

Neuromuscular activation and RPE in the quadriceps at low and high isometric intensities

D. M. Pincivero¹, S. M. Lephart², N.M. Moyna³, R. G. Karunakara⁴ and R.J. Robertson²

Abstract

Introduction. The purpose of this study was to examine neuromuscular activation and ratings of perceived exertion (RPE) at 10% and 80% quadriceps MVC in healthy males.

Methods. Seventeen college-aged volunteers (mean age = 22.6 years, mean height = 178.9 cm, mean weight = 78.8 kg) were assessed for isometric EMG activity of the vastus medialis (VM) and vastus lateralis (VL) at 10% and 80% MVC, and RPE at 80% MVC. Perceived exertion was measured with a modified category ratio scale (CR-10) and was anchored with 1 high and 1 low anchor. Raw EMG signals were sampled via telemetry (rate = 1,000 Hz) and integrated (3 sec) for each contraction for each muscle (bandpass = 16-500 Hz, CMRR = 130 dB). A one-sample *t*-test was performed for each variable and 95% confidence intervals were calculated.

Results. Means and CI for each variable are as follows: 10% MVC VM IEMG ($t_{16} = 5.05$, $p < 0.001$, .95 CI = 3.11 ± 1.3), 80% MVC VM IEMG ($t_{16} = 22.51$, $p < 0.001$, .95 CI = 73.2 ± 6.89), 10% MVC VL IEMG ($t_{16} = 8.10$, $p < 0.001$, .95 CI = 9.41 ± 2.47), 80% MVC VL IEMG ($t_{16} = 39.56$, $p < 0.001$, .95 CI = 87.32 ± 4.68), and 80% MVC RPE ($t_{16} = 11.85$, $p < 0.001$, .95 CI = 5.24 ± 0.93).

Discussion. The major findings illustrate an apparent underestimation of RPE at 80% MVC for the quadriceps. Neuromuscular activation appears to be lower than the expected force output at both intensities for the VM while VL activation corresponded closely at 10% MVC and was higher at 80% MVC.

Key-words: Electromyography – Torque – Confidence interval – RPE.

Introduction

The ratings of perceived exertion (RPE) scale has been carried out repeatedly to detect and interpret sensations arising from the body during physical exercise (9). The development of the category-ratio scale (CR-10) by Borg (1) was founded on the notion to improve previously developed scales as well as meeting the criteria of a "very simple scale" (9). Although the CR-10 scale has been used clinically and in research settings, the

assumption that this scale closely parallels muscle activation lacks conclusive evidence (3, 5, 8, 10).

The validity of the CR-10 scale was established by Noble et al. (10) who found that an increase in RPE during cycling exercise corresponded to increases in blood and muscle lactate. The application of the CR-10 scale during isokinetic quadriceps contractions was performed by Douris (3), and showed that during exhausting exercise, RPE was not affected by movement velocity. During sub-maximal isometric contractions to fatigue in the elbow flexors, Miller et al. (8) found that RPE was higher in patients with fibromyalgia as compared to controls. The use of the CR-10 scale in these investigations, although well justified, appear to rely on the previously stated assumption regarding

¹ Department of Physical Therapy, Eastern Washington University.

² Department of Health, Physical and Recreation Education, University of Pittsburgh.

³ Nuclear Cardiology, Hartford Hospital.

⁴ St. Mary's Hospital, Department of Medicine.

muscle activation. Hasson et al. (5) demonstrated that an increase in RPE during a sustained 50% isometric MVC of the handgrip muscles to fatigue occurred with a concomitant increase in root mean square (RMS) EMG and a decrease in mean frequency. The results obtained from Hasson et al. (5) has established the need and potential for determining neuromuscular activation at varying levels of contraction. At this point, an important question arises: in a research or clinical setting, can it be estimated and quantified with a degree of certainty or confidence that neuromuscular activation and RPE correspond to force levels? It was therefore, the purpose of this study to examine neuromuscular activation of the quadriceps at low and high contraction intensities (10% and 80% MVC, respectively) and to measure RPE at 80% MVC.

