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Evaluating protocols for normalizing forearm electromyograms during power grip

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ABSTRACT

Many studies use a reference task of an isometric maximum voluntary power grip task in a mid-pronated forearm posture to normalize their forearm electromyographic (EMG) signal amplitude. Currently there are no recommended protocols to do this. In order to provide guidance on the topic, we examined the EMG amplitude of six forearm muscles (three flexors and three extensors) during twenty different maximal voluntary efforts that included various gripping postures, force and moment exertions and compared them to a frequently used normalization task of exerting a maximum grip force, termed the reference task. 16 participants (8 male and 8 female, aged 18–26) were recruited for this study. Overall, maximal muscle activity was produced during the resisted moment tasks. When contrasted with the reference task, the resisted moment tasks produced EMG activity that was up to 2.8 times higher ($p < 0.05$). Although there was no one task that produced greater EMG values than the reference task for all forearm muscles, the resisted flexor and extensor moment tasks produced similar, if not higher EMG activity than the reference task for the three flexors and three extensor muscles, respectively. This suggests that researchers wishing to normalize forearm EMG activity during power gripping prehensile tasks should use resisted flexor and extensor moment tasks to obtain better estimates of the forearm muscles' maximum electrical activation magnitudes.

1. Introduction

In 2012, injuries and musculoskeletal disorders (MSDs) of the distal upper extremity (arm, hand, wrist and fingers) accounted for almost 20% of all lost time claims (WSIB, 2013, p. 86–87). High hand forces in industry are strongly associated with the development of distal arm syndromes such as carpal tunnel syndrome and hand and wrist tendinopathy (e.g., Bernard et al., 1997; Harris et al., 2011). Surface electromyography (EMG) is one tool that is used for task analysis in ergonomic and biomechanical research to give insight into injury risk factors by helping quantify hand forces using EMG models and by determining forearm muscle capacity (the amount of muscle activation each forearm muscle is capable of) (Duque et al., 1995; Bao and Silverstein, 2005; Hoozemans and van Dieën, 2005). Additionally, EMG is used as an input for myoelectrically controlled prostheses. Myoelectric control of the distal upper limb requires the EMG signals of the user's forearm flexors and extensors to be detected and processed to provide EMG amplitudes which can be sent to a hand controller to actuate prosthesis movements (Parker et al., 2006; Scheme and Englehart, 2011; Fougner et al., 2012).

The amplitude of raw EMG signals are not, however, easily interpretable; therefore the amplitudes are often normalized. EMG data are often normalized to a static maximal voluntary electrical activation (MVE) task, sometimes called a Maximum Voluntary Contraction (MVC) (Mirka, 1991; Mathiassen et al., 1995). Normalizing tasks to a person's maximum activation gives better insight into how taxing a given task is, which can be important in injury prevention and task analysis. This normalization can also help reduce the variability that is caused by EMG factors such as electrode spacing, placement, orientation, and skin impedance (Fuglevand et al., 1992; De Luca, 1997; Clancy et al., 2002). The normalized values can then be better compared across people and across days.

Many studies attempting to learn about the effects of work on the distal arm musculature used a normalization task consisting of an isometric maximum voluntary power grip task in a mid-pronated forearm posture (henceforth termed the reference task in this paper) (Table 1). This task is frequently used to normalize the EMG signal amplitude for both flexor and extensor muscles. For investigations looking at tasks that only require gripping and

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Table 1
Maximum voluntary electrical activation tasks used in this study. All tasks were isometric, maximal exertions and were performed in a seated position with 90° of elbow flexion and a natural wrist posture unless stated otherwise. References show examples of studies that used a given task to normalize EMG data to.

