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Review Article

The Effect of Eccentric Contractions on the Brain Waves Characteristics: A Systematic Review

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ABSTRACT

A growing body of evidence indicates that different neural control strategies may exist for human contractions. This brief systematic review focuses on the specificity of the control strategy used by the central nervous system during eccentric contractions. The findings of previous studies indicate the effects of eccentric exercise on cortical regions and their cooperation as functional networks that support motor functions. Articles were searched in international databases including PubMed, Web of Science and Google Scholar. After initial screening and deleting irrelevant studies, 10 studies were chosen for the analysis. Studies were assessed and analyzed methodologically. Proper interventions were selected according to the least error criteria or the degree of strength. There is lack of study investigating the effects of muscle contraction types (isometric, concentric and eccentric) on the central nervous system, which is reflected in the EEG. Then, further investigations should answer this question: "how does the EEG-measured brain activity for the following bands (delta 1-4 Hz, theta 4-8 Hz, alpha 8-13 Hz and beta 13-20 Hz) change during acute eccentric and concentric contractions". Moreover, this review highlighted that (1) Few neuroimaging studies have explored the brain activation during eccentric actions, (2) Brain activity in motor-related cortices is higher during eccentric than concentric actions and (3) Prefrontal cortex appears to be highly involved in the regulation of cortical motor drive during eccentric contractions.

Keywords: Eccentric contraction, Brain activation, Electroencephalography (EEG), Functional magnetic resonance imaging (fMRI).

Introduction

Every kind of movements consist of at least isometric concentric (CC) and/or eccentric (EC) muscle contractions. During eccentric contractions the load on the muscle is greater than the force developed by the muscle and the muscle is stretched, producing a lengthening contraction, (vice versa for concentric contractions) [1, 2]. Most movement cycles consist of both eccentric and concentric muscle actions (e.g., during jumping, an eccentric movement generally occurs before the concentric action) and a large proportion of our daily living activities require accurate control of eccentric movements (e.g., returning a wine glass onto the table surface or lowering a grocery bag into the vehicle trunk), that less well understood.

Eccentric muscle actions produce less muscle activation (measured by electromyography or EMG) than concentric muscle actions under similar loading conditions [3-6]. This is mainly due to fewer motor units being recruited during eccentric compared to concentric muscle actions as well as a lower discharge rate of these activated motor units [7-10]. One interesting observation is that the motor unit pool of a muscle is not fully activated during maximal voluntary eccentric contractions. It, as assessed by the twitch interpolation technique, whereas almost all motor units are active during concentric contractions [8, 11-13].

Many studies suggest that the central nervous system (CNS) possesses unique strategies for controlling eccentric muscle actions [14-18]. There are three approaches in order to understand CNS behavior as a function of brain activity [19]. Electroencephalography (EEG) is the only non-invasive brain imaging modality that uses sensors that are light enough to wear while performing dynamic motor tasks and have sufficient time resolution to record changes in brain activity on the timescale of natural human movements [20]. There are also other methods for functional neuroimaging: functional magnetic resonance imaging (fMRI), that measures brain activity by detecting changes associated with blood flow. This technique relies on the fact that cerebral blood flow and neuronal activation are coupled. When an area of the brain is in use, blood flow to that region also increases [21]. The other method is near-infrared spectroscopy (NIRS), for measuring the regional metabolism of the brain and skeletal muscles during exercise. NIRS can be applied in a number of areas. For example, since the late 1990s, increasing numbers of researchers have used it for brain mapping studies. [22-24].

The characteristics of brain signals includes: A **delta** wave as a high amplitude brain wave with a frequency of oscillation between 1–4 Hz and known likes slow-wave sleep. **Theta** waves with the frequency range from 4 Hz to 8 Hz. Theta is seen normally in young children. It may be seen in drowsiness or arousal in older children and adults; it can also see in meditation. **Alpha** waves with the frequency range from 8 Hz to 13 Hz, seen in the posterior regions of the head on both sides, higher in amplitude on the dominant side. It emerges with closing of the eyes and with relaxation, and attenuates with eye opening or mental exertion. Over the motor cortex **beta** waves (13-30 Hz) are associated with the muscle contractions that happen in isotonic movements and are suppressed prior to and during movement changes. Beta activity is increased when movement has to be resisted or voluntarily suppressed. **Gamma** brainwaves are very fast EEG activity above 30 Hz. Although further research is required on these frequencies, we know that some of this activity is associated with intensely focused attention and in association with the brain to process and bind information from different areas of the brain [25].

