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Ratings of Perceived Exertion in Active Muscle During High-Intensity and Low-Intensity Resistance Exercise

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ABSTRACT

This investigation compared ratings of perceived exertion specific to the active muscles used during resistance exercise (RPE-AM) using the 15-category Borg scale during high-intensity (HIP) and low-intensity (LIP) weight lifting. Ten men (23.2 ± 3.6 years) and 10 women (21.8 ± 2.7 years) performed 2 trials consisting of seven exercises: bench press (BP), leg press, latissimus dorsi pull down, triceps press, biceps curl, shoulder press, and calf raise. The HIP and LIP protocols were completed in counterbalanced order. During HIP, subjects completed 5 repetitions using 90% of 1 repetition maximum (1RM). RPE-AM was measured after every repetition. During LIP, subjects completed 15 repetitions using 30% of 1RM. RPE-AM was measured after every third repetition. RPE-AMs were greater ($p \leq 0.001$) for HIP than for LIP for each exercise. For example, the mean initial BP RPE was 14.11 ± 2.08 for the HIP and 8.34 ± 1.35 for the LIP. Performing few repetitions using heavier weight is perceived to be more difficult than lifting comparatively lighter weight with more repetitions when external work is held constant.

Key Words: exertional perceptions, Borg 15-category RPE scale, feedforward mechanism

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Introduction

The Borg 15-category rating of perceived exertion (RPE) scale has been applied in various clinical, sport, and wellness settings to evaluate exercise tolerance and prescribe exercise intensity for a wide variety of aerobic modalities. However, use of this scale has not been extensively studied during resistance exercise. The Borg 15 category scale was chosen in the current study because of its properties as a category scale. Category scales should be used in all exercise applications, whereas ratio scales should be used only when correlation to appropriate psychophysical functions is desired.

The components of work associated with resistance exercise (i.e., the amount of weight being lifted, and the number of repetitions) can be manipulated in a single exercise set. Lifting heavy weights with few repetitions is analogous to cycling with a greater brake resistance at a slow pedal rate. In this case, a larger resistance must be overcome to produce a given amount of work. Conversely, the same amount of work can be accomplished by performing more repetitions with comparatively lighter weights. As such, the components of work during resistance exercise can be easily altered while holding total work constant. This has important implications for individuals who use resistance training to increase muscular strength and endurance.

In general, people participating in resistance training desire to enhance either muscle strength or muscle endurance, or both. The training protocols used for these programs are different, although the total volume of work may be identical. Gains in muscle strength are accomplished by lifting heavy weights (e.g., 70–90% of a 1 repetition maximum [1RM]) with few repetitions (2, 4, 6, 13–15). In contrast, gains in muscle endurance are realized by lifting comparatively light (e.g., 30–50% of 1RM) weights with a high number of repetitions (4, 6, 13–15).

Pandolf and Noble found that a slow pedal rate and high flywheel brake resistance elicited higher overall body RPEs than a fast pedal rate with a low flywheel brake resistance during aerobic cycle ergometry when the total external work was held constant (8). The relation between exercise intensity or power output and RPE during leg cycling may in part be contingent upon how the components of power output (i.e., revolutions per minute and flywheel brake resistance) are manipulated. It is unclear whether the pattern of exertional perceptions observed by Pandolf and Noble during aerobic cycle ergometry would be similar to RPE during resistance exercise when the components of physical work are manipulated, but external work is held constant.

Suminski et al. (12) found that lifting heavier weights elicited higher RPEs than lifting comparatively lighter weights. However, the volume of external work varied across protocols, i.e., subjects performed more work during the high- than low-resistance exercise. Therefore, it is unclear whether the higher exertional ratings were attributable to the greater volume of work performed or the greater force exerted during each repetition.

The similarity in perceptual responses noted by Pandolf and Noble (8) and Suminski et al. (12) may not be related to their energy systems given the different energy systems used during cycling (i.e., aerobic) and resistance exercise (i.e., creatine phosphate and anaerobic) (6, 8, 14). It may be that force production or muscle tension could play a major role in mediating RPEs.

