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Brain activation differences between muscle actions for strength and fatigue: A brief review

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AT A GLANCE
Cortex activation in gross motor strength and fatigue activities leads to specific cortical signals and area control strategies depending on the muscle action performed. Critical variables such as muscles, joints, sports, volume, intensity and tasks also play a role in cortical distributions.

ABBREVIATIONS
EEG – electroencephalography
MRCP – related cortical potential
NP – negative potential
PP – positive potential
CNS - central nervous system
EMG – electromyography
MVIC - maximal voluntary contraction

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BACKGROUND: Brain activation differences for strength and fatigue have recently been investigated due to advancements in brain-imaging methods.
AIM: To review brain activation differences between concentric, eccentric and isometric muscle actions for strength and fatigue.
METHOD: 12 studies were selected by accessing PubMed and Web of Knowledge databases.
RESULTS: Collectively, the literature demonstrates that for strength the parietal and frontal lobes of the cortex that control movement preparation, planning and execution, and process feedback information are more activated during eccentric than concentric actions. In the supplementary motor area, event-related desynchronization is continued for both concentric and eccentric actions, but only present at the beginning and end of isometric actions. This indicates the CNS specifically controls each of these muscle actions. For fatigue, cortical activation is greater in the supplementary and premotor areas during isometric actions, but may be greater primarily in the central, occipital and parietal cortical areas for concentric and eccentric actions.
CONCLUSION: Muscular strength can be elicited with eccentric actions to more effectively activate control and memory of movement in the parietal and frontal lobes. Muscular fatigue can be elicited with isometric actions to selectively activate supplementary and premotor areas, or with concentric and eccentric actions for central, occipital and parietal cortical areas.

KEYWORDS brain | activation | muscle action | strength | fatigue

INTRODUCTION

Understanding how the brain functions and how it controls strength and fatigue levels during exercise has been a topic of interest in past years[1-12]. Studies exploring which cortical regions are more activated during specific types of muscle actions have been important for improvements in performance and rehabilitation of movement disorders[1].

Strength is the force that muscle fibers produce at the sarcomere, when activated by motor neurons[13]. Peak torque is the maximal strength a muscle can produce, and is identified as the peak point of anisometric torque curve[14]. Fatigue is the time-related decrease in the capacity of the neuromuscular system to generate force during exercise[3, 15]. While peripheral fatigue is related to the muscle itself, central fatigue is the conscious perception of movement preparation, execution and effort preceded by the brain[3]. Muscular fatigue is usually measured by the decrease in strength over concentric or isometric actions over time[14, 16]. Cortical, spatial and temporal distributions have been found to differ depending on the muscle action performed on strength and fatigue, requiring activation of more or less neurons in the brain[6, 7].

There are three different types of muscle actions: concentric, eccentric and isometric[13]. Concentric actions produce force while shortening, eccentric actions produce force while lengthening, and isometric actions produce force without changes in the muscle length[13]. Muscles are capable of producing the greatest strength eccentrically, followed by isometrically and finally concentrically[13]. These muscle actions have been found to elicit distinct neural commands and muscle activation levels[6, 17].

Primary and supplementary motor cortex activity during fine motor strength and fatigue have been previously described as principally depending on dexterous control and task specificity, especially in finger and hand grip strength[18-23]. However, to date, only a few studies have reported cortical activation patterns during more demanding and intense activities[1, 5-7, 10]. How the brain is activated differently between concentric, eccentric and isometric muscle actions during high intensity performance tasks is less well understood. This is a novel topic that has only recently begun to be investigated via advancements in brain-imaging technologies, such as functional magnetic resonance imaging, position emission tomography, functional near-infrared spectroscopy (fNIRS), and electroencephalography (EEG).

The knowledge of which muscle action elicits each area of the brain in strength and fatigue is critical in the study of movement rehabilitation and conditioning for sports performance. For instance, this can assist clinicians in choosing exercise strategies to improve neurorehabilitation of gait and lower limb control in impaired patients[8], or coaches in prescribing exercises focused on specific muscle actions that elicit greater memory of movement or motor learning to improve motor performance in athletes[6, 7, 12]. Therefore, the aim of this review was to explore studies that tested brain activation differences between concentric, eccentric and isometric muscle actions for strength and fatigue.

METHODS

This review was based on 12 studies[1-12] published between 1996-2013 found by accessing the databases PubMed and Web of Knowledge. Within these, half were about fatigue and half about strength (table 1). The following search terms were used: “brain activation or cortical (cortex) activation & concentric or eccentric or isometric muscle strength”, and “brain activation or cortical (cortex) activation & concentric or eccentric or isometric muscle fatigue”. Articles that did not match these terms were excluded.

Table 1 – Summary of studies.

