Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001249

Greater electromyographic responses do not imply greater motor unit recruitment and 'hypertrophic potential' cannot be inferred

We read with interest the study by Looney et al. (13), investigating the effects of load on electromyography (EMG) amplitude and rating of perceived exertion (RPE) during squats taken to muscular failure. There are numerous interesting takeaways from this study, including the similar RPE outcomes of different loads when sets are taken to failure; however, we demur with the authors' interpretation of the findings.

In the title and the body of the article, the term motor unit (MU) recruitment is used synonymously with EMG amplitude. This is an incorrect assumption, but regrettably a common mistake in sports and exercise science. We find this mistake being made especially when dealing with fatiguing and dynamic conditions, such as those investigated by Looney et al. (13). In fact, Enoka and Duchateau (7) recently described how numerous studies have misinterpreted surface EMG signals by inferring specific MU recruitment. More than two decades previously, De Luca (4) stated, "To its detriment, electromyography is too easy to use and consequently too easy to abuse." Looney et al. (13) state that MU firing rate decreases with fatigue (10, 15) and consequently that the increase in EMG amplitude is caused by increased MU recruitment (19-21) and have applied that same logic to the subsequent interpretation of the findings, as the authors repeatedly state that the greater EMG amplitude observed in the heavier conditions is indicative of greater MU recruitment. Regrettably, the interpretation of EMG is not so straightforward. Moreover, different quadriceps muscles may utilize different neural strategies to maintain force

generation during repeated concentric contractions (6), which makes the findings of Looney et al. (13) particularly difficult to interpret.

Although EMG amplitude is influenced by MU recruitment, MU recruitment cannot be inferred from changes in surface EMG amplitude. The recruitment threshold of high threshold MUs is reduced during sustained, fatiguing contractions (1) and the subsequent recruitment of these MUs assists in the maintenance force production. However, MU cycling may momentarily de-recruit fatigued MUs in order to reduce fatigue (22). This means that, in scenarios that require less force output, such as low-load conditions, there may be lower simultaneous MU recruitment compared to high-load conditions. Ultimately, a comparable complement of the MU population of a particular muscle may be recruited, but not simultaneously as in high-load conditions. This would explain the observation of reduced peak EMG amplitude in low-load training, as reported by Looney et al. (13). These factors, including the reduced recruitment threshold of high threshold MUs, in addition to MU cycling during fatiguing contractions, may also explain other recent work showing differences in peak amplitude measured during surface EMG for high- and low-load conditions (12, 16).

EMG amplitude during fatiguing conditions can be extraordinarily misleading, as EMG measures consist not only of multiple neural components (MU recruitment, rate coding, and possibly MU synchronization), but also of multiple peripheral constituents: muscle fiber propagation velocity and intracellular action potentials (5). Intracellular action potentials are of particular interest during fatiguing conditions, as the ensuing increase in length of intracellular action potentials may augment surface EMG signals, despite a decrease in intracellular action

potential magnitude. These inherent limitations make it impossible to discern MU recruitment from increases in EMG amplitude during fatiguing, dynamic conditions (2, 5, 8, 9). It may be true that greater loads induce greater MU recruitment, but in order to measure this, more advanced methods are needed, such as spike-triggered averaging (3) or initial wavelet analysis followed by principal component classification of major frequency properties and optimization to tune wavelets to these frequencies (11).

In addition to our concerns regarding the confusion of EMG amplitude with MU recruitment, we note that inferring chronic adaptations from acute, mechanistic variables is very difficult. Looney et al. (13) suggest that their findings support the use of heavier loads for hypertrophy. Such a conclusion is unwarranted, as the literature does not currently differentiate between the long-term effects of heavy and light loads on increases in muscular size (18). Data from Mitchell et al. (14) also demonstrated comparable growth of type I and II fibers following 10 weeks of strength training at either low (30%-1RM) or high-loads (80%-1RM). If the differential EMG amplitude between high and low-load training observed by Looney et al. (13) and others (12, 16) is representative of greater recruitment of presumably high threshold MUs, then one would expect a differential hypertrophic response between low and high threshold MUs, which is presently not supported. In fact, from an evidence-based perspective, Schoenfeld et al. (18), in their meta-analysis, showed no difference between studies that have employed lighter or heavier loads to induce hypertrophy. A recent study by the same author confirmed that this was true even in well trained participants (17). Thus, longitudinal trials are clearly needed to elucidate these mechanisms, in addition to comparing individual loading with combined loading schemes.

The findings of Looney et al. (13) provide more data that unequal EMG amplitudes are obtained during fatiguing contractions with low- and high-load conditions and the novel finding that both conditions elicit similar RPE. What these data do not provide, however, is evidence that heavier load contractions recruit more MUs and that this can be inferred to result in greater hypertrophy. We hope that our letter helps put these findings into a clearer perspective.

