Perceived exertion, electromyography, and blood lactate during acute bouts of resistance exercise

KRISTEN M. LAGALLY, ROBERT J. ROBERTSON, KARA I. GALLAGHER, FREDRIC L. GOSS,
JOHN M. JAKICIC, SCOTT M. LEPHART, STEVEN T. McCAW, and BRET GOODPASTER

Illinois State University, Normal, IL; Brown, Medical School and Miriam Hospital, Providence, RI; and University of Pittsburgh, Pittsburgh, PA

ABSTRACT

LAGALLY, K. M., R. J. ROBERTSON, K. I. GALLAGHER, F. L. GOSS, J. M. JAKICIC, S. LEPHART, and B. GOODPASTER. Perceived exertion, electromyography, and blood lactate during acute bouts of resistance exercise. *Med. Sci. Sports Exerc.*, Vol. 34, No. 3, pp. 552–559, 2002. **Purpose:** This study examined ratings of perceived exertion (RPE) during resistance exercise in women. In addition, changes in blood lactic acid and biceps muscle activity assessed using electromyography (EMG) were investigated as potential mediators of RPE during resistance exercise. **Methods:** Twenty female volunteers (age, 25 ± 4 yr) performed one set of biceps curl exercise at 30%, 60%, and 90% of their one-repetition maximum (1-RM). Total work was held constant by varying the number of repetitions during each of the three intensities. The three intensities were performed in random order. RPE responses were assessed for both the active muscle (RPE-AM) and the overall body (RPE-O) following each intensity. EMG data were collected from the biceps brachii muscle during each intensity. Blood samples were taken before and following the intensities and analyzed for blood lactic acid concentration. **Results:** A two-factor repeated-measures ANOVA showed a significant RPE (region) × intensity interaction ($P < 0.02$). Both RPE-AM and RPE-O increased as the intensity of exercise increased. EMG activity increased significantly ($P < 0.01$) as the intensity of exercise increased. A two-factor repeated measures ANOVA performed on the blood lactate data showed a significant ($P < 0.04$) time × intensity interaction. Postexercise [Hla] was significantly greater ($P < 0.01$) at 90% 1-RM than at 30% 1-RM. No significant differences were found in [Hla] between 30% and 60% 1-RM, or between 60% and 90% 1-RM. **Conclusion:** These results indicate that monitoring RPE may be a useful technique for regulating resistance exercise intensity. Moreover, blood lactate and activity of the involved muscle may mediate the relation between RPE and resistance exercise intensity. **Key Words:** RPE, WEIGHT LIFTING, FEMALES, EMG, LACTIC ACID

A number of physiological responses (i.e., metabolic acidosis, ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_2$)) during dynamic exercise are thought to mediate the intensity of perceived exertion (4,17,22,23,26–28). Borg's model of the effort continua postulates that the perceived exertion responses during dynamic exercise are related to these and other physiological responses (2). The model conceptualizes that the response to an exercise stimulus involves three main effort continua: physiological, perceptual, and performance (2,27). A functional link is presumed between the three effort continua. As such, perceptual responses likely provide much of the same information about exercise performance as do selected physiological responses (27). The interdependence between these two types of responses (i.e., perceptual and physiological) during dynamic exercise performance provides a rationale for both the clinical and sport applications of ratings of perceived exertion (RPE) in exercise testing and exercise prescription (2,27). This perceptual-physiological link has been established during dynamic aerobic exercise, but not resistance exercise.

Previous research suggests that RPE is related to the percentage of the one-repetition maximum (1-RM) lifted during resistance exercise. Suminski et al. (29) found that the RPE for the overall body was significantly higher during exercise at 70% 1-RM than at 50% 1-RM. Lagally et al. (19) found that both RPE for the overall body and RPE for the active muscle were significantly higher for an acute bout of resistance exercise at 90% 1-RM than at 30% 1-RM. In this paradigm, total work was held constant for both resistance exercise intensities in order to eliminate the possibility that RPE responses were dependent on work performed. When examined concurrently, the findings of Suminski et al. (29) and Lagally et al. (19) indicate that RPE may be a valid method of determining differences in resistance exercise intensity.