Topic	Author	Aim	Sample	Cortical Signal Recording	Main Results
Strength	Fang et al. 2001	To evaluate if levels of EEG-derived MRCP differed between concentric and eccentric submaximal muscle actions	8 healthy adults	EEG	Two main MRCP components were greater for eccentric compared to concentric muscle actions
	Fang et al. 2004	To evaluate if levels of EEG-derived MRCP differed between concentric and eccentric maximal muscle actions	8 healthy adults	EEG	MRCP was greater in eccentric compared to concentric muscle actions both in amplitude and area dimension
	Gwin & Ferris 2012	To test if electrocortical dynamics were related to lower limb muscle activation and its consistency across different types of muscle action	8 healthy adults	EEG	Isometric and isotonic muscle actions resulted in different electrocortical spectral modulations
	Ushiyama et al. 2010	To investigate muscle dependency and training-related alterations of corticomuscular coherence	24 untrained (U) 12 ballet dancers (BD), and 10 weightlifters (W)	EEG	Oscillatory coupling differed among muscles. BD and W showed smaller EEG-EMG coherences compared to U
	Albeln et al. 2013	To investigate cortical activation different intensities from 20% to 100% intensity of unilateral isometric leg extension exercise	11 healthy adults	EEG	Graded intensities required greater brain cortical activity within the primary motor cortex
	Dal Maso et al. 2012	To investigate the role of the primary motor cortex on controlling antagonist muscles activity during isometric muscle action	10 strength trained and 10 endurance trained adults	EEG	An association between increased activation of the primary motor cortex and a decrease in antagonist muscles activation was found
Fatigue	Taylor et al. 1996	To examine the excitability of the motor cortex during sustained fatiguing contractions at 30 and 100% MVIC of elbow flexion using transcranial magnetic stimulation (TMS)	10 healthy adults	TMS + EMG	Motor-evoked potential elicited by cortical stimulus, increased progressively during sustained 30% and 100% MVIC
	Berchicci et al. 2013	To investigate neurophysiological mechanisms underlying fatigue during lower limb isometric muscle actions	27 healthy adults	EEG	Peripheral fatigue increased MRCP in the supplementary and premotor areas. Perception of effort was related to supplementary, premotor, primary motor and prefrontal cortices
	Kubitz et al. 1996	To measure aerobic exercise effects on EEG activity	34 healthy students	EEG	15 minutes of aerobic exercise on a cycle ergometer increased activation in the frontal and temporal areas of the brain. Not exercising decreased activation in these areas
	Mechau et al. 1998	To measure exercise effects with increasing intensity on EEG activity	19 athletes	EEG	Faster stages of running led to correspondingly progressive increases in activation. There was a similar stage-by-stage decrease in activation following exercise with increased blood lactate accumulation.
	Bailey et al. 2008	To measure brain activity effects during graded exercise	20 healthy adults	EEG	Graded cycle ergometer exercise led to significant brain activation only after 200W was reached, and persisted until 10 minutes post-exercise
	Dun-Lewis et al. 2011	To investigate differences in cortical activity after 3 different protocols of isometric squat	7 resistance trained adults	EEG	No differences were found across protocols in peak torque decrements or brain activity after 24 hours of recovery

BRAIN ACTIVATION AND MUSCLE STRENGTH

The original evidence that the central nervous system (CNS) acts differently between muscle actions was taken from electromyographic (EMG) studies[17]. Eccentric actions result in lower recruitment and discharge rates of active motor units compared to concentric and isometric actions. This suggests that the CNS uses unique control strategies depending on the muscle action performed[6, 17]. However, only recently has research directly confirmed these preliminary findings. Fang et al. in two studies[6, 7] investigated differences in cortical potential (MRCP) signals between elbow flexion concentric and eccentric muscle actions. They found that for both sub-maximal and maximal strength measurements, EEG-derived MRCP negative potential (NP) and positive potential (PP) were greater, and NP onset occurred earlier with eccentric than concentric muscle actions in parietal and frontal lobes of the cortex [6]. While MRCP NP is related to cortical preparation, planning and execution of movements, NP onset is the additional time needed for the cortex to send distinct strategies to control a movement, while MRCP PP processes feedback information[6]. These results may be related to eccentric actions being more complex to perform than concentric actions as they require altered motor unit recruitment and a distinct CNS control strategy, including greater cortical activity to activate high threshold motor units with high twitch force and a low discharge rate[6, 7]. Additionally, eccentric actions lead to greater muscle damage, which requires the cortex to plan and modulate gravity assisted movements[6, 7].

