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Research Article

Brain Activation During Maximum Concentric and Eccentric Knee Extension Muscle Contractions

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ABSTRACT

Purpose: In spite of mounting evidence indicating that concentric and eccentric knee extensor muscle contractions might have special nervous system control strategies, the differentiation of brain frequencies between concentric and eccentric movements and how the motor cortex programs this contraction has been less studied. In this study, the brain and muscle activation differences during maximum concentric and eccentric contractions were compared.
Methods: Nine healthy volunteers performed 20 maximum eccentric and 20 maximum concentric knee extensor contractions. Electroencephalography (EEG) signals from sensorimotor-related cortical areas were recorded simultaneous with the electromyography (EMG) of the knee extensor muscles. In the spectral analysis the performance related power values were calculated for Theta (4-7 Hz) and Alpha (7-12 Hz).
Results: The time-domain results revealed, longer time and greater cortical activity is required for the preparation of an eccentric contraction. For the eccentric task, the cortical activity was greater, but the EMG was lower in comparison to the concentric task values. Statistical analysis showed significant higher and lower Theta and Alpha power in both types of contractions compared to the resting state, respectively.
Conclusion: These findings suggest that increased Theta power is associated with task complexity and focused attention and decreased Alpha power values with increased information processing in the somatosensory cortex.

Introduction

Our daily movements are classified into a great extent of concentric and eccentric contractions. During the last decade, various studies have indicated that mechanical and neurophysiological characteristics of eccentric contractions (EC) are different from concentric contractions (CC) [1-3]. A fundamental question raised is how the brain functions during high intensity concentric and eccentric contractions. Several brain measure tools have been used to determine the relationship between cortical activity and contraction types [4-6]. In the first attempt to outline potential differential central control mechanisms between EC and CC, Fang *et al*. (2001) monitored EEG signals at submaximal intensity levels of the elbow flexor muscle. Their results indicated that the EC produced less muscle activation (measured by EMG), while the EEG recordings indicated a significantly greater magnitude of brain activation for EC than CC. Subsequently, they implemented the last study at the maximal intensity level of the elbow flexor muscle activities [5]. Confirming

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previous findings, the EMG activity was lower during eccentric muscle actions, but the level of movement-related cortical potential (MRCP) calculated from EEG signals was notably higher for eccentric compared to concentric tasks. Additionally, they found that the EEG onset, which is related to the mental preparation as subject begins the muscle movement, occurred significantly earlier for EC.

To our knowledge, it has not been explored whether different frequency bands of the brain respond similarly to the muscle contractions or not. The brain oscillations in the motor network are in associate with specific perceptual, sensorimotor or cognitive processes [7]. In more detail different authors had described the Theta (4-7 Hz) power as an indicator of attention and it is thought to reflect executive functions, as well as movement selection and initiation [8]. The Alpha (7-12 Hz) spectral power is probably the most studied frequency component in EEG research. Moreover, it has been related to a number of states and functions such as anticipatory attention, inhibitory control, and sensory processing [9-11]. Understanding how these cortical oscillations activated during eccentric muscle actions may be critical for a better cortical control as well as for improvements in both performance and rehabilitation. The number of studies investigating the neural strategy between CC and EC is consistently growing, but there has been lack of research on the lower extremities. Also, it was speculated that differences between concentric and eccentric contractions occur when the exerted forces are high. In this context the purpose of this study is to investigate the temporal and spectral features of EEG signals during eccentric and concentric contractions of knee extensor muscles against maximum load and velocity.

Methods

I Participants

Nine male participants took part in one experimental session (age mean [SD] = 25 [3.2] years old, weight = 72.2 [7.3] kg, height = 174.5 [8.6] cm and all right-footed). All participants were free from abnormality and none had suffered from neuromuscular or musculoskeletal injury.

II Instrumentation

EMG and EEG signals were collected using a 24-channel eWave amplifier (ScienceBeam, LTD, Iran). 24 bit data were recorded with 1k Hz sampling rate. The Biodex System Isokinetic Dynamometer (System_4, Biodex Medical Systems Inc., USA) was used for isometric, concentric, and eccentric measurements.