A growing body of evidence indicates that different neural control strategies may exist for human contractions [14-18], but no previous study has done to indicate if the brain signal differs between eccentric versus concentric muscle actions. The purpose of this systematic review is to provide the latest evidences from neuroimaging studies that have explored the brain activation during movement caused by eccentric muscle contractions.

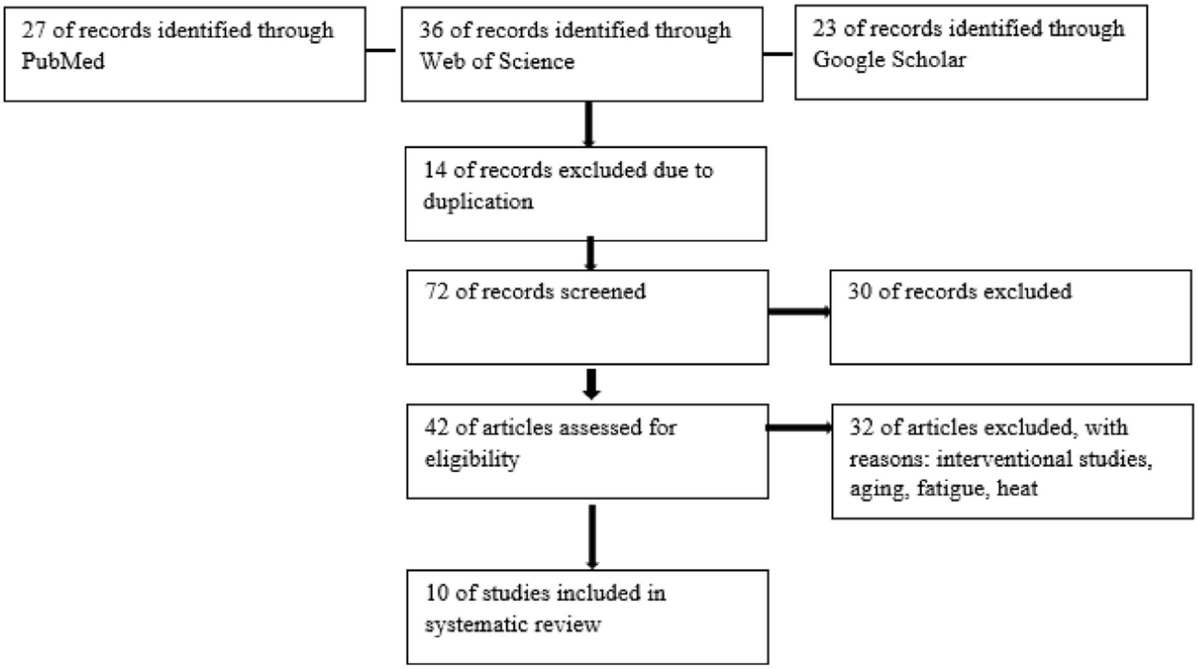
Material and Methods

The review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for systematic reviews. One reviewer performed initial database searches for articles investigating the effect of muscle contractions on brain waves characteristics (last search September 2017). After searching in international databases including Pubmed, Web of Science and Google Scholar, proper interventions were selected according to the least error criteria or the degree of strength. No limits were applied for language and foreign papers were translated. The eligibility criteria were pure/passive or acute/chronic eccentric muscle contractions and changes in EEG parameters and cortical regions during muscle contractions. In this review, we used the following search terms to search all trials, registers and databases: eccentric exercise and cortical activity, eccentric exercise and motor unit behavior, exercise training and neural adaptations and changes in EEG parameters and cortical regions during exercise.

The included studies were assessed and analyzed methodologically. These studies were performed between 1983 and 2017. To increase the likelihood that all relevant studies were identified, electronic database searching was supplemented by examining the reference list of relevant retrieved articles.