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Previous studies, however, have not clearly defined the physiological mechanisms that might mediate the intensity of exertional perceptions during resistance exercise. It has been hypothesized that exertional perception at least in part involves a feedforward neurophysiological mechanism (5,6,21). This mechanism holds that during dynamic exercise, there is a link between the magnitude of central motor efferent (feedforward) commands and both the motor unit recruitment and firing frequency necessary to maintain a given level of muscular tension. In order to increase motor unit recruitment and firing frequency, central feedforward commands from the motor cortex must also increase (5). Corollary signals branching from these efferent commands are transmitted to the sensory cortex. An increase in the magnitude and/or firing frequency of these corollary signals to the sensory cortex in turn increases the intensity of the perception of physical exertion (6,21). Electromyography (EMG) provides a neuromotor determination of the magnitude of central motor feedforward commands and, by extension, the exertional signal frequency carried by corollary sensory pathways (5,6,17). As EMG increases in the presence of increasing muscular tension, so does the intensity of exertional signals arising from the active muscle groups (16,21). Whether or not this final common neuromotor pathway applies to resistance exercise is unclear. In the context of the present investigation, it was expected that feedforward neuromuscular commands would be higher when lifting a heavy weight fewer times than when lifting a lighter weight many times. If this is the case, both EMG activity and RPE should also be comparatively higher under a heavy weight condition. Consistent with this expectation, Garcin et al. (10) and Hasson et al. (13) have shown that EMG activity is significantly correlated with RPE during resistance exercise.

There is considerable evidence both supporting and refuting the role of blood lactic acid concentration ([Hla]) as a mediator of perceptions of exertion in active limbs during dynamic exercise (3,7,14). Because both blood [Hla] and RPE exhibit a strong positive relation with power output, it is possible that the two variables reflect dynamic exercise intensity, without being causally related (22). In contrast, there is some support for [Hla] as an independent mediator of exertional perceptions during resistance exercise (18,24,29). As resistance exercise is typically anaerobic in nature, the role of blood lactate as a possible physiological mechanism that may mediate the intensity of perceptual responses during resistance exercise was also examined in this investigation. The purpose of this investigation was twofold: 1) to examine the effect of three different resistance exercise intensities on RPE, EMG, and blood [Hla] responses in females; and 2) to examine whether potential neurophysiological (i.e., EMG) and anaerobic metabolic (i.e., [Hla]) factors are potential mediators of RPE during resistance exercise.

METHODS

Subjects

Twenty women (age, 24.6 ± 3.8 yr; height, 64.7 ± 2.4 inches; weight, 136.9 ± 15.2 lb; body fat, 19.0 ± 5.1%) between the ages of 18 and 35 yr participated in this cross-sectional, counterbalanced investigation. With an effect size of 0.5 and alpha = 0.05, power was determined to be 0.86 with 20 subjects. Women were used as subjects in this investigation because most of the previous research in this area used males, and when both men and women were used as subjects, no gender effect was seen (25). Subjects reported being moderately trained, recreational weight lifters (i.e., they strength trained 2–4 times·wk^{-1} for at least 6 months). These subjects were recruited from University of Pittsburgh personal fitness, weight training, and aerobics classes. Subjects reported that they were not taking performance-enhancing drugs at the time of the experiment, had no skeletal muscle or endocrine disorders that contraindicate exercise testing, and were nonsmokers. During the course of the testing, subjects were instructed to refrain from any nonexperimental anaerobic or resistance exercise; maintain normal dietary habits; abstain from alcohol, caffeine, and nicotine for at least 24 h before the testing session; and present for testing in a 3-h postprandial state. Each participant completed a medical history questionnaire and provided their written consent to participate. The Biomedical Institutional Review Board of the University of Pittsburgh approved all procedures used in this investigation.