Andrew D. Vigotsky, BS
Arizona State University
Phoenix, AZ

Chris Beardsley, MSc
Strength and Conditioning Research Limited
London, UK

Bret Contreras, MA
Auckland University of Technology
Auckland, New Zealand

James Steele, PhD
Southampton Solent University
Southampton, UK

Dan Ogborn, PhD
McMaster University
Hamilton, Ontario

Stuart M. Phillips, PhD
McMaster University
Hamilton, Ontario

References

1. Adam A and De Luca CJ. Recruitment order of motor units in human vastus lateralis muscle is maintained during fatiguing contractions. *J Neurophysiol* 90: 2919-2927, 2003.
2. Behm DG, Leonard AM, Young WB, Bonsey WA, and MacKinnon SN. Trunk muscle electromyographic activity with unstable and unilateral exercises. *J Strength Cond Res* 19: 193-201, 2005.
3. Boe SG, Stashuk DW, and Doherty TJ. Motor unit number estimation by decomposition-enhanced spike-triggered averaging: control data, test-retest reliability, and contractile level effects. *Muscle Nerve* 29: 693-699, 2004.

4. De Luca CJ. The use of surface electromyography in biomechanics. *J Appl Biomech* 13: 135-163, 1997.
5. Dimitrova NA and Dimitrov GV. Interpretation of EMG changes with fatigue: facts, pitfalls, and fallacies. *J Electromyogr Kinesiol* 13: 13-36, 2003.
6. Ebersole KT, O'Connor KM, and Wier AP. Mechanomyographic and electromyographic responses to repeated concentric muscle actions of the quadriceps femoris. *J Electromyogr Kinesiol* 16: 149-157, 2006.
7. Enoka RM and Duchateau J. Inappropriate interpretation of surface EMG signals and muscle fiber characteristics impedes progress on understanding the control of neuromuscular function. *J Appl Physiol (1985)*: jap 00280 02015, 2015.
8. Ertas M, Stalberg E, and Falck B. Can the size principle be detected in conventional EMG recordings? *Muscle Nerve* 18: 435-439, 1995.
9. Freund HJ. Motor unit and muscle activity in voluntary motor control. *Physiol Rev* 63: 387-436, 1983.
10. Harwood B, Choi I, and Rice CL. Reduced motor unit discharge rates of maximal velocity dynamic contractions in response to a submaximal dynamic fatigue protocol. *J Appl Physiol (1985)* 113: 1821-1830, 2012.
11. Hodson-Tole EF and Wakeling JM. Variations in motor unit recruitment patterns occur within and between muscles in the running rat (Rattus norvegicus). *J Exp Biol* 210: 2333-2345, 2007.
12. Jenkins ND, Housh TJ, Bergstrom HC, Cochrane KC, Hill EC, Smith CM, Johnson GO, Schmidt RJ, and Cramer JT. Muscle activation during three sets to failure at 80 vs. 30 % 1RM resistance exercise. *Eur J Appl Physiol*, 2015.
13. Looney DP, Kraemer WJ, Joseph MF, Comstock BA, Denegar CR, Flanagan SD, Newton RU, Szivak TK, DuPont WH, Hooper DR, Hakkinen K, and Maresh CM. Electromyographical and Perceptual Responses to Different Resistance Intensities in a Squat Protocol: Does Performing Sets to Failure With Light Loads Recruit More Motor Units? *J Strength Cond Res*, 2015.
14. Mitchell CJ, Churchward-Venne TA, West DW, Burd NA, Breen L, Baker SK, and Phillips SM. Resistance exercise load does not determine training-mediated hypertrophic gains in young men. *J Appl Physiol (1985)* 113: 71-77, 2012.
15. Mottram CJ, Jakobi JM, Semmler JG, and Enoka RM. Motor-unit activity differs with load type during a fatiguing contraction. *J Neurophysiol* 93: 1381-1392, 2005.
16. Schoenfeld BJ, Contreras B, Willardson JM, Fontana F, and Tiryaki-Sonmez G. Muscle activation during low- versus high-load resistance training in well-trained men. *Eur J Appl Physiol* 114: 2491-2497, 2014.
17. Schoenfeld BJ, Peterson MD, Ogborn D, Contreras B, and Sonmez GT. Effects of Low-Versus High-Load Resistance Training on Muscle Strength and Hypertrophy in Well-Trained Men. *J Strength Cond Res*, 2015.
18. Schoenfeld BJ, Wilson JM, Lowery RP, and Krieger JW. Muscular adaptations in low-versus high-load resistance training: A meta-analysis. *European journal of sport science*: 1-10, 2014.
19. Smilios I, Hakkinen K, and Tokmakidis SP. Power output and electromyographic activity during and after a moderate load muscular endurance session. *J Strength Cond Res* 24: 2122-2131, 2010.

20. Stock MS, Beck TW, and Defreitas JM. Effects of fatigue on motor unit firing rate versus recruitment threshold relationships. *Muscle Nerve* 45: 100-109, 2012.
21. Toigo M and Boutellier U. New fundamental resistance exercise determinants of molecular and cellular muscle adaptations. *Eur J Appl Physiol* 97: 643-663, 2006.
22. Westad C, Westgaard RH, and De Luca CJ. Motor unit recruitment and derecruitment induced by brief increase in contraction amplitude of the human trapezius muscle. *J Physiol* 552: 645-656, 2003.