Papers were considered for inclusion only if: they enrolled healthy human subjects; they used cerebral neuroimaging methods for evaluating brain activation responses; they evaluated acute brain responses in resting conditions without any interference (e.g. fatigue, heat) during real and imagined motor tasks. (See Table 1).

Table 1. Search Strategy



Results

The search of Pubmed, Web of Sciences and Google Scholar databases provided a total of 86 articles. After adjusting for duplicates 72 remained. Of these, 30 studies were discarded because these papers clearly did not meet the criteria. The remaining 42 articles were examined in more detail. After performing additional analyses to help understand whether the results of the review are robust, all of which should be reported, it appeared that 32 studies discarded. Ten studies met the inclusion criteria and were included in the systematic review.

The subjects participated in these studies were healthy volunteers with no history of major injury and no known neurological or musculoskeletal deficits, and also researchers chose between 10 to 20 subjects for their experiments. In the most studies the contractions procedures were performed alternatively, concentric followed by eccentric contractions (e.g., CC→ EC→ CC, etc.).

Table 2 summarized each study with relevant findings. Collectively, the findings indicate: longer time and higher cortical signal amplitude (EEG) for eccentric movement preparation and execution, greater magnitude of cortical signals with wider activated brain area (EEG, fMRI), and weaker brain functional connectivity (fMRI) between primary motor cortex (M1) and other cortical areas involved in the motor network during eccentric muscle actions. Only some differences among studies due to the forms of movement with overload were observed in the contralateral (to the active hand) M1 activity during eccentric movement [1, 2, 27].

Table 2. Summary of included studies evaluating the efficacy of contraction type and exercise on CNS

Author	Aim	Sample	Tools	Method
Krause et al. (1983)	Changes in the parameters of the EEG power density spectrum during static muscle contractions	Four healthy male subjects (25-40 years)	EEG	Isometric contraction of biceps brachii for 30% of MVC for as long as possible
Yue et al. (2000)	Determine if the level of brain activation during human voluntary thumb extension movement would be different from that during flexion movement	Five men and three women, ranging in age: (22 to 53 years)	fMRI, EEG	Thumb flexion and extension with a rubber band
Fang et al. (2001)	Determine whether the level of MRCP measured cortical activation differs between the two types of muscle activities	Eight volunteers (6 men and 2 women, 27.75 ±7.21 years)	Monopolar EEG	50 concentric and 50 eccentric contractions of the elbow flexor muscles (speed of ;25°/s)
Fang et al. (2004)	Determine spatial and temporal distributions of MRCP signals during MVC tasks of eccentric and concentric contractions of elbow flexor muscles	Eight men (26–31 years)	EEG	40 concentric and 40 eccentric maximum voluntary elbow flexor muscle contractions
Kwon and Park (2011)	Whether cortical activity associated with eccentric contraction of the wrist extensors differed from that of concentric contraction	Fifteen healthy subjects (9 males and 6 females; 25.53 ± 1.51 years)	fMRI	4 repeating blocks of eccentric and concentric exercise of the wrist extensors
Gwin and Ferris (2012)	Relation between electrocortical dynamics and lower limb muscle activation	Eight healthy volunteers (7 males; 1 female; age range 21–31 years)	EEG	20 repetitions of the knee and ankle joints (activation with limb movement, concentric followed by eccentric)
Olsson et al. (2012)	Examine differences in recruited brain regions during the concentric and the eccentric phase of an imagined maximum resistance training task of the elbow flexors	Eighteen healthy individuals (8 males and 10 females, mean age 26.4 years)	fMRI	Resistance training of the elbow flexors (a series of sub-maximum alternating concentric and eccentric contractions of the elbow flexors)
Yao et al. (2014)	Whether old people exhibiting increased difficulties in performing EC than CC	Eleven young (4 males and 7 females, 23.25 ± 4.09 years) and nine old (3 males and 6 females, 68.72 ± 3.14 years)	fMRI	20 CC and 20 EC testing trials of index finger (the first dorsal interosseous (FDI) muscle)
Yao et al. (2016)	Examine FC within cortical motor control network based on fMRI data collected during CC and EC contractions	Eleven subjects (4 males and 7 females, ranging from 20 to 32 years)	fMRI	20 CC and 20 EC testing trials of index finger (the first dorsal interosseous (FDI) muscle)
Kang et al. (2016)	Investigating the activity of the cerebral cortex after resistance training in the elderly	11 females and 11 males aged between 65 and 70 years	EEG	CC and EC contractions of knee extensors, 10 times per set for 3 sets, three times a week for 4 weeks

Note: * EEG: electroencephalography; * fMRI: functional magnetic resonance imaging; * MVC: maximum voluntary contraction; * CC: concentric; * EC: eccentric * MRCP: movement-related cortical potential.