Orientation Session

The experiment was undertaken using two separate sessions administered over a 2-wk period. Sessions were separated by at least 48 h and no more than 168 h. The experimental procedures were in accordance with the policy statements of the American College of Sports Medicine. The initial session was an orientation session, during which descriptive information for each subject was obtained, including height, weight, and body composition. In addition, procedures for the assessment of muscle activity and lactic acid were explained, and the medical history form was administered. Body density and body fat were estimated from skin-fold measures determined with a Lange caliper. Subcutaneous adipose measures were taken at the triceps, suprailiac, and thigh sites (1). Body density and percent body fat were predicted according to the procedures of Jackson and Pollock (15).

During the orientation session, a 1-RM for the dominant arm (i.e., writing arm) was determined using the method of Lombardi (20) for the biceps curl exercise. Free weights were used during all data collection sessions. Proper lifting technique (see experimental session procedures, below) was demonstrated for the subjects before the 1-RM assessment. The 1-RM value was used to set the 30%, 60%, and 90% 1-RM intensities undertaken during the experimental session.

Perceived exertion assessment procedures. Both an undifferentiated (RPE for the overall body) and a differentiated (RPE for the active muscle) rating of perceived exertion were assessed following each exercise intensity. Only a few previous studies have examined RPE specific to the active muscle during resistance exercise (10,12), and neither specifically examined the validity of this measure. The test-retest reliability of active muscle RPE was examined in a previous investigation in a subset of five subjects and ranged from 0.73 to 1.00 (12). This investigation assesses both an overall body and an active muscle RPE in order to establish the validity of both RPE measures during resistance exercise.

The 15-category Borg Perceived Exertion Scale was used to assess both overall body (RPE-O) and active muscle (RPE-AM) perceived exertion ratings in all data collection sessions. The following scaling and anchoring procedures (11) for the Borg RPE scale were administered to each subject before the 1-RM procedures: You are about to undergo a weight lifting exercise test. The scale before you contains numbers from 6 to 20 and will be used to assess your perceptions of exertion while lifting weights. The perception of physical exertion is defined as the subjective intensity of effort, strain, discomfort, and/or fatigue that you feel during exercise. We use this scale so that you may translate into numbers your feelings of exertion while exercising. The numbers on the scale represent a range of feelings from "no exertion at all" to "maximal exertion." In order to help you select a number that corresponds to your subjective feelings within this range, consider the following. When the exertion during weight lifting feels "extremely light," respond with a number 7. As an example, you should respond with a number 7 when you are doing your repetition without any added weight. When the exertion during weight lifting feels "extremely hard," respond with a number 19. As an example, a response of 19 would be appropriate when your feelings of exertion are the same as when you are lifting your maximum weight. You will be asked to make two separate ratings of perceived exertion. The first should deal with your feelings of local exertion in the muscle(s) you are using to perform the lift. When rating the feelings in local muscles, be sure to attend only to the specific sensations in these body regions. For example, when rating your local perceptions of exertion during the biceps curl exercise, consider only your biceps brachii muscle. The second rating should deal with your feelings of exertion for your overall body. When rating your overall exertion, be sure to select the number that most accurately corresponds to your total body feelings. Round your ratings to the nearest whole value. Please give each rating as accurately as possible, without underestimating or overestimating the exertion. Use the attached verbal descriptors to help you rate your feelings. Give any number you feel is appropriate to describe your perception of exertion in the muscles that you are using during the lift and also in your total body.

The rating scale anchors were established by having each subject perform an unweighted repetition and a 1-RM using the biceps curl exercise. The exertional feelings in the active (biceps) muscle and overall body were assigned a 7 and a 19 on the Borg scale. Subjects were instructed to assign a rating of 6 to any perceptions of exertion that were less than those experienced during the unweighted repetition and a rating of 20 to any perceptions of exertion that were greater than those experienced during the 1-RM.

Experimental Session

Each subject was randomly assigned to an experimental sequence that included three resistance exercise intensities set at 30%, 60%, and 90% 1-RM. Subjects performed one set of a single arm biceps curl exercise within each exercise intensity. The three intensities were performed on the same day in order to minimize the time requirement for a given testing session, increase subject adherence, and permit a more accurate comparison of intraindividual EMG data.