III Experimental Design

EEG electrodes were attached based on 10-20 International electrode placement system at 14-sites: F3, F4, Fp1, Fp2, C3, C4, P3, P4, T3, T4, T5, T6, O1 and O2 [12]. For the reference electrode we used the right mastoid process. EMG data was recorded from the right vastus lateralis (VL), and the right vastus medialis (VM) muscles. Bipolar circular 8 mm diameter silver/silver chloride electrodes were attached to the skin overlying the belly of each muscle based on SENIAM recommendations [13]. Before performing the knee motions, subjects were instructed to sit on the dynamometer chair, with the hip angle of 85° [14]. The lever arm of the dynamometer was firmly attached to the shank at around 5 cm on top of the lateral malleolus. Velcro straps placed firmly across the hip and trunk to minimize unnecessary movements during the knee contractions. Before starting the measurements, the resting-state EEG and EMG data were recorded for 1 minute during which they sat quietly with no movement. Then, EMG and torque values were obtained while the participants performed maximal voluntary isometric contractions (100% MVC) three times for 5 seconds each at 60˚ of knee angle.

The main experiment consisted of 20 trials for concentric or eccentric contractions. A familiarization phase was held, and the participants performed three eccentric and concentric movements at velocities of 90, 180 and 240°/s. After a 5-minute rest, the experiment began with randomized order of contractions. In CC, participants contracted their dominant leg, including four sets of 5 maximum repetitions (with a 2-minute rest interval between sets) of knee extensors, at 240°/s angular velocity, over the whole knee range of motion (100° to 0°). In EC, four sets of 5 maximum eccentric contractions (with a 2-minute rest interval between sets) was performed for each subject on the same leg that maximally resisted the downward movement of the lever arm through the full range of motion (0° to 100°) at the same angular velocity (240°/s) [14]. Participants had a mandatory 5-minute rest between the two conditions. All participants were instructed to keep their bodies relax and avoid eye blinks and facial muscle contractions during knee contractions to minimize artifacts.

IV Data Analysis

The EMG data was band-pass filtered in the range of 10-400 Hz and notch filtered at 50 Hz to reduce main noise. Afterwards the root mean square (RMS) values with a moving window of 50 ms were calculated. For EMG onset analysis, we used a method previously published [15]. In this algorithm, the muscle activity onset is identified at the instant when the signal amplitude exceeds the baseline activity level by two standard deviations and last for more than 50 ms. Among all EEG electrodes, C3, C4, F3 and F4 were selected to analyze because these are the main locations of the brain to record Movement-Related Cortical Potential (MRCP) [16]. The recorded data were taken to MATLAB R2017a (MathWorks, USA) and processed as follows. The EEG signal was filtered using a band-passed filter (0.1-40 Hz) for DC and high-frequency noise removal [17].

V EEG Temporal Analysis

The Movement-Related Cortical Potential (MRCP) is used to predict upcoming movements and indicating the preparation and planning of the motor cortex. The MRCP is the pre-movement activity of the motor cortex that is preceded by a negative wave in the EEG records and beginning about 500 ms before voluntary movement production [18]. For detecting movements, we segmented the EEG data into epochs of 1.5-second before and after the EMG onset (-1000 to 500 milliseconds). The MRCP occurs at frequencies of around 0-5 Hz [19]. The amplitude of MRCP was defined as the maximum suppression of the signal in each trial. To detect the MRCP onset we marked the moment at which the signal crossed the baseline level (the averaged EEG signal during resting-state) [20].

VI EEG Spectral Analysis

In spectral analysis, fast Fourier transforms (FFT) were calculated for all epochs to analyze spectral power (μV^2). The average power of C3, C4, F3 and F4 channels were computed for each frequency band: Theta (4-7 Hz) and Alpha (7-12 Hz) across all trials of eccentric and concentric contractions for each subject [21]. Statistical comparisons were performed in SPSS r22 software (IBM, USA). To confirm the normal distribution, Kolmogorov–Smirnov test was applied. Paired t-test were run to compare the results of the torque and EMG between concentric and eccentric muscle actions. We carried out a 4 × 2 repeated measures ANOVA on MRCP amplitude and onset time with factors "EEG electrodes" (C4, C3, F4 and F3) and "type of contraction" (CC vs EC) as within participant factors. Also, two 4 × 3 repeated measures ANOVA were run to determine whether the mean and standard deviation of power in the Theta and Alpha frequencies varied between the resting-state, concentric and eccentric muscle contractions. The significance level was defined as $p < 0.05$.

