

Perceived exertion responses to novel elbow flexor eccentric action in women and men

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ABSTRACT

O'CONNOR, P. J., M. S. POUDEVIGNE, and J. D. PASLEY. Perceived exertion responses to novel elbow flexor eccentric action in women and men. *Med. Sci. Sports Exerc.*, Vol. 34, No. 5, pp. 862–868, 2002. **Purpose:** The primary aim was to describe perceived exertion responses to different intensities of eccentric exercise in women and men. **Methods:** 42 adults (21 men and 21 women, 7 per condition) completed elbow extension exercises with a weight corresponding to 80%, 100%, or 120% of maximal voluntary concentric strength. Total work was equated by manipulating the number of repetitions in the 80% ($N = 45$), 100% ($N = 36$), and 120% ($N = 30$) conditions. **Results:** A two-way ANOVA showed significant main effects for the intensity and sex factors. Perceived exertion ratings were strongly dependent on exercise intensity, and women reported lower RPEs than men. A separate three-way mixed model ANOVA that included a repetition factor showed that perceived exertion ratings increased similarly across the first 30 repetitions in all exercise conditions. Significant partial correlations were found between mean RPE during the eccentric exercise bout, and the mean intensity of delayed-onset muscle pain measured from 12- to 72-h postexercise after controlling for the relative exercise intensity ($r_{12;3} = 0.28$) or the maximum concentric strength of the elbow flexors ($r_{12;3} = 0.33$). **Conclusions:** 1) for both women and men, there is a positive association between the intensity of eccentric exercise performed with the elbow flexors and RPE; 2) perceived exertion ratings increase significantly then plateau when repeated eccentric muscle actions are performed at constant, submaximal absolute intensities; 3) women rate eccentric exercise performed at the same intensity (relativized to MVC-C) as being less effortful compared with men; and 4) RPE during eccentric exercise can account for a small but significant amount of variability in delayed-onset muscle pain after statistically controlling for differences in strength or relative intensity. **Key Words:** BICEPS BRACHII, DOMS, GENDER, MUSCLE SORENESS, PERCEPTION OF EFFORT, RPE, SEX, WEIGHT LIFTING

More than 400 papers have been published involving perceived exertion (18). Most of these investigations have inquired into perceptions of effort during lower body, large muscle, dynamic, low-resistance exercises involving both eccentric and concentric muscle actions, such as cycling or running. Much less is known about perceived exertion responses to resistance exercise (8–11,13,14,16,17,19,21–23,30,33). The relative dearth of knowledge about perceived exertion during eccentric muscle actions (12,20,36) provided one rationale for the present investigation.

The few prior investigations concerning perceptions of effort during eccentric exercise have documented that ratings of perceived exertion are lower when work of the same absolute intensity is performed by eccentric muscle actions compared with concentric contractions (12,20,36). These experiments, and others showing lower RPE values during eccentrically biased types of physical activity, such as downhill walking and running (15,24), support the idea that

local feelings of strain in the working muscles dominate exertional perceptions during eccentric muscle actions. This prior research, however, has been limited to perceived exertion responses elicited during bouts of exercise performed continuously for 3–10 min, whereas perceived exertion responses to each eccentric repetition have not been detailed (12,15,16,20,24).

Perceived exertion responses to eccentric muscle actions are of interest in part because eccentric muscle actions appear to require unique activation strategies by the nervous system. For example, there is experimental evidence showing a decrease in the size of electrical potentials evoked in muscle by transcranial and peripheral nerve stimulation during eccentric compared with concentric contractions (6,7). Also, there is a greater resistance to fatigue (decline in force) during repeated contractions as well as a greater decline in EMG amplitude with eccentric compared with concentric muscle action (6,7). If central and peripheral nervous system requirements to perform eccentric muscle actions differ from what occurs during concentric contractions, this may result in unique perceptual responses during eccentric actions. Accordingly, it is of interest to learn whether this is true by more carefully documenting perceived exertion responses to eccentric muscle action. Unaccustomed eccentric actions are of special interest because

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they can result not only in muscle injury and reduced muscle function but delayed-onset muscle pain, which may influence whether individuals are willing to adopt or maintain a program of regular physical activity (3). Information about perceptual effort during unaccustomed eccentric actions ultimately could lead to a method for preventing delayed-onset muscle pain or help to explain why women and men often adopt different physical activity programs (e.g., men engage in weight lifting more frequently and participate in other types of exercise at a higher intensity) compared with women (31).