In all three intensities, total work (i.e., total weight lifted over a specified time period) was the same. To keep work similar, the number of repetitions performed at each intensity was varied. Total work for each intensity was determined by multiplying resistance × repetitions (percent 1-RM × number of repetitions) as follows: four repetitions were performed at 90% 1-RM, six repetitions were performed at 60% 1-RM, and 12 repetitions were performed at 30% 1-RM. Two magnetic PlateMates (Fitness Factory Outlet, Broadview, IL) weighing 1.25 lb each were used to ensure that the resistance lifted was as close to each specified percentage as possible. During all intensities, repetition frequency was paced by a metronome set at 60 bpm. This cadence resulted in one complete repetition every 4 s. The initial 2 s included the concentric phase of the lift and the final 2 s included the eccentric phase of the lift.

On arrival at the Center for Exercise and Health-Fitness Research, subjects were asked to sit quietly and read the instructions for the use of the Borg RPE scale. After a 10-min rest period, a 3-mL blood sample was taken and EMG electrodes were positioned. Each subject then performed a series of warm-up lifts that consisted of eight repetitions of the biceps curl exercise performed at 20% of the previously determined 1-RM. The warm-up was performed before performance of the 30%, 60%, and 90% intensities.

Lifting procedures. To ensure that the body position and range of motion were the same for each intensity, subjects performed the lift while standing against a wall. The subject was asked to flex her knee joint until her lower back was in contact with the wall. This was determined by visual inspection. The elbow joint of the arm performing the lift remained in contact with the wall throughout the range of motion. The starting position in the range of motion required the arm to be fully extended and the plate portion of the free weight to be in contact with the wall. The end position of the lift (i.e., concentric contraction) was at full elbow flexion, with the weight contacting the shoulder. One complete repetition consisted of moving from the starting position to the ending position and back to the starting position. A footswitch, which acted as a sensor, was placed on the end of the free weight to indicate the start and the finish of each repetition. When the weight contacted the wall with the arm in the extended position, the footswitch registered the end of the previous repetition and the beginning of the next. A trained researcher was present during all testing sessions to ensure proper range of motion. Any lift that deviated from proper technique was not counted and the

TABLE 1. RPE responses at three resistance exercise intensities.

	Intensity (% 1-RM)	Mean ($N = 20$)	± SD	Range
RPE-AM	30	11.0[a,b]	2.0	6–15
	60	12.9[a,b]	1.1	11–15
	90	15.6[a,b]	2.1	13–20
RPE-O	30	9.7[a,b]	2.0	7–13
	60	11.1[a,b]	2.0	7–14
	90	13.2[a,b]	2.7	8–20

[a] Within a given RPE, means with the same superscript are significantly ($P < 0.01$) different from the other intensities.
[b] Within a given intensity, means with the same superscript are significantly ($P < 0.01$) different from the other RPE.

subject was asked to return to the starting position and repeat the lift. Subjects were instructed to exhale during the concentric phase of the lift and inhale during the eccentric phase of the lift. Subjects rested for approximately 20 min between intensities to allow adequate time for lactate and muscle activity to return to baseline levels. RPE-AM and RPE-O were obtained immediately following exercise in all intensities.

Lactate measurement. A 3-mL blood sample was drawn from a prominent forearm vein by an experienced investigator before and following each exercise intensity. The initial resting sample was drawn from the nonactive arm. All other samples were taken from the active arm. The blood samples were immediately analyzed for lactic acid concentration using a Yellow Springs (YSI) 2700 Select Biochemistry analyzer (Yellow Springs Institute, Inc., Yellow Springs, OH).