Results

The torque percent (peak torque/body weight) for eccentric contraction (mean [SD] = 128.67 [1.42]) was significantly higher than concentric contraction (72.78 [1.26]) (t (17) = 14.76, p<.001). The EMG values (percent of MVC) of VL and VM muscles during eccentric contraction (VL = 71.99 [8.62], VM = 81.15 [8.36]) were significantly lower than the EMG of these muscles during concentric contraction (VL = 116.76 [16.14], VM = 127.96 [15.2]) (VL: t (9) = 16.73, p<.001, VM: t (9) = 20.98, p<.001). The MRCP amplitudes were higher, but not significantly different during EC compared to CC. Furthermore, the MRCP onset time were occurred significantly earlier for eccentric than concentric contractions (Figure 1). Means and standard deviations (SD) of MRCP parameters (amplitude and onset time) of each channel during concentric and eccentric contractions are summarized in (Table 1).

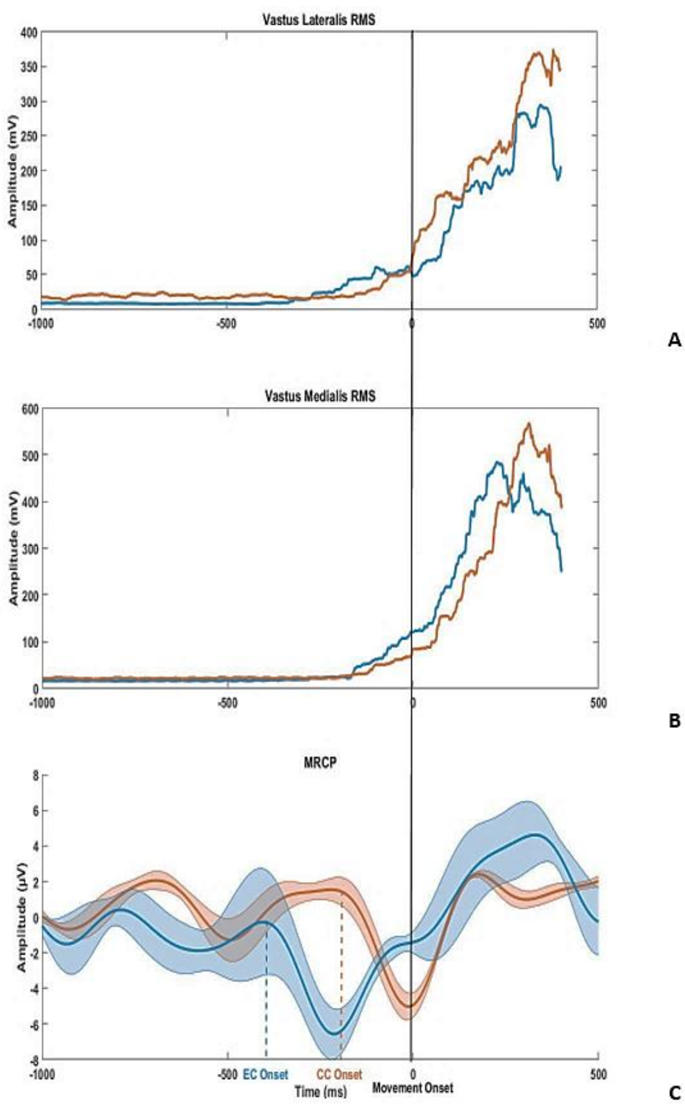
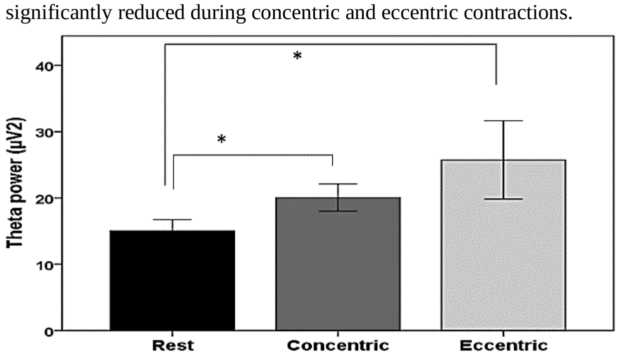