Previous investigations have used an overall body rating of perceived exertion (RPE-O) to monitor resistance exercise intensity (5, 12). Differentiated RPEs, however, are specific to an anatomical area and are distinguished from overall body ratings, which are a gestalt of the overall body sensation of effort (7, 10, 11). As such, overall body ratings are assumed to reflect the weighted input of the differentiated signals (10). Differentiated perceptual signals arising from active muscles and joints have been studied extensively during aerobic exercise (7, 11). However, differentiated ratings of perceived exertion specific to the active muscles used during resistance exercise (RPE-AM) have not been studied.

Therefore, this investigation examined RPE-AM used during resistance exercise during 2 different but equal work weight-training protocols: (a) high resistance with a low number of repetitions (high intensity protocol, or HIP) and (b) low resistance with a high number of repetitions (low intensity protocol, or LIP).

It was hypothesized that a HIP would elicit higher RPE-AMs than a LIP of the same external work.

Methods

Approach to the Problem

The study was designed to measure RPE-AM used during resistance exercise. The components of work (i.e., resistance and number of repetitions) were manipulated; however, the external work was constant between protocols. RPE-AMs were taken at equal work increments during both protocols using the Borg 15-category scale. Repetition speed did not vary across protocols.

Experimental Design

A counterbalanced experimental design was used in which subjects completed 2 trials (i.e., HIP and LIP). The experiment involved 3 days of participation by each subject. On day one, subjects reported to the Human Energy Research Laboratory (HERL) where their body weight and percentage of body fat were measured. Percentage of body fat was determined using skin fold calipers (9). A 1RM was then obtained for each of the 7 exercises (3). In addition, subjects were read the instructions for use of the Borg 15-category scale (3). The RPE-AM low and high perceptual anchors were established (3).

The sequence of the exercises performed during the 3 days of testing was flat bench barbell chest press, leg press, latissimus dorsi (lat) pull down, triceps press down using the latissimus dorsi pull-down machine, seated biceps preacher curl, Smith machine barbell shoulder press, and seated calf raise.

Body position (i.e., hand grips, torso, and leg position, etc.) and range of motion were standardized for each exercise. Flat barbell bench press involved the use of a standard straight bar with Olympic plates added for resistance. The grip was such that the thumbs were even with the outside of the shoulders when the bar was resting on the support props. Complete range of motion consisted of lowering the bar until it touched the chest, to locking the elbows at the top of the press. Leg presses were performed in the seated position on a 45° angle Universal machine with the feet parallel and placed shoulder width apart. Complete range of motion involved bending the knees to a 90°angle with the thighs at a 45° angle to the torso, then pressing forward until the knees were locked. Lat pull downs were done on a Pyramid machine in the seated position with the palms forward and the hands placed at the bend on the outer grip on the bar. A complete repetition involved pulling the bar from overhead until it touched the chest slightly below the clavicle. Triceps press downs were executed with the subject standing and gripping the lat pull-down bar with the elbows pressed against the sides; forearms were positioned straight forward with the palms facing down. The range of motion was from the resting position with the elbows bent at the highest position allowed with the upper arms at the subject's sides, to the extended position with the forearm press extended along the lateral side of the thighs and the elbows locked. Biceps preacher curls were performed with the subject seated at the bench and used the wide grips on the standard Olympic curl bar. A complete range of motion involved going from the extended position with the elbows locked to the contracted position where the bar touched the chin. During the Smith machine barbell shoulder presses, the thumbs were placed on the bar in line with the outside of the shoulder. The barbell was lowered until touching the chest slightly below the clavicle. The barbell was then pressed upward until the elbows were locked. Seated calf raises were performed on a machine loaded with Olympic plates. The range of motion involved the extension of the ankle joint from the point where it was completely flexed to the point where it was fully extended. If the subject failed to complete a repetition, a spotter assisted the subject in that lift. The assisted lift did not count. The subject was given a 30-second rest and then asked to complete the total required number of repetitions. A spotter also ensured that the subjects performed the exercise properly. Subjects were instructed to inhale during the eccentric contraction and exhale during the concentric contraction of each repetition of every exercise. Total work performed was held constant in both protocols. This type of design allowed perceived exertion to vary across resistance while holding external work constant (8, 10, 11). For example, in the HIP, the subject lifted 3 times the weight per repetition as required in the LIP, but only one-third as often. The subjects were randomly assigned to a counterbalanced testing sequence. Five subjects repeated exercises in both protocols to evaluate the test–retest reliability of the RPE-AM. The range of r values was 0.73 to 1.00.