Electrocortical activation has also been found to vary between dynamic and isometric muscle actions[8], as well as between different joints, muscles and sports[8, 12]. Utilizing EEG during knee and ankle flexion-extension strength tasks, Gwin & Ferris[8] found that event-related desynchronization (ERD), which is the suppression of oscillatory cortical activity, was continued across the entire isotonic concentric/eccentric actions, but was only present at the beginning and end of isometric actions, indicating that CNS may specifically control each of these muscle actions . In addition, knee and ankle joints led to different spatial distributions in the cortex. Similarly, Ushiyama et al.[12]utilized EEG-EMG coupling while subjects produced 30% isometric force and found that corticomuscular coherence was greater in lower limbs than upper limbs, and less in ballet dancers and weightlifters compared to untrained subjects. They suggested that the oscillatory activity of the sensorimotor cortex may be related to long term training of different muscles for improved control of muscular strength.

The spatial and cortical distributions may also differ by the intensity of the isometric action[1]. Albeln et al.[1] found that primary motor cortex activity increased according to the intensity of the exercise during knee extension at 20, 40, 60, 80 and 100% of MVIC. Although they did not record EEG activity at 100% of MVIC, their results demonstrate that the primary motor cortex is the main region of the brain involved in unilateral isometric MVIC, as the premotor cortex, primary somatosensory cortex and somatosensory association cortex followed dissimilar patterns. This is in accordance with Dal Maso et al.[4], who found that increased knee extension MVIC force was associated with the primary motor cortex, which could also be responsible for decreasing knee flexion co-contraction. However, knee isometric unilateral and bilateral maximum strength have been found to differ due to bilateral limb deficit, which may be related to neural inhibition[24]. Additional research using EEG may be needed to explain cortex functioning in both conditions.

BRAIN ACTIVATION AND MUSCLE FATIGUE

While different muscle actions appear to be activated by different areas of the brain[2, 3, 9, 10], cortex activation may also depend on whether fatigue is central or peripheral[13]. Taylor et al.[11] reported that muscle activation and motor-evoked potential elicited by cortical stimulus, increased progressively during sustained 30% and 100% MVICs. Berchicci et al.[3] found that while lower-limb knee extension isometric peripheral fatigue led to an increase in MRCP in the supplementary and premotor areas, the perception of effort was related to supplementary, premotor, primary motor and prefrontal cortices. This supports that the decline in muscle force may not uniquely determine fatigue, since exercise during fatiguing bouts may be sustained due to subjective sensations[2, 3, 9, 10].

However, fatigue over repeated concentric and eccentric muscle actions has been found to be intensity, volume and task dependent. Kubitz et al.[9] found that while 15 minutes of aerobic exercise on a cycle ergometer resulted in increased activation in the frontal and temporal areas of the brain, watching a videotape for 15 minutes (not exercising) led to decreased activation in these same areas. Mechau et al.[10] showed that progressively faster stages of running led to correspondingly progressive increases in activation mainly in the central, occipital and parietal cortical areas. Additionally, there was a similar stage-by-stage decrease in activation following exercise with increased blood lactate accumulation. They concluded that this could be due to alterations in the afferent systems, which may influence cortical activity in intense exercise.

Moreover, cortical activity has also been found to begin only after high intensities are reached in repeated concentric muscle actions, and may or not persist post-exercise. Bailey et al.[2] found that a graded cycle ergometer exercise with increasing loads of 50W every 2 minutes led to significant brain activation only after 200W was reached, and persisted until 10 minutes post-exercise. This pattern occurred at 8 sites of 3 different cortical areas, but was not different between hemispheres. Dun-Lewis et al.[5] did not find differences in peak torque decrements or brain activity 24 hours after resistance trained subjects performed exercises focused on increasing magnitude and rate of force development. For all protocols, EEG topographical maps indicated low levels of activity after the recovery period.

We were unable to identify any study that measured brain activation during fatigue caused by eccentric muscle actions. Additional studies directly comparing fatigue between different muscle actions are needed to arrive at definitive conclusions.

CONCLUSION

This review explored studies that tested brain activation differences between concentric, eccentric and isometric muscle actions for strength and fatigue. Collectively, although there are not many studies published about this topic the literature demonstrates that muscular strength can be elicited with eccentric actions to more effectively activate control and memory of movement in the parietal and frontal lobes, which can better stimulate motor performance. Muscular fatigue can be elicited with isometric actions to selectively activate supplementary and premotor areas, or with concentric and eccentric actions for central, occipital and parietal cortical areas. Subjective sensations of fatigue are related to self-perception and cognitive aspects, which are related to motor learning. This review may assist in the study of brain function with gross motor strength and fatigue exercise, which may help to advance rehabilitation of movement disorders, as well as in strength and conditioning program design for sports performance. This could help clinicians in creating neurorehabilitation exercise programs focused on specific muscle actions for improving affected limb control in impaired patients, or coaches to prescribe exercises to elicit specific cortical signals and area control strategies to enhance performance in athletes. Additional research with more direct comparisons of unilateral and bilateral concentric, eccentric and isometric muscle actions in strength and fatigue are needed to further investigate this topic.

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