Figure 1: EMG of Vastus Lateralis **A)** Vastus Medialis **B)** muscles and the MRCP **C)** of C3 electrode during concentric (red) and eccentric (blue) contractions (CC, and EC, respectively). The vertical line indicates the movement onset. Note that the muscle activity (EMG) is lower, but the MRCP is greater for EC than CC.

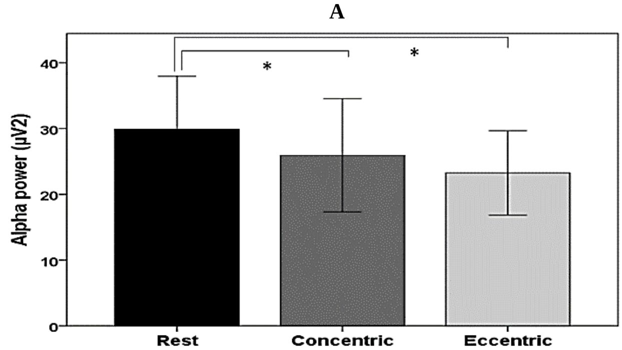
Table 1: Measurements of the amplitude (µV) and the onset time (ms) of the Movement-Related Cortical Potential (MRCP) during the concentric and eccentric tasks (mean [SD]).

MRCP	**Contraction**	**Electrode**			
		C4	C3	F4	F3
Amplitude	Concentric	-5.0259 [0.069]	-5.0466 [0.077]	-4.9756 [0.084]	-4.9083 [0.032]
	Eccentric	-6.4237 [0.39]	-6.5361 [0.48]	-6.3958 [0.27]	-6.3975 [0.18]
Onset	Concentric	-193.11 [1.56]	-192.45 [0.38]	-190.42 [0.65]	-190.26 [1.72]
	Eccentric	-398.48 [1.45]	-399.27 [0.86]	-395.04 [1.16]	-396.33 [1.22]

EEG power spectra demonstrated differences between the resting-state, concentric and eccentric contractions in the Theta and Alpha frequency bands. The averaged Theta power of all electrodes exhibited significantly higher value in the concentric (mean [SD] = 20.061 [2.518] μV^2) and eccentric contractions (25.717 [7.239] μV^2) compared to the resting-state (15.066 [2.068] μV^2) (Figure 2A). Additionally, the resting-state Alpha power (29.876 [9.896] μV^2) had a significant greater value compared to both type of contractions. The Alpha power was lower, but not significantly different in EC (23.247 [7.885] μV^2) compared to CC (25.937 [10.548] μV^2) (Figure 2B). Together, these results indicated that Theta power value has increased during both type of contractions in comparison with the resting-state, and Alpha power value has significantly reduced during concentric and eccentric contractions.



A



B

Figure 2: The averaged **A)** Theta power and **B)** Alpha power of all electrodes (C4, C3, F4 and F3) during resting-state, maximum concentric and maximum eccentric contractions (* $P<0.05$).

Discussion

This study investigated the level of cortical activation between concentric and eccentric muscle contractions. Our first goal was to compare the time domain characteristics of EEG signal during these two types of muscle actions. The MRCP amplitude was greater but not significantly, during eccentric than concentric task and the onset time of MRCP occurred earlier for eccentric than concentric contraction. The second goal was to investigate the spectral features in the EEG at resting-state, concentric and eccentric task. Our findings indicated that Theta power increased during both type of muscle contractions compare to the rest time, but Alpha power decreased during CC and EC.