Materials and methods

Subjects

Subjects for this study consisted of 17 healthy, college aged male volunteers (mean age = 22.6 ± 2.85 years, mean height = 178.9 ± 5.3 cm, mean weight = 78.8 ± 9.5 kg). All subjects were physically active but had not actively taken part in a resistance training program for the lower extremity at least 6 months prior to the study. Individuals with a history of cardiovascular disease, hypertension, or orthopedic pathology were excluded from participating in this study. All subjects provided written informed consent as approved by the Biomedical Institutional Review Board at the University of Pittsburgh. All subjects were assessed for isometric EMG of the quadriceps at 10% and 80% of their maximal voluntary contraction (MVC) as well as RPE at 80% MVC.

Measurement of isometric torque

Isometric torque was measured with the Biodex System II Isokinetic Dynamometer (Biodex Medical Inc., Shirley, NY). Subjects were placed in a comfortable, upright seated position on the Biodex Accessory chair and were secured using thigh,

pelvic, and torso straps in order to minimize extraneous body movements. The lateral femoral epicondyle was used as the bony landmark for matching the axis of rotation of the knee joint with the axis of rotation of the dynamometer resistance adapter. Once the subject was placed in a position that allowed for a comfortable and unrestricted motion for knee extension and flexion from a position of 90 degrees of flexion to terminal extension, the following measurements were taken: seat height, seat inclination, dynamometer head height, and resistance pad level. These measures were recorded and stored in the Biodex Advantage Software program, version 4.0, (Biodex Medical Inc., Shirley, NY) in order to standardize the testing position for each individual subject. Gravity correction was obtained by measuring the torque extended on the dynamometer resistance adapter with the knee in a relaxed state at terminal extension. Values for isometric torque were automatically adjusted for gravity by the Biodex Advantage Software program. Calibration of the Biodex dynamometer was performed according to the specifications outlined by the manufacturer's service manual. During measurement of maximal isometric torque, each subject was required to fold their arms across their chest and were given verbal encouragement as well as visual feedback from the Biodex monitor in an attempt to achieve a maximal effort level (4, 7). All procedures, and verbal encouragement were administered by the same investigator for all subjects.

Measurement of perceived exertion

Perceived exertion was measured with a modified category-ratio scale (CR-10) as developed by Borg (1) (Fig. 1). The use of this scale has been previously found to correlate positively with increasing levels of lactate accumulation and has been suggested that qualitative changes in motor unit recruitment may be perceived (10). Although studies have evaluated perceived exertion during strength training exercises with a CR-10 scale, anchoring the perceptual range has not been utilized (3, 5, 8).

In order to provide the subjects in the present study with a context through which sensation

- 0 - **Nothing at all**
- 1 - **Very light**
- 2 - **Light**
- 3 - **Moderate**
- 4 - **Somewhat hard**
- 5 - **Hard**
- 6 -
- 7 - **Very hard**
- 8 -
- 9 -
- 10 - **Extremely hard (Almost max)**
- - **Maximal**

Fig. 1. - Modified category ratio scale (CR-10) for measuring RPE.

intensities can be evaluated, 1 high and 2 low anchors were applied under isometric conditions (9). While seated in the Biodex dynamometer chair, the subjects were asked to sit quietly and to "think about the feelings in their quadriceps and to assign a rating of 0 to those feelings". Subjects were then asked to perform a maximum voluntary isometric contraction (MVC) of their quadriceps with their knee set at an angle of 60 degrees of flexion. This specific knee angle has been demonstrated to generate maximal active quadriceps tension (14, 15). All subjects were provided 2-3 sub-maximal followed by 2 maximal familiarization trials. Subjects were asked to contract their quadriceps as hard as they could and to maintain this contraction for 5 seconds. Prior to the contraction, subjects were asked to "think about the

feelings in their quadriceps at the end of the contraction and to assign a rating of 10 to those feelings". Following a brief period of volitional recovery (1-2 min) subjects were asked to contract isometrically at an intensity equivalent to 10% of their individual MVC for 5 seconds. Subjects were asked to match a horizontal line on the Biodex computer monitor that corresponded to this intensity. Prior to this contraction, subjects were asked to "think about the feelings in their quadriceps at the end of the contraction and to assign a value of 1 to those feelings". Following another brief period of volitional recovery, subjects were then asked to contract isometrically at an intensity equivalent to 80% of their individual MVC for 5 seconds. Prior to the contraction, subjects were asked to "think about the feelings in their quadriceps at the end of the contraction and rate those feelings out of 10". All ratings were performed while the subjects visually observed the CR-10 scale.

