Sports Medicine and Rehabilitation Journal

Review Article
Published: 08 Dec, 2017

Does Central Control Mechanism is same for Eccentric and Concentric Muscle Contractions?

Wan X Yao[1], William M Land[1], Xing Lu[2], Xiaojing Liu[2], Zhiguo Pan[3] and Guang H Yue[4]*

[1]Department of Kinesiology, University of Texas at San Antonio, USA

[2]Department of Kinesiology, Beijing Sports University, China

[3]Department of Kinesiology, Yuncheng University, China

[4]Department of Kinesiology, Human Performance and Engineering Laboratory, USA

Abstract

Comparing to the research in determining the mechanical and peripheral neural characteristics of two types of muscle contractions (i.e., eccentric (EC) and concentric muscle contractions (CC)) which has been ongoing for over 60 years, the study of central neural control underlying voluntary EC and CC has just started a decade ago. Although the research in determining central neural control is relatively new, some interesting findings are, however, noteworthy to be highlighted. The purpose of this review was to provide a comprehensive account of the studies in central neural control underlying EC and CC. Previous studies report greater activation within the cortical motor network for controlling eccentric contractions (EC) compared to concentric contractions (CC), despite lower muscle activation levels associated with EC vs. CC in healthy, young individuals. When aging factor was considered, research finds that the EC resulted in significantly stronger activation in the motor control network than CC in the young and elderly groups. However, the biased stronger activation towards EC was significantly greater in the elderly compared to the younger group especially in the secondary and association cortices such as supplementary and premotor motor areas and anterior cingulate cortex. However, when functional connectivity (FC) was examined, research finds that CC has much stronger FC than EC. The findings of the studies with examining central neural control during EC and CC are useful for potentially guiding the development of targeted therapies to counteract age-related movement deficits and to prevent injury.

Keywords: Brain activation; Concentric contraction; Eccentric contraction; EEG; FMRI

Introduction

Our daily movements consist of shortening (concentric) and lengthening (eccentric) muscle contractions with the mechanical and peripheral neurophysiological characteristics associated with the eccentric (EC) and concentric contractions (CC) having been well documented [1]. In general, it has been found that the two types of muscle activities are different in many ways, although they are accomplished by the same muscles. For example, after a period (30 min) of repetitive eccentric and concentric contractions at 50% maximal intensity, only those who performed eccentric exercise showed a significant reduction in mechanical stiffness and an increase in magnetic resonance imaging (MRI) T_2 relaxation time of the working muscle [2]. In addition, previous studies [3,4] suggest that EC and CC may follow different motor-unit recruitment orders during non-fatigue muscle contractions [5,6]. Furthermore, compared to CC, EC had a smaller magnitude of electromyographic (EMG) signal against a given resistance, as well as depressed corticospinal neuron [7,8] and monosynaptic reflex [7,9] excitability. Attributed the lower level of EMG for EC to fewer motor units being recruited and a lower discharge rate of the active motor units. The studies by Duclay et al. [10,11] further postulate that the differences in EMG activities between the two types of contractions are a result of differential modulations of moto neuron excitability at supraspinal and/or spinal levels, and the fact that the modulation of the spinal moto neuron excitability by the supraspinal centers can be contraction-type specific [12].

While the study of the mechanical and peripheral neural characteristics of muscle contractions has been ongoing for over 60 years, the examination of central neural control underlying voluntary EC and CC has only recently been undertaken. Although the research in determining central neural control is relatively new, some interesting findings are, however, noteworthy to be highlighted. Thus,

OPEN ACCESS

Correspondence:
Wan X Yao, Department of Kinesiology, The University of Texas at San Antonio, Health, & Nutrition College of Education & Human Development, San Antonio, TX 78249, USA, Tel: 210- 458-5642; E-mail: wanxiang.yao@utsa.edu

Received Date: *24 Oct 2017*
Accepted Date: *30 Nov 2017*
Published Date: *08 Dec 2017*

Citation:
Yao WX, Land WM, Lu X, Liu X, Pan Z, Yue GH. Does Central Control Mechanism is same for Eccentric and Concentric Muscle Contractions?. Sports Med Rehabil J. 2017; 2(3): 1025.

the purpose of this review is to provide a comprehensive account of the studies in central neural control underlying EC and CC.