I Time Domain

The first measured parameter is related to movement preparation. There was a trend indicating that the MRCP amplitude was greater for eccentric action compared to the concentric task. Second, the MRCP onset time, which is related to the mental preparation before the movement initiation, occurred significantly earlier for eccentric contractions. These results indicated that the level of brain activation during the planning phase had a trend to be higher for eccentric than concentric contractions. From the MRCP onset time, it's been obtained that the main prolonged preparation occurred during the early preparation phase. In fact, it implies that in EC the additional time was required in the early preparation. The results of the present study are in line with previous observations indicating that, for the eccentric task, the cortical activity (MRCP) was greater but the muscle activity (EMG) was lower in comparison to the concentric task values (lower MRCP but higher EMG) [4, 5].

In the last decade, a few neurophysiological mechanisms have been used to clarify neuromuscular control associated with eccentric and concentric muscle contractions [1-3]. One study that used transcranial magnetic stimulation (TMS), have indicated greater motor cortex excitability for EC compared with CC, whereas CC might rely more on spinal-reflexive mechanisms [22]. Simply put, eccentric contractions utilize greater amount of excitability as a compensatory strategy at the motor cortex so that the inhibition is elucidated at the spinal level [22-24]. These investigations reinforce the previous results that eccentric muscle contractions utilize unique neural mechanisms compared with other types of muscle contraction.

II Frequency Domain

To our knowledge, this is the first attempt to investigate the power of brain frequencies for concentric and eccentric muscle actions. The comparison of brain activation during concentric and eccentric contractions was associated with significant changes in spectral features in the Theta and Alpha power. In sport, Theta power has been investigated in activities such as golf, marksmanship, free shooting in basketball, and rifle shooting [25, 26]. The results indicated higher power of Theta before the trigger pull that reflecting increased attention up to the moment of the trigger pull [27].

In this study, concentric and eccentric muscle contractions exhibited significantly higher frontal Theta-power compared with the resting-state EEG. This finding was consistent with numerous studies in cognitive and sensorimotor tasks that describe the role of this frequency associated with focused attention and task complexity [25, 28]. The enhancement of frontal Theta power, while subjects engage in complex, attention-demanding tasks have indicated in most neuroimaging studies [28]. Speculations could lead to the idea that a higher level of concentration is needed for the concentric and eccentric contractions to select the relevant information for a good performance.

The second frequency band that shows significant differences between both type of contractions and the resting situation is the Alpha frequency. Alpha activity is inversely correlated to the number of neuronal populations activated during cognitive and motor processes [29, 30]. Our results showed significant reduction of Alpha power for both type of contractions compared to the resting-state. There was more (but not significant) reduction of this frequency power for EC that indicates the notion of a higher cortical activation compared with the concentric contraction. There is mounting evidence that greater level of cortical control to prepare, plan and perform are needed for eccentric contractions [1-3]. To control a movement and also degree of difficulty which requires increased preparing, planning, programing, greater brain effort is needed to control the process. It is mainly accepted that alpha oscillations functions are to actively inhibit unnecessary processing in the brain, and also controlling task irrelevant processing [31, 32]. Consequently, the Alpha power decrement during eccentric movement may suggest a particular neural strategy for inhibiting muscle activity to reduce the unwanted stretch reflex and harmful muscle damage.

Nowadays, owing to the main defining properties of eccentric muscle contractions, the higher force production and lower energetic cost, there is an increasing attraction in using eccentric contractions in sport training and rehabilitation techniques [33]. Indeed, the growing interest to use the eccentric contraction in several fields, might be due to its unique neural recruitment pattern. In fact, eccentric exercise compared to concentric, has the ability to attenuate deficits in neuromuscular control by increasing cortical excitability and also by targeting particular neural pathways in the brain [34]. In spite of considerable amount of available data, a significant gap still remains in understanding of the mechanisms underlying the adaptations of the neuromuscular system to eccentric exercise. More research should look comprehensively to understand how eccentric-based exercise programs involving the central nervous system.