Measurement of neuromuscular activation

Neuromuscular activation was measured through the use of surface electromyography for the vastus medialis (VM) and vastus lateralis (VL) muscles. Bi-polar circular surface electrodes (Ag/AgCl) were placed on the appropriate muscles with an inter-electrode distance of 1.5 cm. Prior to electrode placement, the area was shaved, cleaned with isopropyl alcohol and abraded in order to reduce skin impedance. Skin resistance was measured with an Ohm meter, and values below 2 kOhms were accepted. Electrode placement for the vastus medialis was 20% of the distance from the medial joint line from the knee to the anterior superior ilias spine (18). Electrode placement for the vastus lateralis muscle was the midpoint between the head of the greater trochanter and the lateral femoral epicondyle (6). The reference electrode was placed over the medial shaft of the tibia approximately 6-8 cm below the inferior pole of the patella. EMG activity was collected and recorded via telemetry by an 8 channel FM transmitter and differential amplifier (Noraxon Telemyo, Noraxon Inc., Scottsdale, AZ) worn by the subject in a backpack. EMG signals were sampled at a rate of 1,000 Hertz and broadcast to

a FM receiver where they were bandpass filtered (16-500 Hz) and underwent analog to digital conversion by a 16 bit A-D board interfaced to a Pentium microprocessor (Compaq Presario). Following full-wave rectification of the raw signals, EMG activity was integrated (IEMG). The IEMG area ($\mu V \cdot s$) was calculated by the Myosoft Software program (Noraxon Inc., Scottsdale, AZ) during the duration of the sub-maximal isometric quadriceps test. EMG signals collected within the first and last second of each isometric test were not used for analysis because of knee movement that may have occurred at the initiation and completion of the test. Therefore a 3 sec window of IEMG signals were calculated for analysis. Integrated EMG measurements have previously demonstrated high reliability of coefficients for the vastus medialis and vastus lateralis muscles ranging from $r = 0.92$ to $r = 0.94$ and $r = 0.77$ to $r = 0.84$, respectively (12, 16).

Statistical analysis

Isometric IEMG activity for each muscle at 10% and 80% MVC were calculated and expressed as a percentage of the IEMG at 100% MVC. A one-sample t-test was performed on each variable to calculate confidence intervals (95%) in order to estimate the relative range of neuromuscular activation at 10% and 80% MVC and perceived exertion at 80% MVC.

Results

Means, standard deviations, standard errors of the mean and 95% confidence intervals (CI) are presented in Table 1. 95% confidence intervals

demonstrate an underestimation of IEMG for the VM at 10% and 80% MVC and RPE at 80% MVC. The results also appear to demonstrate an overestimation of IEMG activity for the VL at 80% MVC.

Discussion

The present investigation attempted to establish the level of neuromuscular activation and RPE at low and high isometric intensities. Through the application of high and low anchors, subjects were provided with a reference to which sensations can be compared and evaluated (10). The major findings of the current study demonstrate an "underestimation" of RPE (mean = 5.23) at 80% MVC. It also appears evident that at 10% MVC, the VM and VL were activated at levels of 3.11% and 9.4%, respectively, of the IEMG during a 100% MVC. Furthermore, at 80% MVC, neuromuscular activation of the VM was lower than the expected force output (73.23%) while the VL was higher (87.23%).