Experimental Trials

HIP. After reporting to the HERL, the subjects then walked to the weight room in the same building. An exercise-specific warm-up consisting of 8 repetitions with 15% of the subject's predetermined 1RM was performed before each exercise (e.g., a bench press warm-up preceded the bench press experimental trial). The resistance was then set at 90% (to the nearest 5 pounds) of the subject's predetermined 1RM for each exercise. A metronome set to 20 repetitions per minute was used to control the speed of each repetition. Subjects were then asked to perform 1 set of 5 repetitions for each exercise in the protocol. Subjects rested for 2 minutes between each exercise set. RPE-AM was obtained after the completion of every repetition in each set for each exercise. To facilitate the reporting of RPE-AM, the Borg 15-category scale was positioned at the subject's eye level during each set of exercise.

LIP. The procedure for this experimental protocol was identical to that used in the HIP, except the weight was set at 30% (to the nearest 5 lb) of the predetermined 1RM lift for each exercise. Fifteen repetitions were performed in each exercise. RPE-AM values were obtained after every third repetition, thus keeping the total work constant at each perceptual measurement point across protocols.

Table 1. Subject characteristics (n = 20).*

Sex	N	Age (y)	Weight (kg)	Body fat (%)
Male	10	23.2 ± 3.6	85.0 ± 14.0	10.5 ± 3.9
Female	10	21.8 ± 2.7	61.1 ± 4.2	19.5 ± 3.9

* Values are means ± standard deviations.

Subjects

Twenty college-aged students (10 men and 10 women) that were currently participating in weight-training exercise at least 2 times per week for a minimum of 3 weeks were recruited to participate in this study. The subjects reported they did not have skeletal muscle, cardiovascular, or endocrine limitations to exercise participation. Signed, written informed consent was obtained from each subject before their participation. The subjects also reported that they were free of performance enhancing (e.g., anabolic steroids and illegal drugs) at the time of testing and were nonsmokers. They were required to refrain from exercise 48 hours before each trial, not eat for at least 4 hours before each trial, follow the same diet on the day of each trial, and to abstain from alcohol, caffeine, and nicotine (e.g., smokeless tobacco) for at least 24 hours before their tests. Each subject performed the experimental trials at the same time of day. Testing times varied between subjects, but were kept constant for each individual. Testing sessions were separated by at least 48 and not more than 168 hours.

Statistical Analyses

Frequency distributions confirmed that RPE-AM was normally distributed. The α was set at $p < 0.05$, which was accepted as significant. Using an RPE-AM effect size of 0.5, power was determined to be 0.86 with 20 subjects. A regression model was used to test the linearity of perceived exertion responses for each exercise in each experimental trial. Slopes and measurement points (i.e., after every repetition in the HIP and every third repetition in the LIP) of RPE-AM were compared using dependent t-tests. Initial measurement points are the variables measured immediately after the first measurement point (i.e., immediately after the first repetition in the HIP and immediately after the third repetition in the LIP).

Results

Subject characteristics, separated by gender, are presented in Table 1. However, all analyses were conducted on the combined subject pool (n = 20). Using repetition number at equal work increments as the independent variable, RPE-AM was determined to be linear, with a positive slope, throughout a given set of resistance exercise in each protocol.

Table 2. Initial ratings of perceived exertion specific to the active muscles used during resistance exercise (RPE-AM) measurement point values of the high-intensity and low-intensity protocols.†

Exercise	High-intensity protocol	Low-intensity protocol
Bench press	14.11 ± 2.08*	8.34 ± 1.35
Leg press	14.84 ± 1.97*	9.94 ± 1.50
Lat pull down	14.75 ± 1.33*	8.56 ± 1.09
Triceps press	13.93 ± 1.97*	8.18 ± 1.22
Biceps curl	14.01 ± 2.06*	8.41 ± 1.23
Shoulder press	14.52 ± 1.61*	9.39 ± 1.41
Calf raise	15.35 ± 1.66*	9.26 ± 1.38

† Values are mean ± standard deviations.
* Different from the low-intensity protocol ($p \leq 0.001$).

The RPE-AM measurement points for each exercise were higher ($p \leq 0.001$) for the HIP compared with the LIP (Table 2).