Conclusion

The present EEG analysis of concentric and eccentric muscle contractions found a difference in the cortical control of the concentric and eccentric contractions. The results of the time-domain analysis revealed that for the early preparation phase of an eccentric contraction a longer time is required, and a greater cortical activity is needed. In fact, due to the complexity of the eccentric movements, they might require a unique neural drive strategy to carry out the actions. It can be speculated that strategy selection, control and coordination in eccentric contraction needs more neuronal resources compared with a concentric task. In spectral analysis, Theta and Alpha power values were different between resting-state and muscle contractions. These findings suggest that increased Theta power is associated with task complexity and focused attention and decreased Alpha power values with increased information processing in the somatosensory cortex.

Conflicts of Interest

None.

Consent

A written consent was taken from all participants prior to experimentation.

References

1. Ali Sharifnezhad, Moein Koohestani, Henning Budde (2018) The Effect of Eccentric Contractions on the Brain Waves Characteristics: A Systematic Review. *J Adv Sport Tech* 1: 41-48.
2. Stéphane Perrey (2018) Brain activation associated with eccentric movement: A narrative review of the literature. *Eur J Sport Sci* 18: 75-82. [Crossref]
3. R M Enoka (1996) Eccentric contractions require unique activation strategies by the nervous system. *J Appl Physiol* 81: 2339-2346. [Crossref]
4. Y Fang, V Siemionow, V Sahgal, F Xiong, G H Yue (2001) Greater movement-related cortical potential during human eccentric versus concentric muscle contractions. *J Neurophysiol* 86: 1764-1772. [Crossref]
5. Yin Fang, Vlodek Siemionow, Vinod Sahgal, Fuqin Xiong, Guang H Yue (2004) Distinct brain activation patterns for human maximal voluntary eccentric and concentric muscle actions. *Brain Res* 1023: 200-212. [Crossref]
6. Joo Hee Park, Heon Seock Cynn, Kwang Su Cha, Kyung Hwan Kim, Hye Seon Jeon (2018) Event-related desynchronization of mu rhythms during concentric and eccentric contractions. *J Mot Behav* 50: 457-466. [Crossref]
7. Kanosue Kazuyuki, Nagami Tomoyuki, Tsuchiya Jun (2015) Sports Performance. *Springer Japan*.
8. Raphael Kaplan, Christian F Doeller, Gareth R Barnes, Vladimir Litvak, Emrah Düzel et al. (2012) Movement-related theta rhythm in humans: coordinating self-directed hippocampal learning. *PLoS Biol* 10: e1001267. [Crossref]
9. J Baumeister, K Reinecke, M Weiss (2008) Changed cortical activity after anterior cruciate ligament reconstruction in a joint position paradigm: an EEG study. *Scand J Med Sci Sports* 18: 473-484. [Crossref]
10. M Grunwald, T Weiss, W Krause, L Beyer, R Rost et al. (2001) Theta power in the EEG of humans during ongoing processing in a haptic object recognition task. *Brain Res Cogn Brain Res* 11: 33-37. [Crossref]
11. Wolfgang Klimesch (2012) Alpha-band oscillations, attention, and controlled access to stored information. *Trends Cogn Sci* 16: 606-617. [Crossref]