Sensations arising during muscle contractions have been hypothesized to originate via feedforward and feedback mechanisms. The feedforward mechanism involves the simultaneous transmission of a copy of neural commands from the motor cortex to the somatosensory cortex (corollary discharge) (2). A feedback mechanism has also been proposed where afferent inflow from musculotendinous and articular mechanoreceptors and chemoreceptors transmit information regarding the state of the muscle contraction (2, 11, 13). In regards to RPE measures in the current investigation, it is hypothesized that the feedforward mechanism may be primarily responsible for sensation perception. This notion is formulated on the

Table 1. - One sample t-test and 95% confidence intervals (.95 CI) results for vastus medialis (VM) and vastus lateralis (VL) IEMG at 10% and 80% MVC and rating of perceived exertion (RPE) at 80% MVC

Variable	Mean (%)	SD	SDERR	t_{16}	.95 CI
VM 10% MVC	3.11	2.54	0.62	5.05	1.80-4.41
VM 80% MVC	73.23	13.41	3.25	22.51	66.34-80.13
VL 10% MVC	9.41	4.79	1.16	8.10	6.95-11.88
VL 80% MVC	87.32	9.10	2.21	39.56	82.64-91.99
RPE 80% MVC	5.23	1.82	0.44	11.85	4.30-6.17

fact th
utilized
apprec
ducts.
alterna
feedfor
ent im
charge
outflow

The
low co
activat
VL ac
force.
less th
appro:
than f
7%).

implic
neuro
efficien
and 2
articul
each c
force
relatio
EMG
ultima
the ra
Such
ings. I

Th
clinica
ceived
ing th
ancho
proce
RPE
output
utiliza
cautic
feedfo
ing to

Summ

Th
relati

fact that the short duration of the contraction utilized in this study (5 sec) did not result in an appreciable accumulation of metabolic end products. In comparison, a fatiguing contraction may alternatively result in a "shift" towards a combined feedforward and feedback mechanism where afferent impulses are compared to the corollary discharge and appropriate adjustments to motor outflow are made (2).

The findings from this study also show that at a low contraction intensity (10% MVC), relative VM activation is lower than the force output whereas VL activation is more closely approximated with force. Interestingly, though, VM activation is still less than the force output at 80% MVC by approximately 7% where VL activation is greater than force by the same magnitude (approximately 7%). These results demonstrate two significant implications: 1) at low contraction intensities, neuromuscular activation appears to be more efficient at achieving an expected force output, and 2) at high contraction intensities, the uni-articular VM and VL muscles appear to "balance" each of their relative contributions to achieve the force output. Although both linear and non-linear relationships have been demonstrated between EMG and force during isometric contractions, the ultimate influence on this relation is suggested to be the range and pattern of motor unit discharge (17). Such an explanation to support the present findings, however, may be presumptuous.

The CR-10 scale may be a useful tool in both the clinical and research settings for evaluating perceived exertion. Currently, however, studies applying this scale have done so without an appropriate anchoring procedure (3, 5, 8). Even though this procedure was applied in the current investigation, RPE did not correspond with the relative force output (80% MVC). As a consequence, future utilization of this scale should be done so with caution as well as with an understanding of the feedforward and feedback mechanisms contributing to RPE (2).

Summary

The present investigation demonstrates the relative range in which neuromuscular activation

of the VM and VL muscles occur at low and high exercise intensities, as well as RPE at 80% MVC. The underestimation of RPE illustrates a significant issue regarding the use of this scale during isometric contractions. The relative contribution of feedforward and feedback mechanisms to perceived exertion may be a function of other factors not evaluated in the current study. It is suggested that future investigations attempt to identify RPE responses during prolonged contractions to examine the role of fatigue on these measures. Such an approach may better define the relative roles of the previously stated mechanisms contributing to perceived exertion.

Acknowledgements

This project was partially supported by a grant from the University of Pittsburgh School of Education Research Awards Committee.