Thus, the primary purpose of this investigation was to describe perceived exertion responses to different intensities of unaccustomed elbow flexor eccentric exercise in healthy adult women and men. We sought to determine whether exertion ratings: (a) would be associated with exercise intensity, and (b) would increase with repeated repetitions of eccentric muscle actions performed at a constant absolute intensity.

An additional purpose of the investigation was to make a sex comparison. Based on prior research (4) comparing perceived exertion during leg cycle ergometry in men and women performing work rates relativized to a physical reference (% peak power output), it was hypothesized *a priori* that women would have lower exertion ratings than men at each relative exercise intensity.

Because unaccustomed eccentric exercise is known to result in delayed-onset muscle pain, it also was possible to document the magnitude of the relation between the intensity of perceptions of effort during the eccentric exercise bout and the intensity of delayed-onset muscle pain. It is well established that higher intensities of unaccustomed eccentric exercise produce greater muscle injury and delayed-onset muscle pain (37). Nevertheless, large individual differences in delayed-onset muscle pain responses occur among people, unaccustomed to resistance exercise, who perform identical exercise protocols at the same relative intensity. For example, among a sample unaccustomed to performing resistance exercise, individuals ($N = 31$) exhibiting low blood creatine kinase responses to 70 maximal eccentric actions of the forearm flexors reported significantly lower muscle pain intensity (~40% less) 1–5 d after exercise compared with individuals who performed an identical exercise bout but exhibited a moderate ($N = 50$) or high ($N = 28$) blood creatine kinase response (3). The factors that contribute to this variability in pain have not been fully explicated. However, it is possible that a small but meaningful amount of variability in pain responses could be accounted for by individual differences in muscle injury resulting from variations in central command (i.e., the central nervous system's descending neural drive from the motor cortex resulting in activation of motoneurons). Variations in central command can occur even when healthy individuals perform exercise at the same relative exercise intensity (35). Moreover, it is possible that interindividual variations in muscle microinjury sustained during the initial muscle actions of an experiment involving repeated eccentric actions could contribute to additional variations in cen-

tral command later in the exercise bout. Because perceived exertion has been used as an index of central command (e.g., 28), the relation between perceived exertion and the subsequent delayed-onset muscle pain was explored to learn whether perceived exertion is related to delayed-onset muscle pain. We reasoned that a meaningful relationship between the effort reported during the eccentric exercise bout and the average intensity of the delayed-onset muscle pain could be ascertained after statistically controlling for factors, such as the relative exercise intensity, that are known to influence the amount of muscle injury and delayed-onset muscle pain.

METHODS

Subjects. Healthy university undergraduates who reported not performing arm-curl weight training during the prior 4 months were recruited after the investigation was approved by the Institutional Review Board. Potential participants completed a medical history questionnaire. Excluded were those who reported: (a) severe dizziness, chest pain, or bone/joint problems that could have been aggravated by exercise; and (b) the current use of any type of prescription medication except for oral contraceptives (11 of the women reported using an oral contraceptive). All participants read and signed an informed consent. Twenty-one men and 21 women participated. Selected characteristics of the male and female samples included the following: mean (\pm SD) age (21.9 ± 2.6 vs 20.8 ± 1.0 yr), height (179.7 ± 8.5 vs 166.1 ± 6.6 cm), and weight (78.9 ± 10.5 vs 58.0 ± 7.4 kg), respectively. A companion paper addressed the question of whether sex or resting blood pressure influences delayed-onset muscle pain intensity (in review).

Overall experimental design. Testing was conducted on six separate days. The purpose of the first two testing days, which were separated by a minimum of 48 h, was to determine the maximum voluntary concentric contraction strength of the elbow flexors. These strength tests were limited to concentric contractions to avoid delayed-onset muscle injury and pain. On test day 3, which occurred 5 d after test day 2, the participants completed a bout of eccentric exercise during which perceived exertion ratings were obtained. On test day 3, the participants were assigned to one of the following three elbow flexor eccentric exercise intensity conditions: condition 1 (80% maximal concentric strength \times 45 repetitions), condition 2 (100% maximal concentric strength \times 36 repetitions), or condition 3 (120% maximal concentric strength \times 30 repetitions). The number of repetitions was varied for each intensity so as to equate the groups on total work performed. Delayed-onset muscle pain intensity ratings were obtained every 12 h for 72 h after eccentric exercise.