Measurement of neuromuscular activation. Neuromuscular activation of the biceps brachii muscle was measured using surface electromyography. Bipolar circular surface electrodes (Ag/AgCl) were placed on the belly of the biceps brachii muscle with an interelectrode distance of 1.5 cm. Before electrode placement, the area was cleaned with isopropyl alcohol and abraded in order to reduce skin impedance. Skin resistance was determined to be less than 2 kΩ. The reference electrode was secured over the acromion process. All electrodes remained in place until data collection was completed in all three intensities. EMG activity was recorded via telemetry using an FM transmitter and differential amplifier (Noraxon Telemyo, Noraxon, Inc., Scottsdale, AZ). The EMG signals from the biceps brachii were broadcast to an FM receiver where they were bandpass filtered (16–500 Hz) and underwent analog-to-digital (A-D) conversion (1000 Hz) by a 16-bit A-D board interfaced to a Pentium microprocessor (Intel Corporation, Santa Clara, CA) before rectification. A footswitch was secured to the end of the free weight to indicate the start and finish of each repetition. The footswitch was interfaced with the EMG data so that contact with the wall was synchronized with measurement of muscle activity. The time elapsed between each footswitch mark was equivalent to the duration of each repetition. Each repetition from all intensities was examined separately to assess the duration of the concentric portion of the lift. It was found that all subjects completed the concentric phase during the first 60% of each repetition. Therefore, the mean EMG amplitude (AEMG), peak EMG amplitude (PEMG), and integrated EMG (IEMG) were calculated from the first 60% of each repetition and then averaged over the set of repetitions. Eccentric data were not included because of differences in the neural recruitment strategies between concentric and eccentric muscle contractions (30).

Data Analysis

Perceived exertion responses to the three resistance exercise intensities were treated with a two-factor (RPE (region) × intensity) repeated-measures analysis of variance (ANOVA), with both RPE and intensity being within-subject factors. In this analysis, the RPE factor had two levels (RPE-AM and RPE-O), whereas the intensity factor had three levels (30%, 60%, and 90% 1-RM). *Post hoc* analyses (i.e., three 2 × 2 repeated-measures ANOVA) were performed to probe significant interactions and main effects. The alpha level was adjusted using the Bonferroni procedure ($0.05/3 = 0.0167$).

The mean AEMG, PEMG, and IEMG responses for the concentric phase of the biceps curl during each of the three resistance intensities were treated with separate one-factor, repeated-measures ANOVAs. *Post hoc* analyses using paired *t*-tests were performed to examine differences in AEMG, PEMG, and IEMG between the three resistance exercise intensities.

A two-factor (time × intensity) repeated-measures ANOVA examined blood [Hla] across the three intensities. *Post hoc* analyses (i.e., three 2 × 2 repeated-measures ANOVA) were performed to probe significant interactions and main effects. The alpha level was adjusted using the Bonferroni procedure ($0.05/3 = 0.0167$). In addition, Pearson's product-moment correlation coefficients were calculated between the two RPE measures and all three EMG measures as well as between the two RPE measures and blood [Hla] for all three intensities. A P value of 0.05 was used to establish statistical significance. All analyses were performed using the Statistical Package for the Social Sciences (SPSS, Inc., Chicago, IL).

RESULTS

The results of this investigation found that as resistance exercise intensity increased (30%, 60%, and 90% 1-RM) with total work held constant, there were corresponding increases in both RPE-AM and RPE-O. Means and standard deviations for RPE-AM and RPE-O are shown in Table 1.

TABLE 2. EMG responses at three resistance exercise intensities.

	Intensity (% 1-RM)	Mean ($N = 15$)	± SD	Range
PEMG (mV)	30	630.3[a]	330.9	277–1313
	60	832.4[a]	348.6	359–1523
	90	990.9[a]	320.5	456–1515
AEMG (mV)	30	186.2[a]	78.9	91–331
	60	306.8[a]	130.8	146–583
	90	389.1[a]	163.5	200–705
IEMG ($mV \cdot s^{-1}$)	30	448.9[a]	190.8	218–799
	60	739.3[a]	315.6	349–1405
	90	936.5[a]	395.7	465–1701

[a] Within a given EMG measure, means with the same superscript are significantly ($P < 0.01$) different from other intensities.

Results of the two-factor (RPE (region) × intensity) repeated-measures ANOVA indicated that there were significant ($P < 0.01$) main effects for both RPE and intensity. In addition, a significant ($P < 0.02$) RPE × intensity interaction was found.