Type	#	Task Name	Description	Reference(s)
Posture Tasks (performed on mounted handle)	1	Reference Task	Neutral[a] wrist position. Squeeze	Alizadehkhaiyat et al. (2007), Bao and Silverstein (2005), Clancy et al. (2008), Das et al. (2005), Duque et al. (1995), Oskouei et al. (2013), Kim (2012), Kong and Lowe (2005), Mogk and Keir (2003), Roman-Liu and Konarska (2009)
	2	Full Voluntary Flexion	Grab handle with fully flexed wrist. Squeeze	Duque et al. (1995)
	3	Full Voluntary Extension	Grab handle with fully extended wrist. Squeeze	
Force Tasks (performed on mounted handle)	4	Push	Squeeze while inducing a force directed forwards along the axis of the forearm	Wells and Greig (2001), Greig and Wells (2004, 2008), Morose et al. (2004), Koppelaar and Wells (2005)
	5	Pull	Squeeze while inducing a force directed backwards along the axis of the forearm	
	6	Dorsal	Squeeze while inducing a force directed toward the back of the hand with a rigid wrist	
	7	Palmar	Squeeze while inducing a force directed toward the palm of the hand with a rigid wrist	
	8	Up	Squeeze while inducing a force directed up along the axis of the handle with a rigid wrist	
	9	Down	Squeeze while inducing a force directed down along the axis of the handle with a rigid wrist	
Moment Tasks (performed using calibration object)	10	Flexor	Squeeze and resist while investigator induces ...wrist extension	Wells and Greig (2001), Greig and Wells (2004, 2008), Morose et al. (2004), Bao and Silverstein (2005), Koppelaar and Wells (2005)
	11	Extensor	... wrist flexion	
	12	Pronator	... forearm supination	
	13	Supinator	... forearm pronation	
	14	Radial Deviator	... wrist ulnar deviation	
	15	Ulnar Deviator	... wrist radial deviation	
Diagonal Moment Tasks (performed using calibration object)	16	Extensor/Radial Diagonal	... wrist flexion and ulnar deviation	Hoozemans and van Dieën (2005)
	17	Extensor/Ulnar Diagonal	... wrist flexion and radial deviation	
	18	Flexor/Radial Diagonal	... wrist extension and ulnar deviation	
	19	Flexor/Ulnar Diagonal	... wrist extension and radial deviation	
Miscellaneous	20	Resisted Finger Extension	Fist closed. Forearm pronated. Participant's fist is enclosed by investigator's hands. Participant tries to open fist	Au and Keir (2007)

[a] The wrist position was frequently described as neutral however this was not further specified.

squeezing, a reference task of an isometric maximum voluntary power grip seems reasonable. Even so, a comparison of the muscle activation levels induced by the reference task (gripping and squeezing) versus tasks requiring the generation of moments of force has shown that the reference task does not fully activate forearm musculature or realistically reflect certain manual tasks (Morose et al., 2004; Koppelaar and Wells, 2005; Greig and Wells, 2008). If the normalizing task does not fully activate a forearm muscle, it will underestimate its MVE which will lead to overestimation of its relative muscle activity (e.g., Chopp et al., 2010).

Many tasks require only gripping and squeezing, but a large number of tasks also require forces and moments to be exerted. Tasks like using a hammer or a screwdriver require different forearm muscle activity than simply gripping; thus, other normalization tasks could lead to more interpretable signal amplitudes.

Multiple normalization tasks have been reported; however there are no recommended tasks for normalizing electromyographic signals from the distal arm during power grip exertions. In addition to the reference task, other tasks described have included gripping using diverse postures and gripping whilst exerting a force or a moment of force (see Reference(s) in Table 1). No comprehensive comparison has been made between these normalization tasks. In addition, few studies clearly state how they normalize their data and what wrist posture was employed. Usually a general statement is made that tasks were done in an undefined neutral posture.

Therefore, the objectives of this study are: to compare the EMG amplitudes during different maximal gripping tasks to the reference task, and identify which task or tasks maximally activate the highest number of muscles simultaneously.

2. Methodology

2.1. Participants

Eight male (height = 176.8 ± 7.0 cm, weight = 84.2 ± 8.3 kg) and eight female (height = 165.0 ± 5.2 cm, weight = 63.1 ± 6.7 kg) right hand dominant university students, aged 18–26, were recruited for this study. None of the participants reported any injury (acute or chronic) or pain in the upper extremity over the last 6 months. This project was reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee. All participants provided informed consent.

2.2. Instrumentation

Surface EMG (sEMG) signals were used to quantify forearm muscle activity. Signals were monitored for six muscles: Flexor