12. H H Jasper (1958) Report of the committee on methods of clinical examination in electroencephalography. *Electroencephalogr Clin Neurophysiol* 10: 370-375.
13. H J Hermens, B Freriks, C Disselhorst Klug, G Rau (2000) Development of recommendations for SEMG sensors and sensor placement procedures. *J Electromyogr Kinesiol* 10: 361-74. [Crossref]
14. Ali Sharifnezhad, Robert Marzilger, Adamantios Arampatzis (2014) Effects of load magnitude, muscle length and velocity during eccentric chronic loading on the longitudinal growth of vastus lateralis muscle. *J Exp Biol* 217: 2726-2733. [Crossref]
15. P W Hodges, B H Bui (1996) A comparison of computer-based methods for the determination of onset of muscle contraction using electromyography. *Electroencephalogr Clin Neurophysiol* 101: 511-519. [Crossref]
16. David J Wright, Paul S Holmes, Dave Smith (2011) Using the movement-related cortical potential to study motor skill learning. *J Mot Behav* 43: 193-201. [Crossref]
17. Andreas Widmann, Erich Schröger (2012) Filter effects and filter artifacts in the analysis of electrophysiological data. *Front Psychol* 3: 233. [Crossref]
18. Jochen Baumeister (2013) Sensorimotor control and associated brain activity in sports medicine research. *Habilitation* 237.
19. Aqsa Shakeel, Muhammad Samran Navid, Muhammad Nabeel Anwar, Suleman Mazhar, Mads Jochumsen et al. (2015) A review of techniques for detection of movement intention using movement-related cortical potentials. *Comput Math Methods Med* 2015: 346217. [Crossref]
20. Imran Khan Niazi, Ning Jiang, Olivier Tiberghien, Jørgen Feldbæk Nielsen, Kim Dremstrup et al. (2011) Detection of movement intention from single-trial movement-related cortical potentials. *J Neural Eng* 8: 066009. [Crossref]
21. György Buzsáki (2006) Rhythms of the Brain. *Oxford University Press*.
22. M Gruber, V Linnamo, V Strojnik, T Rantalainen, J Avela (2009) Excitability at the motoneuron pool and motor cortex is specifically modulated in lengthening compared to isometric contractions. *J Neurophysiol* 101: 2030-2040. [Crossref]
23. Stuart Goodall, Glyn Howatson, Lee Romer, Emma Ross (2014) Transcranial magnetic stimulation in sport science: a commentary. *Eur J Sport Sci* 14: S332-S340. [Crossref]
24. Hirofumi Sekiguchi, Kimitaka Nakazawa, Shuji Suzuki (2003) Differences in recruitment properties of the corticospinal pathway between lengthening and shortening contractions in human soleus muscle. *Brain Res* 977: 169-179. [Crossref]
25. Jochen Baumeister, Kirsten Reinecke, Heinz Liesen, Michael Weiss (2008) Cortical activity of skilled performance in a complex sports related motor task. *Eur J Appl Physiol* 104: 625-631. [Crossref]
26. A J Haufler, T W Spalding, D L Santa Maria, B D Hatfield (2000) Neuro-cognitive activity during a self-paced visuospatial task: comparative EEG profiles in marksmen and novice shooters. *Biol Psychol* 53: 131-160. [Crossref]
27. M Doppelmayr, T Finkenzeller, P Sauseng (2008) Frontal midline theta in the pre-shot phase of rifle shooting: differences between experts and novices. *Neuropsychologia* 46: 1463-1467. [Crossref]
28. Joanne L Park, Malcolm M Fairweather, David I Donaldson (2015) Making the case for mobile cognition: EEG and sports performance. *Neurosci Biobehav Rev* 52: 117-130. [Crossref]
29. Donald L Schomer, Fernando H Lopes da Silva (2012) Niedermeyer's electroencephalography: basic principles, clinical applications, and related fields. *Lippincott Williams & Wilkins*.
30. Erol Başar (2012) A review of alpha activity in integrative brain function: fundamental physiology, sensory coding, cognition and pathology. *Int J Psychophysiol* 86: 1-24. [Crossref]
31. W Klimesch, M Doppelmayr, D Röhm, D Pöllhuber, W Stadler (2000) Simultaneous desynchronization and synchronization of different alpha responses in the human electroencephalograph: a neglected paradox? *Neurosci Lett* 284: 97-100. [Crossref]
32. Wolfgang Klimesch, Paul Sauseng, Simon Hanslmayr (2007) EEG alpha oscillations: the inhibition–timing hypothesis. *Brain Res Rev* 53: 63-88. [Crossref]
33. Lindsey K Lepley, Adam S Lepley, James A Onate, Dustin R Grooms (2017) Eccentric exercise to enhance neuromuscular control. *Sports Health* 9: 333-340. [Crossref]
34. Yong Hyun Kwon, Ji Won Park (2011) Different cortical activation patterns during voluntary eccentric and concentric muscle contractions: an fMRI study. *NeuroRehabilitation* 29: 253-259. [Crossref]