The interaction effect (RPE × intensity) was analyzed by performing three separate 2 × 2 (RPE × intensity) repeated-measures ANOVA to compare RPE-AM and RPE-O at all intensities. The results of the analysis on 30% and 90% 1-RM indicated a significant RPE × intensity interaction ($F(1,19) = 9.62$, $P < 0.01$). Although RPE-AM was higher at 90% 1-RM than at 30% 1-RM, the magnitude of the difference between RPE-AM and RPE-O was greater at 90% 1-RM than at 30% 1-RM. In addition, these analyses indicated that RPE-AM was significantly ($P < 0.01$) higher than RPE-O during all three intensities and that there were significant ($P < 0.01$) differences in each RPE measure among the three resistance exercise intensities.

Complete EMG data were obtained on 15 subjects. Five subjects had missing or incomplete EMG data because of instrument artifact and were not included in the analyses. Group means ± standard deviations for the rectified mean AEMG, mean PEMG, and mean IEMG from the concentric phase of each biceps curl are shown in Table 2. The analyses revealed significant ($P < 0.01$) main effects for AEMG, PEMG, and IEMG. *Post hoc* analyses using paired *t*-tests with the alpha adjusted using the Bonferroni procedure ($0.05/3 = 0.0167$) showed that all three EMG measures increased significantly as the resistance exercise intensity increased from 30% to 60% to 90% 1-RM. The results from the correlational analyses performed between RPE and AEMG, PEMG, and IEMG indicated positive, but statistically nonsignificant, correlations ranging from 0.19 to 0.47.

Blood lactic acid data were available at all measurement time points in 8 of the 20 subjects that constituted the total sample. Therefore, only the data for these eight subjects were included in the analyses. Means ± standard deviations for [Hla] data are shown in Table 3. The results of the two-factor (time × intensity) repeated-measures ANOVA indicated significant ($P < 0.03$) main effects for time and intensity. In addition, a significant time × intensity interaction ($F(2,14) = 4.02$, $P < 0.04$) was observed. The interaction effect was analyzed by repeating a 2 × 2 (time × intensity) ANOVA to compare [Hla] during all intensities over time. These analyses indicated that [Hla] increased significantly ($P < 0.01$) from before to after exercise during all three intensities. Additionally, postexercise [Hla] was significantly ($P < 0.01$) greater in 90% 1-RM (3.7 $mmol \cdot L^{-1}$) than in 30% 1-RM (2.53 $mmol \cdot L^{-1}$). No significant differences were found in [Hla] between 30% and 60% 1-RM, or between 60% and 90% 1-RM. Correlation coefficients calculated between RPE and blood [Hla] were statistically nonsignificant, and ranged from −0.68 to 0.20.

DISCUSSION

We have hypothesized that the physiological processes that may mediate the intensity of perceived exertion during resistance exercise involve an increased muscle activity (as measured by EMG) and increased blood [Hla]. These neurophysiological and metabolic responses result from an increase in muscle force production during resistance exer-

TABLE 3. Blood lactic acid concentration responses at three resistance exercise intensities.

	Intensity (% 1-RM)	Mean ($N = 8$)	± SD	Range
Before exercise ($mmol \cdot L^{-1}$)	30	1.01	0.28	0.647–1.41
	60	1.12	0.31	0.648–1.57
	90	1.07	0.30	0.700–1.59
After exercise ($mmol \cdot L^{-1}$)	30	2.53[a,b]	1.04	0.825–4.13
	60	2.96[a]	1.17	0.805–4.64
	90	3.70[a,b]	1.54	0.952–5.57

[a] Within a given intensity, means with the same superscript are significantly ($P < 0.01$) different from preexercise values.
[b] At the postexercise measurement period, means with the same superscripts are significantly ($P < 0.01$) different.

cise. It was the intent of the present investigation to demonstrate a link between these selected physiological responses and both differentiated and undifferentiated perceived exertion responses associated with increasing resistance exercise intensity. The results indicate that there were uniform increases in RPE, EMG, and [Hla] in response to increases in resistance exercise intensity from 30% to 60% to 90% 1-RM. These data provide support for a functional link among the three main effort continua (physiological, perceptual, and performance) during resistance exercise (2).