Maximum voluntary concentric contraction (MVC-C) strength of the elbow flexor. Maximal voluntary concentric contraction strength of the elbow flexors was determined while the participants were in a seated position using a "preacher bench." Markings were made on the floor to standardize the position of the chair. The height

of the arm rest and seat components of the preacher bench were adjustable. After being fitted to each individual, the heights of the arm rest and seat were measured, and subsequent days' tests were performed at the same heights. The participants warmed up by completing two sets of eight repetitions of elbow flexion only using a dumbbell with a weight of 2.26 kg for women and 4.52 kg for men. After a 2-min rest period, the participants attempted to perform a single elbow flexion starting with a weight equal to 90% of the estimated maximal. This estimated maximal was based on the perceived difficulty reported in completing the warm-up and pilot testing showing a mean maximal strength of 14 kg for men and 5.5 kg for women. If the participant could not perform an elbow flexion with this weight using correct form, then, after resting for a minimum of 1 min, the procedure was repeated with a reduced weight of 0.45–2.26 kg. Correct form was defined as having the feet remaining on the floor, the nonexercising hand remaining in the lap, and the triceps of the exercising arm remaining resting against the preacher bench. If the lift could be performed using good form then a weight of 0.45–2.26 kg was added. Approximately five maximal flexion attempts were needed to determine the MVC-C strength. An investigator lowered the weight after each lift so that the participants avoided completing any eccentric actions with the elbow flexor muscle group. After a 48-h recovery period, strength was assessed again as described above but starting with a weight close to the previously established maximum. The mean (\pm SD) MVC-C strength for the entire group was 9.6 (\pm 4.7 kg) on test day 1 and 9.7 (\pm 4.8 kg) on test day 2. The test-retest reliability of the MVC-C was high (i.e., one-way random effects model, intraclass correlation of $R = 0.98$). The highest weight lifted on the 2 days served as the criterion MVC-C strength value. The mean RPE associated with the criterion MVC-C was 18.47, and no significant differences were observed among the exercise intensity conditions (18.35, 18.45, and 18.6 for both men and women assigned to the 80%, 100%, and 120% conditions, respectively) or between the female and male subjects (18.3 and 18.6, respectively).

Eccentric exercise bout. On test day 3, the participants were assigned to one of the following three elbow flexor eccentric exercise intensity conditions: condition 1 (80% MVC-C strength \times 45 repetitions), condition 2 (100% MVC-C strength \times 36 repetitions), or condition 3 (120% MVC-C strength \times 30 repetitions). The number of repetitions was varied for each intensity so as to equate the groups on total work performed. The total work was estimated by the following formula and converted to international units: total work = mass lowered \times repetitions \times estimated distance the mass was lowered (0.6 m). There were no significant differences among the conditions in total work, and the mean total work for the entire sample was 946 J. In each condition, the participants were instructed to perform each eccentric muscle action (i.e., elbow extension) in a slow (\sim 3 s) and controlled fashion. A tape-recorded voice assisted the participant in controlling the speed of the movement, and this pacing also ensured that the amount of rest

time (25 s) between each lift was equal among the conditions. The reason for allowing 25 s of rest was to provide time for the activated muscle to recover between each lift. After each elbow extension, an investigator raised the weight and the participant provided a rating of the perceived exertion for the just completed muscle action by using the 6–20 perceived exertion scale (2).

Perceived exertion instructions. The following perceived exertion instructions were employed for the eccentric exercise session. After each arm movement, we will ask you to rate the perceived intensity of the exercise using the perceived exertion scale shown above. By perceived exertion we mean the intensity of the effort you gave in lowering the weight. You should consider a value of 7 to be equal to the effort given when flexing and extending your arm with no weight in your hand. Please flex and extend your arm. Also, you should consider a value of 19 to be equal to the perceived effort you would feel in association with a typical maximal effort on your part such as the effort you gave during the maximal exercise tests you performed on testing days 1 and 2. The term “typical maximal” is used in this regard because sometimes you might give an effort that goes higher than typical. So, today if you give a higher than typical maximal effort then you should rate your effort as 19.5 or 20. Also, as just indicated, whole numbers or half numbers can be used. You should use the verbal anchors (e.g., very light, very hard, etc. . .) to assist you in giving your perceptions a numeric rating. Do not underestimate or overestimate—just be as accurate as you can.