Characteristics of Central Neural Control of EC and CC

Magnitude of movement-related cortical potential derived from EEG recordings is greater for EC than CC

The first attempt at examining the central neural control of EC and CC was made by Fang et al. [13]. They first conducted a study to monitor electroencephalography (EEG) signals at submaxial intensity levels of the elbow flexor muscle [13]. Interestingly, they observed that although the activity of the elbow flexor muscle (EMG) were lower during EC than CC, the magnitude of movement-related cortical potential (MRCP) derived from the EEG recordings was significantly greater for EC than CC. To determine if similar patterns of brain activations underlie the MRCP during the EC and CC, Fang et al. [14] conducted a similar study but at the maximal intensity level of the elbow flexor muscle activities. Once again, they found that although the magnitudes of EMG were lower during EC than CC, the magnitudes of MRCP derived from the EEG recordings was significantly greater for EC than CC. In addition, they also found that the onset of the MRCP for the EC (2,040 ms before the trigger) was much earlier than the CC (1,760 ms before the trigger). The earlier onset for the EC was assumed to give the EC earlier preparation [14].

At first glance, the findings that the magnitudes of MRCP are greater while the EMG measures were lower for the EC compared to the CC seem to be contradictory to previous studies. For example, studies with monkey [15] and human subjects [16] found a positive relationship between MRCP and muscle output. Furthermore Siemionow et al. [17], demonstrated a linear relationship between MRCP recorded from scalp locations overlying the sensorimotor and supplementary motor areas elbow flexor muscle EMG, which tentatively indicates that the MRCP is a measure of the signal of the motor cortical output neurons that scales muscle output. However, as Fang et al. [13] argued, this indication may not be true since the MRCP onset time was >400 ms before the onset of EMG activity for both the EC and CC. Thus, the MRCP signals may also reflect planning and preparation for actions. Therefore, a greater magnitude of MRCP is not necessarily associated with a greater magnitude of EMG activity.

Consequently Fang et al. [13,14], hypothesized that the greater cortical signal (MRCP) and the earlier onset of MRCP for EC might be due to greater effort in planning and programming the lengthening contractions that are more difficult to perform, prone to muscle tissue damage, and may possibly be involved with a different control strategy such as a reversed motor unit recruitment order.

Central neural controls underlying EC and CC for elderly subjects are similar to young subjects, but brain activities are stronger for elderly compared to younger subjects

Literature has consistently demonstrated that elderly individuals exhibit poorer movement stability or force steadiness during EC than CC [18,19]. Although movement stability during EC is also poorer than CC in young individuals, the magnitude of deficit is significantly larger in older than younger age groups [18,19], indicating force/movement control ability for EC is more affected in older adults and this poses greater risks for injury during EC activities. Fang et al. [13,14] reported greater activation in the cortical motor network in controlling EC compared to CC despite lower muscle activation level associated with EC *vs.* CC in young healthy individuals. It is unknown, however, whether elderly individuals who exhibit increased difficulties in performing EC than CC possess this unique central neural control mechanism for EC movements. To address this question, Yao et al. [20] examined functional MRI (fMRI) data acquired from the first dorsal interosseous (FDI) muscle during EC and CC in young (20-32 years) and older (67-73 years) individuals.

Yao et al. [20] found that the activation level (activation volume measured by fMRI) was higher during EC than CC in all cortical regions and cerebellum in both young and older groups, indicating that EC requires greater cortical resources to accomplish the movement. The general finding of greater cortical activation during EC than CC is consistent with Fang et al.'s [13,14] EEG studies. Furthermore, Kwon and Park [21] found similar results in their fMIR study examining brain signals during the two types of muscle activities. Although Yao et al.'s [20] fMRI findings are similar to the fMRI results of Kwon and Park [21], there is a substantial contradiction regarding activation in the primary motor cortex (M1). While Yao et al. [20] observed a larger activation volume in M1, as in all other cortical areas, during EC than CC in both young and old groups, Kwon and Park [21] found that CC was associated with greater M1 activities compared to EC in young individuals.