Discussion

The purpose of this investigation was to examine RPE-AM used during 2 different resistance exercise regimens: (a) HIP and (b) LIP. Perceived exertion responses were found to distribute as a linear function of both protocols (3). RPE-AM was found to be significantly higher in the HIP than in the LIP for all 7 exercises that were studied.

Suminski et al. (12) found that when the volume of external work was increased by adding weight, subjects reported higher RPE-Os. Pandolf and Noble found that a slow pedal rate and high flywheel brake resistance elicited higher RPE-Os than a fast pedal rate with a low flywheel brake resistance when the total external work was held constant (8). The results of the current study agree with these 2 studies. That is, the greater resistance load and therefore force generation during skeletal muscle contraction, the higher the exertional perceptions.

As stated earlier, the relation between exercise intensity or power output and RPEs during leg cycling and resistance exercise may in part be contingent upon how the components of power output (i.e., revolutions per minute and flywheel brake resistance during cycle ergometry and resistance and repetitions during resistance exercise) are manipulated. Pandolf and Noble attributed their findings to greater force production in the active muscle required to overcome a comparatively larger resistance (8). When muscles must overcome a heavy resistance, greater tension development in active muscle fiber requires an increase in motor unit recruitment and firing frequency (7). To produce this greater force, additional skeletal muscle fibers must be recruited. As such, a greater number of motor units must be stimulated. This is accomplished by sending a stronger efferent signal from the motor cortex. Smaller, more excitable motor units are recruited first, followed by larger, less excitable motor units. A stronger stimulus may be necessary to cause these larger, less excitable motor units to contract. It is unclear whether the stronger signal is due to an increased efferent firing rate, a stronger efferent signal required for depolarization, or a combination of both (6). These neuromotor variables were not measured in the current study. Regardless, it is believed that more intense corollary signals sent to the sensory cortex from the motor cortex as a result of the above process during heavy resistance exercise may be the primary cause of the differences observed in RPE-AM between protocols (1, 7). The current results are consistent with the feed-forward mechanism underlining the final common neurological pathways for exertional perceptions described by Cafarelli and Bigland-Ritchie (1). When muscles must overcome a heavy resistance, greater tension development in active muscle fiber requires an increase in motor unit recruitment and firing frequency (7). This may explain the RPE responses noted by Pandolf and Noble during cycle ergometer exercise when the components of power output (i.e., flywheel brake resistance and pedal rate) were manipulated (8). This may also explain the results of the current study as well as Suminski et al. (12) when the components of work (i.e., resistance and repetitions) are manipulated during resistance exercise.

As stated previously, the current results are in agreement with Pandolf and Noble during aerobic cycle exercise and Suminski et al. during resistance exercise, although the resistance exercise studies differ from the aerobic cycling study in the energy system used to stimulate skeletal muscle contraction. This would suggest that something other than the energy system used during the exercise could play a major role in mediating exertional perceptions. Further examination of the magnitude of efferent motor signals and the role they play in force production during resistance exercise could provide further insight into the results of the current investigation. Electromyography could be used in future studies to examine the magnitude of the motor signal that triggers an active muscle contraction. The relation between these responses and RPE-AM may further validate Cafarelli's feed-forward model.

Practical Applications

Perceived exertion responses obtained with the Borg 15-category scale during resistance exercise may be useful in determining exercise prescriptions in clinical, wellness, and recreational settings. The scale is easy to use and has been shown to be effective in regulating exercise intensity for a variety of aerobic exercise modes. The current findings suggest that RPE-AM could be used to regulate intensity during both strength and endurance weight lifting protocols. Individuals could base their training intensity on the RPE-AM, and not on an overall feeling of exertion. That is, the undifferentiated response is somewhat less anatomically precise than the differentiated rating. Another potential outcome of using RPE-AM could be an increase in adherence of novice exercisers during the early stages of training. Adaptations in skeletal muscle strength, cross-sectional area, specific tension, and circumference have been shown to be similar after 10 weeks of high- and low-intensity resistance exercise program in previously untrained men (2). It is possible that resistance exercise programs that elicit lower RPE-AM (i.e., low intensity) could be prescribed at the onset of training. This potentially would lower the dropout rate associated with beginning exercise programs and not compromise skeletal muscle adaptations.

Note: Randall F. Gearhart, Jr. is now at Southern Illinois University, Carbondale, IL 62901.

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