Pain intensity assessment. After the eccentric exercise bout was completed, each participant was given a folder containing pain data recording sheets and was requested to make elbow flexor muscle pain intensity ratings every \sim 12 h for 72 h. These ratings were made in the presence of the investigators 24, 48, and 72 h after the eccentric exercise bout. The ratings made at \sim 12, \sim 36, and \sim 60 h after the eccentric exercise bout were made outside of a laboratory setting. Muscle pain intensity was assessed by making a vertical line with a pen through a 100-mm horizontal visual analog scale printed on paper. The pain was stimulated by having the participants slowly flex and extend the elbow of the exercised arm (27).

Data analysis. To minimize data entry errors, data were entered into two spread sheets by two investigators and verified for accuracy. A small amount of pain intensity data (\sim 5%) was missing due to participants who failed to attend the 24-, 48-, or 72-h postexercise test sessions. Missing data were estimated by inserting mean scores calculated for a given individual from his or her actual data obtained from the trial before and after the missing data trial. In a few instances, data were missing on the last trial (i.e., 72-h postexercise), and in these cases, the percentage change across the last two trials observed for the rest of the group was applied to the individual whose datum was missing (34). The conclusions of the investigation were unchanged whether the estimated missing data were included or excluded. Data were analyzed using SPSS Statistical Software version 9.0 (SPSS Inc. Chicago, IL). The data were normal

and no outliers were found. Descriptive data are presented as mean (\pm SD). A two-way ANOVA was employed to test for intensity and sex main effects and interactions holding total work constant (i.e., using the mean of all repetitions in each condition). The statistical power of this mixed model two-way ANOVA for detecting a large effect (i.e., Cohen's $d = 0.80$) is 0.76 for the main sex effect, 1.00 for the main intensity effect, and 0.96 for the sex \times intensity interaction (26). This power analysis was based on tables in which the sample size per group was 20 and the correlation between repeated measurements was 0.80. The equivalent power calculation for detecting a medium size effect (i.e., Cohen's $d = 0.50$) was 0.36 for the main sex effect, 1.00 for the main intensity effect, and 0.58 for the sex \times intensity interaction (26). Because this two-way ANOVA precludes an examination of possible main effects of repetitions or interactions between repetitions and the other factors, a three-way, mixed-model ANOVA also was employed to test for intensity, sex, and repetition (i.e., repeated measurements of the first 30 repetitions in each condition) main effects as well as the associated interactions. This analysis was possible only up to the maximal number of repetitions performed in all three conditions (i.e., the first 30 in each condition). The Bonferroni method was used for *post hoc* tests. The magnitude of selected effects of interest was quantified using either eta squared (η^2) or Pearson r . A partial correlation was used to assess the relationship between the mean RPE during the eccentric exercise bout and the mean pain intensity 12- to 72-h postexercise while controlling for the relative intensity of the eccentric exercise bout (i.e., assignment to 80%, 100%, or 120% MVC-C, coded as a dummy variable) or the maximum voluntary concentric strength of the elbow flexors.

RESULTS

A two-way ANOVA on the average perceived exertion values during the eccentric exercise bouts revealed a significant main effect for intensity ($F = 4.63$; $df = 2,36$; $P = 0.016$; $\eta^2 = 0.204$) and sex ($F = 6.88$; $df = 1,36$; $P = 0.013$; $\eta^2 = 0.16$). The men rated the exercise as more effortful than did the women. *Post hoc* tests showed that perceived exertion values were significantly higher only in the 120% MVC-C condition compared with the 80% MVC-C condition ($P = 0.013$), and no significant sex \times intensity interaction was found ($F = 0.17$; $df = 2,36$; $P > 0.05$; $\eta^2 = 0.009$). The mean perceived exertion data are illustrated in Figure 1.