Kwon and Park [21] argued that because M1 was traditionally considered to be responsible for movement execution rather than for planning/programming, it was reasonable to see more M1 activity during CC than EC as CC is involved with a higher level of EMG or greater motor unit activities [13,14]. However, recent studies [22,23] report that M1 is not only involved in executing a movement via its direct pathway to the motor neuron pool in the spinal cord, but also plays an important role in planning the movement. Possible explanations for the different observations regarding M1 activation during EC and CC between the two studies may be attributed to the different muscles employed for the movements (FDI in Yao et al.'s study [20] and wrist extensors in Kwon and Park [21]), as well as the load applied to the contractions (Yao et al. [20] applied 30% maximal load while Kwon and Park did not apply an external load). In addition, stronger brain activities found in M1 during EC in Yao et al.'s study [20] could be due to M1's engagement in planning the EC movements to deal with its higher degree of movement difficulty.

A major interest of Yao et al.'s study [20] was to determine if older individuals applied similar central neural control strategies as young individuals in dealing with EC and CC activities. They [20] found that although both young and old groups exhibited greater cortical activation during EC than CC, this biased brain activation towards EC was more prominent in the older than the younger group, especially in the secondary and cortices. For example, the older group showed a significantly higher EC-to-CC ratio in the supplementary motor area (SMA), premotor cortex (PMC), and anterior cingulate cortex (ACC) compared to the younger group. The role of these higher-order cortical fields in motor control is well described in a standard neuroscience textbook (Part VI/Movement, [24]). Among these higher-order control centers, the SMA and ACC demonstrated a significantly higher activation level within older rather than younger adults during EC vs. CC, indicating that the two areas play an exceptionally important role in modulating EC movement in later life. It is well known that the SMA is a secondary motor area and is involved in controlling complex and coordinated motor acts [25]. Given the complex nature of the EC (compared to CC) and its increased level of difficulty (poorer EC movement stability) in late adulthood, it is not surprising to see augmented activity in the SMA during EC in older adults. It has been known that the cingulate association cortex is a part of the limbic system that controls emotion, motivation, and other cognitive functions. Within the cingulate cortex, however, there exist distinct motor areas within the ACC adjacent to the SMA with connections to the M1 and parietal association cortex, and they (SMA and ACC) are considered as an integrated motor control center (termed as medial premotor area) and shared similar functions in motor control [25]. Thus, Yao et al. [20] postulated that the SMA and ACC play a special role in modulating EC performance during aging, perhaps by compensating for age-related degenerative adaptations in the motor control network that might have specially deteriorated he network's ability to control more complex EC movements.

Unlike the secondary and association motor cortices that showed a higher EC- to- CC activation ratio in late adulthood, the primary motor and sensory cortices (M1, S1), however, exhibited a significantly higher such ratio in younger individuals. Yao et al. [20] suggested that older individuals might need to rely more on the secondary and association cortices to deal with more complex EC movements, while the young adults were apt to use the primary motor and sensory areas to handle the more difficult EC. However, the validity of this age- specific brain site for motor planning needs to be further tested by future studies.

Besides the major findings in the contralateral side, Yao et al. [20] also found that ipsilateral (right) hemisphere activation was observed only during EC in M1, S1 and IPL in the elderly group. In addition, only the elderly group had activation in both the left and right putamen in the basal ganglia during both CC and EC. This was the first time these observations have been reported. Yao et al. [20] assumed that these regions played a role in compensating for the worsened ability in the aging control network to manipulate EC movements as these ipsilateral activities were not seen in the younger group. Many studies have reported increased activation in the ipsilateral motor cortex and other regions, and reduced activation laterality during motor performance in healthy aging [26]. Regarding the observation of bilateral activation in putamen during both CC and EC in the older group, Yao et al. [20] suggested that it might be a reflection of heavier use of the basal ganglia-cerebellum-cerebral cortex motor control loop during voluntary motor action by the older adults.