RPE during resistance exercise. Both RPE-AM and RPE-O increased significantly ($P < 0.01$) as resistance exercise intensity increased. These results are consistent with those of previous investigations that examined RPE during resistance exercise. Suminski et al. (29) demonstrated that RPE-O was higher at 70% 1-RM than at 50% 1-RM, and speculated that the perceptual signal was dependent on the percentage of 1-RM lifted. Lagally et al. (19) demonstrated that when total work was held constant, both RPE-O and RPE-AM were higher when 90% 1-RM was lifted than when 30% 1-RM was lifted. In the present investigation, total work was held constant in order to eliminate the possibility that RPE responses were dependent on work performed. As such, it may be concluded that the increases in RPE seen in this investigation and earlier investigations resulted from a systematic increase in the percentage of 1-RM lifted. These results suggest a causal relation between RPE and percentage of 1-RM lifted.

Both differentiated RPE (RPE-AM) and undifferentiated RPE (RPE-O) were measured during the present investigation. Previously, Lagally et al. (19) demonstrated that RPE-a.m. was higher than RPE-O following resistance exercise performed at 30% and 90% 1-RM. The present results are consistent with this previous report in that RPE-AM was higher than RPE-O during all intensities. A higher RPE-AM than RPE-O suggests that the comparatively more focused sensations of discomfort and strain felt in the active muscles were more intense than the dispersed sensations for the overall body. The finding of a higher RPE-AM than RPE-O is not surprising if, as suggested by the results of this investigation, perceived exertion during resistance exercise is related to muscle activity and blood [Hla]. Both muscle activity and blood [Hla] are peripheral events specific to the active muscles, and therefore may intensify feelings of exertion in the active muscles to a greater degree than in the overall body.

The RPE × intensity interaction indicates that the difference between RPE-AM and RPE-O was greater during 90% 1-RM than during 30% 1-RM. This indicates that RPE-AM was disproportionately higher than RPE-O in the 90% 1-RM intensity when compared with the low intensity. This finding is consistent with the blood [Hla] findings, which suggest that the contributions from anaerobic metabolism are comparatively greatest when resistance exercise intensity is very high (i.e., at 90% 1-RM). Furthermore, there may be other peripheral events, such as phosphocreatine depletion and blood pH, which may also act to intensify perceived exertion in the active muscles, particularly during very-high-intensity resistance exercise.

EMG and RPE during resistance exercise. The AEMG, PEMG, and IEMG values were determined during each resistance exercise intensity and used as a measure of muscle activity. Each of the three EMG measures increased significantly as the resistance exercise intensity increased. This suggests that neuromotor activity (i.e., muscle fiber recruitment and firing frequency) was greater as the relativized weight that was lifted became heavier, even with total work held constant during each condition.

The present results demonstrated corresponding increases in both RPE measures and EMG as the resistance exercise intensity increases. During dynamic exercise, it has been shown that effort sensation increases in response to greater neuromotor activity as measured by EMG (4,6,8,16,21). Increases in muscle activity are a direct result of a greater level of central motor efferent commands (5). Corollary copies of motor cortex commands are sent to the sensory cortex, evoking perceptual signals of exertion that are consciously monitored. Therefore, as muscle activity (i.e., EMG) increases, the number of corollary commands received by the sensory cortex increases, intensifying exertional sensations (21). In addition, afferent signals from Golgi tendon organs, muscle spindles, and mechanoreceptors combine with the corollary commands to further intensify and/or refine exertional sensations. The corresponding increases in EMG and RPE seen in this investigation suggest that such a neurophysiological link functions during resistance exercise to signal exertional perceptions.

Support for a feedforward mechanism in regulating exertional sensations during dynamic exercise is seen in a number of previous investigations (5,8,16). Cafarelli and Bigland-Ritchie (5) used a muscle "matching" technique to demonstrate that the sensation of muscle force results mainly from the degree of motor efferent activity, and not from peripheral input. Gandevia and McCloskey (8) observed that, over time, the perceived heaviness of a weight increases as does the electrical activity of the muscle. Such an increase in perceived heaviness results when the motor commands required to perform a given contraction are increased.