A three-way ANOVA using the raw repetition-by-repetition perceived exertion ratings showed significant main effects for repetitions ($F = 124.9$; $df = 29,1044$; $P < 0.0001$; $\eta^2 = 0.776$), intensity ($F = 8.77$; $df = 2, 36$; $P = 0.001$; $\eta^2 = 0.328$), and sex ($F = 5.77$; $df = 1,36$; $P = 0.022$; $\eta^2 = 0.138$). All the interaction effects were statistically nonsignificant, including the repetition \times sex interaction ($F = 1.22$; $df = 29,1044$; $P = 0.196$; $\eta^2 = 0.033$). Figure 2 shows the raw RPE data with an emphasis on the comparison among the 80%, 100%, and 120% MVC-C conditions,

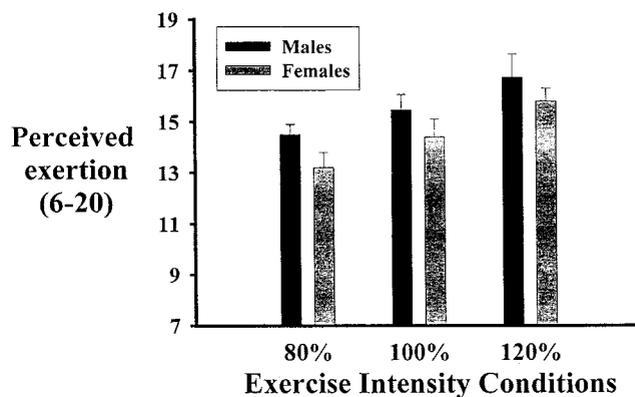


FIGURE 1—Mean (\pm SE) ratings of perceived exertion (6–20) for men and women in response to elbow flexor eccentric exercise at intensities of 80% (45 reps), 100% (36 reps), and 120% (30 reps) of maximal voluntary contraction strength (overall $N = 42$, 7 of each sex per condition).

whereas Figure 3 shows the same data but in a way that highlights the sex differences.

A significant, moderate, positive correlation of $r = 0.42$ was found between the mean ratings of perceived exertion during the eccentric exercise bout and the mean muscle pain intensity ratings obtained from 12 to 72 h after the exercise bout. This relationship is depicted in Figure 4. The partial correlation, although modest in magnitude, remained statistically significant after controlling for the relative exercise intensity ($r_{12,3} = 0.28$, $P = 0.0425$) or after controlling for the maximum voluntary concentric strength of the elbow flexors ($r_{12,3} = 0.33$, $P = 0.018$).

DISCUSSION

For both men and women, RPE increased in association with increased exercise intensity when the perceived exertion values were averaged over all repetitions in an exercise bout. This observation extends to upper body eccentric exercise the findings from prior researchers who examined responses to lower body eccentric exercise (12,20,36). This observation also generally is consistent with prior research

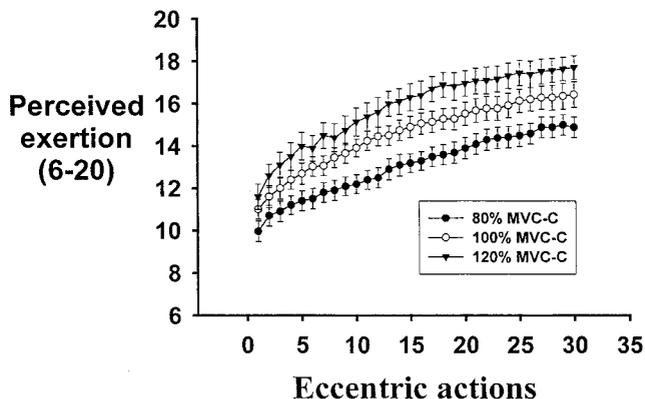


FIGURE 2—Mean (\pm SE) ratings of perceived exertion (6–20) for each of the first 30 repetitions of the 80%, 100%, and 120% intensity conditions ($N = 14$ per condition). Data from men and women have been combined in this figure.