Functional connectivity between M1 and other regions is stronger for CC than EC

In a separate but related study, Yao et al. [27] examined functional connectivity (FC) within the cortical motor control network based on functional magnetic resonance imaging (fMRI) data collected during CC and EC muscle contractions. An interesting finding of Yao et al.'s study [27] is that CC is associated with significantly stronger FC than EC although the patterns of FC map for CC and EC are similar. This finding seems to be contradictory to previous observations [13,14,20,21] that have shown significantly greater activities in motor control related cortical areas during EC than CC. However, as Yao et al. [27] argued, FC and magnitude of cortical activation are two types of measurements and not directly comparable. While the magnitude of cortical activation measures the number and/or intensity of activated cortical areas, the FC is aimed at examining the strength of the relationship between the activated cortical areas with a seed region (left M1 in Yao et al.'s [27] study). Yao et al. [27] further stated that rather than being contradictory to each other, the findings from their study (stronger FC for CC than EC), and from previous studies, higher cortical activation volume and amplitude for EC than CC might be best explained by the fact that stronger brain activation for EC is necessary to compensate for weaker functional connectivity among areas in the motor control network. In other words, the brain control of a CC is more efficient than an EC which may be the result of learning and/or adaptation given that people use more CC than EC, and they pay more attention when performing CC during their daily life. Thus, individuals have better control of CC than EC. However, further study is needed to illuminate whether FC plays a role in determining performance efficiency.

Conclusions

While the literature examining the mechanical and peripheral characteristics of neural control during EC and CC shows greater EMG activities during EC than CC, recent studies on the central neural control underlying the two types of muscle contractions constantly demonstrate that EC is associated with stronger brain activities relative to CC. The greater brain activities associated with EC are interpreted as a strategy to deal with the higher degree of difficulty and/or risk of injury during EC tasks. When comparing the central neural control of EC and CC, younger and older individuals have both been shown to generate greater neural activity during EC compared to CC activities. However, clear age related differences have been observed with respect to all secondary and association cortices engaged in the two types of muscle contractions, with older individuals exhibiting higher EC activation compared to CC, especially in the supplementary motor area and anterior cingulate cortex. Greater activation in higher-order cortical fields for controlling EC movement in late life may reflect activities in these regions to compensate for impaired ability (perhaps in the primary sensorimotor cortices) to control complex EC movements. In addition, research shows that the CC is associated with significantly stronger FC than EC. This finding may indicate that CC tasks are more highly learned, and thus more efficient than EC.

References

1. Duchateau J, Enoka RM. Neural control of shortening and lengthening contractions: influence of task constraints. J Physiol. 2008;586(24):5853-64.

2. Sesto ME, Chourasia AO, Block WF, Radwin RG. Mechanical and magnetic resonance imaging changes following eccentric or concentric exertions. Clin Biomech (Bristol, Avon). 2008;23(7):961-8.

3. Howell JN, Fuglevand AJ, Walsh ML, Bigland-Richie B. Motor unit activity during isometric and concentric-eccentric contractions of the human first dorsal interosseus muscle. J Neurophysilogy. 1995;74(2):901-4.

4. Nardone A, Romano C, Schieppati M. Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. J Physiol. 1988;409:451-71.

5. Bawa P, Jones KE. Do lengthening contractions represent a case of reversal in recruitment order? Prog Brain Res. 1999;123:215-20.

6. Kossev A, Christova P. Discharge pattern of human motor units during dynamic concentric and eccentric contractions. Electroencephalogr Clin Neurophysiol. 1998;109(3):245-55.

7. Abbruzzese G, Morena M, Spadavecchia L, Schieppati M. Response of arm flexor muscles to magnetic and electrical brain stimulation during shortening and lengthening tasks in man. J Physiol. 1994;481(2):499-507.