A neuromuscular feedforward mechanism of the type described above by Cafarelli and Bigland-Ritchie (5) may also play a role in setting the intensity of exertional perceptions during dynamic resistance exercise. When the weight lifted is heavy, the central motor efferent commands and their corollary commands to the sensory cortex (as well as afferent signals from the periphery) increase. Together, these signals likely act to increase exertional perceptions. The results of the present investigation support this notion by demonstrating that both RPE and muscle activity (measured by EMG) increase as the resistance exercise intensity increases, indicating that the two variables may be functionally related.

Blood lactic acid concentration and RPE during resistance exercise. Blood lactic acid concentration increased significantly from before to after exercise at all three intensities, indicating that anaerobic metabolism did contribute to energy production. In addition, blood [Hla] following 90% 1-RM was higher than blood [Hla] following 30% 1-RM. The increase in blood [Hla] above baseline levels suggests that the contributions from anaerobic metabolism are comparatively greatest when the resistance exercise intensity is very high (i.e., at 90% 1-RM).

These results indicate that there were corresponding increases in both RPE measures and blood [Hla] as the resistance exercise intensity increased. Previous investigations have demonstrated similar findings. For instance, Suminski et al. (29) noted a positive relation between RPE-O and [Hla] during a series of resistance exercises. Both variables increased as the intensity of resistance exercise increased from 50% to 70% 1-RM. Garbutt et al. (9) and Kraemer et al. (18) reported that both RPE-O and blood [Hla] rose significantly over the course of a progressive resistance exercise session. These results are suggestive of a link between blood [Hla] and RPE during resistance exercise. Whether [Hla] acts as an independent mediator of RPE remains unclear. It is possible that the parallel increases in both RPE and [Hla] are really a covariate of the greater muscle activity during increasing exercise intensity. However, as the number of subjects with complete lactate data was less than the full sample, the conclusions regarding the role of lactic acid as a mediator of perceptions of exertion during resistance exercise must be cautiously interpreted.

Correlational analyses may provide further support for a link between perceptual and physiological variables. Several previous studies have demonstrated significant positive correlations between RPE and EMG (10,13), as well as between RPE and blood [Hla] (18) during resistance exercise. In contrast, the correlation coefficients calculated between RPE and both EMG and blood [Hla] in this investigation were statistically nonsignificant. This lack of significance is likely because of the small sample size and narrow response range of both the EMG and blood [Hla] measures, which may be a result of the type of exercise paradigm used in which the intensity varied over a wide range but total work was limited. The minimal amount of total work performed in each intensity during the present investigation may not have been enough to elicit large changes in blood [Hla] or in EMG, and this lack of variability may have attenuated the correlation coefficients. Further research is warranted to more clearly define the relation between EMG, [Hla], and RPE during resistance exercise.

In summary, the results of this investigation suggest a role for central neuromotor drive and [Hla] as mediators of the intensity of RPE during resistance exercise. These results are consistent with previous findings that suggested a potential role for blood [Hla] (24,29) and EMG (4,5) as a mediator of RPE during resistance exercise. Within the limitations of this study, it can be concluded that muscle activity (EMG) and [Hla], two physiological responses associated with resistance exercise, exhibit corresponding increases with perceptual responses as resistance exercise intensity increases. This is consistent with Borg's model of the effort continua, which states that the perceived exertion responses during exercise performance are functionally related to selected physiological variables (2). On the basis of the corresponding increases seen between RPE, EMG, and blood [Hla], it may be concluded that the assumptions underlying the effort continua model apply during resistance exercise in a manner analogous to that during dynamic aerobic exercise.

Address for correspondence: Kristen M. Lagally, Ph.D., Illinois State University, 214 Horton Fieldhouse, Campus Box 5120, Normal, IL 61790-5120; E-mail: kmlagal@ilstu.edu.

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