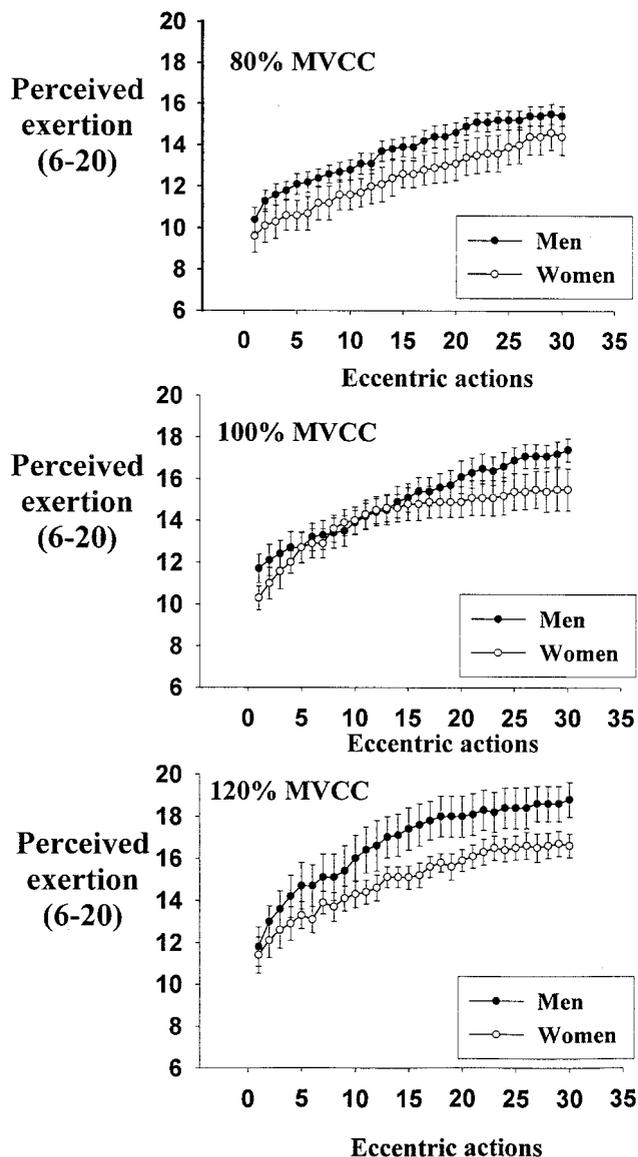


FIGURE 3—Mean (\pm SE) ratings of perceived exertion (6–20) for each of the first 30 repetitions emphasizing the sex differences. Data for the 80%, 100%, and 120% conditions are shown on top, middle, and bottom panels, respectively (both sexes have 7 subjects per data point in each condition).

showing that RPE increases linearly in response to brief, static actions of the quadriceps performed at submaximal intensities ranging from 10% to 90% of MVC (22,23). In addition, this finding is consistent with the observation that overall perceived exertion ratings during typical bouts of resistance exercise (e.g., involving both eccentric and concentric muscle actions, 3 sets of 10 reps of 7 exercises) were higher when the exercises were performed either at an intensity of 70% 1-RM compared with 50% 1-RM (33) or 90% 1-RM compared with 30% 1-RM (8,9). Moreover, the present work shows that women and men have similar perceived exertion responses to increased intensity of eccentric exercise; that is, both sexes report higher perceived exertion when performing an exercise that by objective, physical criteria is more intense. This is similar to what has

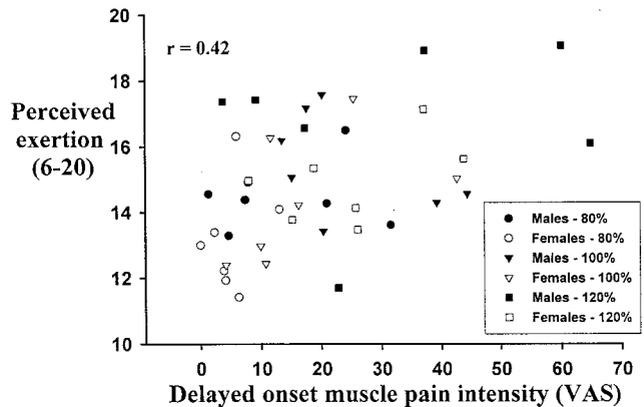


FIGURE 4—A scatterplot showing the relationship between mean perceived exertion ratings during the eccentric exercise bout and mean pain intensity ratings for the elbow flexor muscles obtained from 12- to 72-h postexercise.

been reported for static and dynamic actions of the quadriceps (21,22).

Prior research has not reported perceived exertion ratings for each repeated repetition of eccentric muscle actions (e.g., Figs. 2 and 3). It was found that perceived exertion ratings increased substantially (i.e., 5–6 raw score units) as more repetitions were completed. The pattern and magnitude of increase was similar across the first 30 repetitions for all three exercise intensity conditions. The asymptotic pattern of response showed larger increases in effort occurring during the first ~15 eccentric actions and a plateau occurring during repetitions ~25–30. This finding involving eccentric muscle actions is consistent with prior research showing that ratings of perceived exertion increased during the first half of an exercise bout and then plateaued among individuals running on a treadmill at a constant, submaximal velocity for 30 min (32). The data from this experiment do not shed light on potential neurophysiological mechanism(s) for the observed plateau in RPE. The plateau response is likely due in part to the specific exercise protocol employed, including the relatively long rest period between each repetition (i.e., 25 s) and the fact that exercise intensity was relativized to concentric, rather than eccentric, MVC.