Discussion

The reductions in EMG amplitude and submaximal voluntary activation usually observed during eccentric contractions led to the suggestion that motor unit recruitment and discharge rates during maximal eccentric contractions may be limited to protect against muscle damage [28-31]. The reduced discharge rate of motor units during eccentric contractions is a common finding regardless of load type (inertial load or resisting a torque motor) and indicates that the activation signal sent to the muscle is less during eccentric contraction [8, 32-34].

Despite many differences between the two types of muscle actions and the preferential application of one over the other in a variety of clinical and athletic programs, little is known regarding the control mechanisms underlying eccentric and concentric muscle activities. Yue et al. (2000) and Fang et al. (2001, 2004) were the first to claim that eccentric movement requires a greater cortical control to prepare, plan and perform muscle actions. Overall, several studies have reported a more extended recruitment of brain areas during eccentric muscle actions. This greater extended motor network (including the primary, secondary and association cortices) may be one of control strategy both for activating high-threshold motor unit recruitment and lowering discharge rate of activated motor units during eccentric muscle actions [7, 32].

Movement-related cortical potential (MRCP) is divided into two major components, negative potential (NP) and positive potential (PP). These components are measured separately. In general, NP is thought to be related to movement preparation, planning, and execution, whereas PP is associated with brain signals processing feedback information from the sensory system [35-37].

Fang et al. (2004) reported that although the muscle activation level was significantly lower, the surface electroencephalogram (EEG)-derived movement-related cortical potential (MRCP) was greater and occurred earlier for eccentric than concentric contractions of elbow flexor muscles. These data suggested, for the first time, that the central nervous system (CNS) possesses unique strategies for controlling eccentric muscle actions. But their study was limited to determine spatial and temporal distributions of MRCP signals during planning and execution phases of MVC tasks of eccentric and concentric contractions of elbow flexor muscles.

As indicated by higher force fluctuation about 50–60% in Fang et al. (2001, 2004), force fluctuation is higher during eccentric than concentric contractions. Owings and Grabiner (2000) reported greater errors (force fluctuation) in controlling eccentric than concentric knee extensor contractions. To control a movement with a higher degree of difficulty, the brain may need to devote greater effort or a more extensive neural network may be needed to participate in the controlling process. Neuroimaging studies have shown that when motor tasks with a higher degree of difficulty are performed, the level of brain activation is higher [27, 38, 39].

Eccentric movement requires a greater cortical control to prepare, plan and perform. This is supported by the result of higher eccentric than concentric force fluctuations [1, 27, 38, 40]. This may be one control strategy both for activating high-threshold motor unit recruitment and lowering discharge rate of activated motor units occurring during eccentric muscle actions [32, 38].

To control a movement with a higher degree of difficulty which demands additional planning, programming, sensory motor integration and movement execution by the entire central control network, the brain may need to devote greater effort to participate in the controlling process [2, 39]. In fact, the available sensory feedback from the nervous system may require additional cortical resources to correct the increased force fluctuations during eccentric muscle actions [27, 39].

Additionally, increased EEG cortical activity in the frontal lobe during eccentric task [1, 2] may reflect another control strategy for inhibiting muscle activity in order to reduce the unwanted stretch reflex and deleterious muscle damage. A reduction in neuronal drive to the muscle during maximum eccentric contractions can be accomplished by inhibitory responses to afferent feedback [41, 42]. The inability to fully activate the muscle (i.e. neuronal drive) during maximum eccentric muscle actions is often regarded as a protection mechanism [41]. Nevertheless, there is still an enigmatic association between higher EEG and lower EMG amplitudes during the eccentric movement [1, 2] that deserves further investigation.

