exercise perceived exertion and muscle activation at varied submaximal durations, loads, and muscle actions. *J Strength Cond Res* 31: 1387–1394, 2017.
19. Hori, N, Newton, RU, and Nosaka, K. Weightlifting exercise enhance athletic performance that requires high-load speed. *Strength Cond J* 27: 50–55, 2005.
20. Izquierdo, M, Gonzalez-Izal, M, Navarro-Amezqueta, I, Calbet, JA, Ibanez, J, Malanda, A, Mallor, F, Häkkinen, K, Kraemer, WJ, and Gorostiaga, EM. Effects of strength training on muscle fatigue mapping from surface EMG and blood metabolites. *Med Sci Sports Exerc* 43: 303–311, 2011.
21. Izquierdo, M, Ibanez, J, Calbet, JA, Gonzalez-Izal, M, Navarro-Amezqueta, I, Granados, C, Malanda, A, Idoate, F, Gonzalez-Badillo, JJ, Häkkinen, K, Kraemer, WJ, Tirapu, I, and Gorostiaga, EM. Neuromuscular fatigue after resistance training. *Int J Sports Med* 30: 614–623, 2009.
22. Komi, PV and Tesch, P. EMG frequency spectrum, muscle structure, and fatigue during dynamic contractions in man. *Eur J Appl Physiol Occup Physiol* 42: 41–50, 1979.
23. Lagally, KM, Amorose, AJ, and Rock, B. Selection of resistance exercise intensity using ratings of perceived exertion from the OMNI-RES. *Percept Mot Skills* 108: 573–586, 2009.
24. Lagally, KM, McGaw, ST, Young, GT, Heather, CM, and Thomas, DQ. Rating of perceived exertion and muscle activity during the bench press exercise in recreational and novice lifters. *J Strength Cond Res* 18: 359–364, 2004.
25. Lagally, KM, Robertson, KM, Gallagher, KI, Goss, FL, Jakicic, JM, Lephart, S, and Goospaster, B. Perceived exertion, electromyography and blood lactate during acute bouts of resistance exercise. *Med Sci Sport Exerc* 34: 552–559, 2002.
26. Lins-Filho, ODL, Robertson, RJ, Farah, BQ, Rodrigues, SLC, Cyrino, ES, and Ritti-Dias, RM. Effects of exercise intensity on rating of perceived exertion during a multiple-set resistance exercise session. *J Strength Cond Res* 26: 466–472, 2012.
27. Mayo, X, Iglesias-Soler, E, and Fernandez-Del-Olmo, M. Effects of set configuration of resistance exercise on perceived exertion. *Percept Mot Skills* 119: 825–837, 2014.
28. Naclerio, F and Moody, J. Resistance training. In: *Europe's Active Foundations for Exercise Professionals*. Rieger, T, Naclerio, F, Jimenez, A and Moody, J, eds. Champaign, IL: Human Kinetics, 2015. pp. 67–96.
29. Naclerio, F, Rodríguez-Romo, G, Barriopedro-Moro, MI, Jimenez, A, Alavar, B, and Triplett, NT. Control of resistance training intensity by the omni perceived exertion scale. *J Strength Cond Res* 25: 1879–1888, 2011.
30. Pageaux, B. Perception of effort in exercise science: Definition, measurement and perspectives. *Eur J Sport Sci* 16: 885–894, 2016.
31. Robertson, RJ, Goss, FL, Rutkowski, J, Lenz, B, Dixon, C, Timmer, J, Frazee, K, Dube, J, and Andreacci, J. Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Med Sci Sport Exerc* 35: 333–341, 2003.
32. Tidow, G. Muscular adaptation induced by training and de-training -a review of biopsy studies. *New Stud Athletics* 10: 47–56, 1995.
33. Wretenberg, P, Feng, Y, and Arborelius, UP. High- and low-bar squatting techniques during weight-training. *Med Sci Sports Exerc* 28: 218–224, 1996.