Women rated eccentric exercise performed at intensities of 80%, 100%, and 120% of maximal voluntary concentric strength as being less effortful compared with men who performed the exercise at the same relative intensity. This observation is inconsistent with the finding of no sex difference in RPE responses to resistance exercise that involved brief static (22) or a series of dynamic (21) actions of the quadriceps. Similarly, when physiological reference criteria (e.g., $\dot{V}O_{2peak}$) have been employed to relativize the work rate during dynamic, leg exercise sex differences in RPE have not been observed (29). However, women reported lower perceived exertion during leg cycle ergometry from 60% to 100% of peak power output compared with men (4). Although data from humans are unavailable, indirect evidence suggests that neurobiological mechanisms may be present that could account for perceptual differences when exercise is performed with different body segments.

For example, it has been shown in rodents that analgesic responses to somatosensory stimulation of the hind paws differ substantially compared with the same stimulation presented to the front paws, and that both opioid and non-opioid mechanisms are involved (38). Alternatively, it has been suggested that sex differences in RPE may depend on whether a physiological (e.g., $\dot{V}O_{2peak}$) or a physical (e.g., % peak power output) reference is employed (29). The most parsimonious explanation for the sex differences in RPE observed here is the fact that the absolute work was lower for the women compared with the men. Nevertheless, the design of the present experiment does not allow for a scientifically compelling explanation for the observed sex difference.

Another novel finding of the present investigation was that the mean perceived exertion during the eccentric exercise bout was moderately and positively associated with the mean muscle pain intensity reported from 12- to 72-h post-exercise. The magnitude of the relationship was attenuated after controlling for the strength of the participants and the relative exercise intensity, but it remained a statistically significant relationship. This finding cannot be compared with prior research because we have been unable to find any published studies documenting the magnitude of the relationship between the intensity of an eccentric exercise bout as measured by RPE and the intensity of the subsequent delayed-onset muscle pain. It is well known that objective measures of exercise intensity as well as the prior activity of muscles are two factors that influence the extent of muscle injury and pain after unaccustomed eccentric exercise (3). Other contributing factors are less well established, and may account for only a small amount of the variability, but they are being investigated. For example, Kulig et al. (16) recently reported that delayed-onset muscle pain was greater after a bout of eccentric exercise of the elbow flexors that was performed at a faster velocity than a similar exercise bout that was equated on total work and total time but performed at a slower velocity. Perceived exertion ratings were significantly higher in the high-velocity protocol compared with the low-velocity protocol. A computed correlation between RPE and delayed-onset muscle pain intensity ratings was not reported. Nonetheless, the paper by Kulig et

al. is the only other experiment in which RPE ratings were obtained during a bout of novel eccentric exercise and subsequent ratings of delayed-onset muscle pain were obtained.

Athletes and recreational exercisers alike perform resistance exercise to increase muscle strength and size. The prescription of resistance exercise for healthy individuals depends in part on the goals of the individual, and often a balance is achieved between improvements in muscular strength and endurance. Prescribing intensity for this type of resistance exercise typically involves recommending that a weight be used that can be lifted from 8 to 12 times (1,25). Perceived exertion has been used infrequently in prescribing the intensity of resistance exercise. However, recent guidelines from experts include suggestions for using exertional perceptions in regulating intensity during resistance exercise (25). The practical implications of the present findings are related to the fact that eccentric muscle actions are important in obtaining optimal adaptations that accrue from resistance training (5). Consequently, some body builders, athletes, and recreational exercisers focus on performing only eccentric exercises (often termed “negatives” in lay jargon) during some training cycles. This type of exercise may result in a higher prevalence of weight-lifting injuries, and accurate perceptions of effort may be useful in preventing injuries that result from excessive eccentric exercise protocols. The results of the present study show that variations in eccentric exercise intensity are perceived accurately by both men and women but that men rate eccentric exercise performed at the same relative exercise intensity as being more effortful than women. We predict that as the data base regarding perceptions of effort during resistance exercise increases, more thorough and precise guidelines will be developed including guidelines specific for eccentric exercise protocols.

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