Conclusion

The purpose of this review was to provide the latest documents from neuroimaging studies that have explored the brain activation during eccentric contractions. When a task involves submaximal contractions to either lift an inertial load or push against an imposed load, the amount of motor unit activity differs during shortening and lengthening contractions. Significant new findings indicate that a longer time is needed for the early phase of preparation and greater signal amplitude is needed for executing an eccentric movement. In addition, not only the higher magnitude of MRCP for the eccentric contractions, but also the area of the brain involved in the control process is larger, which may indicate an involvement of more functional regions and a larger number of neurons in the brain to control eccentric than concentric muscle activities. Currently, the different outcomes observed in this review suggest that submaximal and maximal eccentric muscle actions are much harder to perform, and control of eccentric contractions could be more difficult as fewer motor units are often involved.

This study cleared the lack of investigation on the effect of muscle contraction types (isometric, concentric and eccentric) on the CNS, which is reflected in the EEG. Moreover we need further study in order to answer this question: “how does the EEG-measured brain activity for the following bands (delta 1-4 Hz, theta 4-8 Hz, alpha 8-13 Hz and beta 13-20 Hz) change during acute eccentric and concentric contractions”. Moreover, this review highlighted that (1) Few neuroimaging studies have explored the brain activation during eccentric actions, (2) Brain activity in motor-related cortices is higher during eccentric than concentric actions and (3) Prefrontal cortex appears to be highly involved in the regulation of cortical motor drive during eccentric contractions.

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چکیده فارسی

تاثیر انقباض اکسنتریک بر ویژگی‌های امواج مغزی (مرور سیستماتیک)

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شواهد نشان می دهند که استراتژی های کنترل عصبی عضلانی در عضلات اسکلتی متفاوت هستند. این بررسی سیستماتیک، بر استراتژی های کنترلی مورد استفاده در سیستم عصبی مرکزی در هنگام انقباضات اکسنتریک تمرکز نموده است. یافته های تحقیقات بررسی شده، بیان می کنند که تمرین اکسنتریک بر روی نواحی مختلف مغز و همکاری این بخش ها به عنوان شبکه های عملکردی که از عملکرد حرکتی پشتیبانی می کنند، اثر دارد. مقالات مختلف در پایگاههای بین المللی شامل PubMed، Web of Science و Google Scholar مورد جستجو و بررسی قرار گرفتند. پس از غربالگری اولیه و حذف مطالعات نامربوط، ۱۰ مطالعه برای تجزیه و تحلیل انتخاب شدند. بخش روش شناسی مطالعات مورد سنجش و بررسی قرار گرفتند. مداخلات مناسب بر اساس حداقل معیارهای خطا یا درجه قدرت انتخاب شده اند. نتایج این بررسی ها نشان داد که مطالعات اندکی در مورد اثر انواع انقباض عضلانی (ایزومتریک، کانسنتریک و اکسنتریک) بر سیستم عصبی مرکزی، که در سیگنال‌های مغزی منعکس شده انجام شده است. به عنوان نتیجه می توان بیان نمود که تحقیقات آینده باید به این پرسش پاسخ دهند که: "چگونه فعالیت مغز که توسط EEG اندازه گیری شده در باندهای دلتا ۱-۴ هرتز، تتا ۴-۸ هرتز، آلفا ۸-۱۳ هرتز و بتا ۱۳-۲۰ هرتز، در طول انقباضات شدید اکسنتریک و کانسنتریک تغییر می کند". همچنین این مطالعه نشان داد که (۱) تحقیقات اندکی برروی میزان فعالیت مغز در حین انقباضات اکسنتریک صورت گرفته، (۲) فعالیت مغز در سطح قشر حرکتی در حین انقباضات اکسنتریک بیشتر از انقباضات کانسنتریک است و (۳) لب پیشانی قشر مغز نقش تنظیمی بیشتری در حین انقباضات اکسنتریک دارد.

واژه‌های کلیدی: انقباض اکسنتریک، فعالیت مغزی، الکتروانسفالوگرافی (EEG)، تصویربرداری رزونانس مغناطیسی کارکردی (fMRI).

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