8. Sekiguchi H, Kimura T, Yamanaka K, Nakazawa K. Lower excitability

of the corticospinal tract to transcranial magnetic stimulation during lengthening contractions in human elbow flexors. Neurosci Lett. 2001;312(2):83-6.

9. Moritani T, Muramatsu S, Muro M. Activity of motor units during concentric and eccentric contractions. Am J Phys Med. 1987;66(6):338-50.

10. Duclay J, Pasquet B, Martin A, Duchateau J. Specific modulation of corticospinal and spinal excitabilities during maximal voluntary isometric, shortening and lengthening contractions in synergist muscles. J Physiol. 2011;589(11):2901-16.

11. Duclay J, Martin A. Evoked H-reflex and V-wave responses during maximal isometric, concentric, and eccentric muscle contraction. J Neurophysiol. 2005;94(5):3555-62.

12. Duclay J, Robbe A, Pousson M, Martin A. Effect of angular velocity on soleus and medial gastrocnemius H-reflex during maximal concentric and eccentric muscle contraction. J Electromyogr Kinesiol. 2009;19(5):948-56.

13. Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GH. Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. J Neurophysiol. 2001;86(4):1764-72.

14. Fang Y, Siemionow V, Sahgal V, Xiong F, Yue GH. Distinct brain activation patterns for human maximal voluntary eccentric and concentric muscle actions. Brain Res. 2004;1023(2):200-12.

15. Cheney PD, Fetz EE. Functional classes of primate corticomotoneuronal cells and their relation to active force. J Neurophysiol. 1980;44(4):773-91.

16. Becker W, Kristeva R. Cerebral potentials prior to various force deployments. Prog Brain Res. 1980;54:189-94.

17. Siemionow V, Yue GH, Ranganathan VK, Liu JZ, Sahgal V. Relationship between motor activity-related cortical potential and voluntary muscle activation. Exp Brain Res. 2000;133(3):303-11.

18. Laidlaw DH, Hunter SK, Enoka RM. Nonuniform activation of the agonist muscle does not covary with index finger acceleration in old adults. J Appl Physiol (1985). 2002;93(4):1400-10.

19. Laidlaw DH, Kornatz KW, Keen DA, Suzuki S, Enoka RM. Strength training improves the steadiness of slow lengthening contractions performed by old adults. J Appl Physiol (1985). 1999;87(5):1786-95.

20. Yao WX, Li JQ, Jiang Z, Franlin CG, Lancaster JL, Yue GH. Aging interferes central control mechanism for eccentric muscle contraction. Front Aging Neurosci. 2014;6:86.

21. Kwon YH, Park JW. Different cortical activation patterns during voluntary eccentric and concentric muscle contractions: an fMRI study. Neuro Rehabilitation. 2011;29(3):253-9.

22. Lemon RN. Descending pathways in motor control. Annu Rev Neurosci. 2008;31:195-218.

23. Kalaska JF. From intention to action: motor cortex and the control of reaching movements. Adv Exp Med Biol. 2009;629:139-78.

24. Kandel ER, Schwartz JH, Jessell TM, Siegelbaum SA, Hudspeth AJ. Principles of Neural Science. 5th edn. Ohio: The McGraw-Hill Companies, Inc; 2013.

25. Rizzolatti G, Strick PL. Cognitive function of the premotor systems. 5th edn. Ohio: The McGraw-Hill Companies, Inc; 2013.

26. Naccarato M, Calautti C, Jones PS, Day DJ, Carpenter TA, Baron JC. Does healthy aging affect the hemispheric activation balance during paced index-to-thumb opposition task? An fMRI study. Neuroimage. 2006;32(3):1250-6.

27. Yao WX, Jiang Z, Li J, Huang Y, Jiang C, Lancaster JL, et al. Brain functional connectivity is different during voluntary concentric and eccentric muscle contractions. Front Physiol. 2016;7:521.