References

1. BORG, G. A. V.: Psychophysical bases of perceived exertion. *Med. Sci. Sport. Exerc.*, 14: 377-381, 1982.
2. CAFARELLI, E.: Peripheral contributions to the perception of effort. *Med. Sci. Sport. Exerc.*, 14 (5): 382-389, 1982.
3. DOURIS, P. C.: The effect of isokinetic exercise on the relationship between blood lactate and muscle fatigue. *J. Orthop. Sport. Phys. Ther.*, 17 (1): 31-35, 1993.
4. HALD, R. D. and BOTTJEN, E. J.: Effect of visual feedback on maximal and submaximal isokinetic test measurements of normal quadriceps and hamstrings. *J. Orthop. Sport. Phys. Ther.*, 9 (2): 86-93, 1987.
5. HASSON, S. M., WILLIAMS, J. H. and SIGNORILE, J. F.: Fatigue-induced changes in myoelectric signal characteristics and perceived exertion. *Can. J. Sport. Sci.*, 14 (2): 99-102, 1989.
6. HOUSH, T. J., DE VRIES, H. A., JOHNSON, G. O., HOUSH, D. J., EVANS, S. A., STOUT, J. R., EVETOVICH, T. K. and BRADWAY, R. M.: Electromyographic fatigue thresholds of the superficial muscles of the quadriceps femoris. *Eur. J. Appl. Physiol.*, 76: 131-136, 1995.
7. MCNAIR, P. J., DEPLEDGE, J., BRETTKELLY, M. and STANLEY, S. N.: Verbal encouragement: effects of maximum effort voluntary muscle activation. *Br. J. Sport. Med.*, 30: 243-245, 1996.
8. MILLER, T. A., ALLEN, G. M. and GANDEVIA, S. C.: Muscle force, perceived effort, and voluntary activation of the elbow flexors assessed with sensitive twitch interpolation in fibromyalgia. *J. Rheumatol.*, 23: 1621-1627, 1996.

9. NOBLE, B.J. and ROBERTSON, R.J.: *Perceived Exertion*. Human Kinetics Publishers, Champaign, IL, 471, 1996.
10. NOBLE, B.J., BORG, G.A.V., JACOBS, I., CECI, R. and KAISER, P.: A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. *Med. Sci. Sport. Exerc.*, 15 (6): 523-528, 1983.
11. ROTTO, D.M. and KAUFMAN, M.P.: Effect of metabolic products of muscular contraction on discharge of group III and IV afferents. *J. Appl. Physiol.*, 64 (6): 2306-2313, 1988.
12. SLEIVERT, G.G. and WENGER, H.A.: Reliability of measuring isometric and isokinetic peak torque, rate of torque development, integrated electromyography and tibial nerve conduction velocity. *Arch. Phys. Med. Rehab.*, 75: 1315-1321, 1994.
13. THIMM, F. and BAUM, K.: Response of chemosensitive nerve fibers of group III and IV to metabolic changes in rat muscles. *Pflugers Arch.*, 410: 143-152, 1987.
14. THORSTENSSON, A., GRIMBY, G. and KARLSSON, J.: Force-velocity relations and fiber composition in human knee extensor muscles. *J. Appl. Physiol.*, 40 (1): 12-16, 1976.
15. TIHANYI, J., APOR, P. and FEKETE, G.Y.: Force-velocity-power characteristics and fiber composition in human knee extensor muscles. *Eur. J. Appl. Physiol.*, 48: 331-343, 1982.
16. VIITASALO, J.H.T. and KOMI, P.V.: Signal characteristics of EMG with special reference to reproducibility of measurements. *Acta Physiol. Scand.*, 93: 531-539, 1975.
17. WOODS, J.J. and BIGLAND-RITCHIE, B.: Linear and non-linear surface EMG/force relationships in human muscles: an anatomical/functional argument for the existence of both. *Am. J. Phys. Med.*, 62 (6): 287-299, 1983.
18. ZIPP, P.: Recommendations for the standardization of lead positions in surface electromyography. *Eur. J. Appl. Physiol.*, 50: 41-54, 1982.

Address reprint requests to:
 Danny M. Pincivero, Ph.D., CSCS
 Eastern Washington University
 Department of Physical Therapy
 Mail Stop 4, 526 5th Street
 Cheney, WA 99004-2431
 Tel.: (509) 623 42 77
 Fax: (509) 623 42 21
 E-mail: dpincivero@ewu.edu