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Scientific/Clinical Article

Hand strengthening exercises in chronic stroke patients: Dose-response evaluation using electromyography

Jonas Vinstrup MSc [a,*], Joaquin Calatayud PhD [a,b,c], Markus D. Jakobsen PhD [a], Emil Sundstrup PhD [a], Jørgen R. Jørgensen BSc [d], Jose Casaña PhD [c], Lars L. Andersen PhD [a,e]

[a] Department of Musculoskeletal Disorders, National Research Centre for the Working Environment, Copenhagen Ø, Denmark
[b] Department of Physical Education and Sports, Laboratory of Physical Activity and Health, University of Valencia, Valencia, Spain
[c] Department of Physiotherapy, University of Valencia, Valencia, Spain
[d] Center for Rehabilitation of Brain Injury, University of Copenhagen, Copenhagen, Denmark
[e] Department of Health Science and Technology, Physical Activity and Human Performance group, SMI, Aalborg University, Aalborg, Denmark

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A B S T R A C T

Study Design: Cross-sectional.
Purpose of the Study: This study evaluates finger flexion and extension strengthening exercises using elastic resistance in chronic stroke patients.
Methods: Eighteen stroke patients (mean age: 56.8 ± 7.6 years) with hemiparesis performed 3 consecutive repetitions of finger flexion and extension, using 3 different elastic resistance levels (easy, moderate, and hard). Surface electromyography was recorded from the flexor digitorum superficialis (FDS) and extensor digitorum (ED) muscles and normalized to the maximal electromyography of the non-paretic arm.
Results: Maximal grip strength was 39.2 (standard deviation: 12.5) and 7.8 kg (standard deviation: 9.4) in the nonparetic and paretic hand, respectively. For the paretic hand, muscle activity was higher during finger flexion exercise than during finger extension exercise for both ED (30% [95% confidence interval {CI}: 19-40] vs 15% [95% CI: 5-25] and FDS (37% [95% CI: 27-48] vs 24% [95% CI: 13-35]). For the musculature of both the FDS and ED, no dose-response association was observed for resistance and muscle activity during the flexion exercise ($P > .05$).
Conclusion: The finger flexion exercise showed higher muscle activity in both the flexor and extensor musculature of the forearm than the finger extension exercise. Furthermore, greater resistance did not result in higher muscle activity during the finger flexion exercise. The present results suggest that the finger flexion exercise should be the preferred strengthening exercise to achieve high levels of muscle activity in both flexor and extensor forearm muscles in chronic stroke patients. The finger extension exercise may be performed with emphasis on improving neuromuscular control.
Level of Evidence: 4b.

Introduction

Stroke is a global and disabling neurological condition, affecting more than 7 million people in the United States alone.[1,2] Although mortality rates are decreasing due to a combination of interventions and public health programs, for example, improved control of hypertension,[3] the number of stroke incidents is steadily increasing due to demographic changes in the population.[4,5] Following stroke, up to 74% of patients rely on long-term help to perform activities of daily living (ADL),[6] and about 50% show impaired upper limb and hand function (Santisteban et al, 2016). These numbers are not surprising, as severe motor impairments of both upper and lower limb function following stroke are seen in many patients,[2,7] as a consequence of ischemic or hemorrhagic injury to areas associated with motor function.[8]

Physical training has been shown to improve functional deficits following stroke.[9] This is especially important since low levels of physical activity do not only pose a risk factor for increased stroke mortality[10] but is also very common after stroke.[11] In this regard, bilateral muscle strength and power are impaired in this group of

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* Corresponding author. Department of Musculoskeletal Disorders, National Research Centre for the Working Environment, Lersø Parkalle 105, DK 2100 Copenhagen Ø, Denmark. Tel.: (+45) 39 16 52 00; fax: (+45) 39 16 52 01.
E-mail address: jonasvinstrup@gmail.com (Jonas Vinstrup).

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patients,[12,13] with pronounced abnormal muscle activation and diminished functional use of the distal portion of the upper limbs.[7,14] This makes it difficult to perform most ADL as these involve the upper limb. To regain function following stroke, it is therefore recommended to implement intensive strength training in both upper and lower limb rehabilitation practices,[15,16] underlining the importance of identifying the most effective training types and modalities.

In healthy subjects, muscle activity of forearm muscles can be used to predict hand grip forces.[17] Interestingly, the forearm extensors have been shown to fatigue faster than the flexors during isometric gripping tasks.[18,19] In stroke patients, grip strength is associated with higher levels of independence during ADL[20] and correlates moderate to highly with function and performance tests of the upper limb.[21,22] Although no consensus on which outcome measures to choose when evaluating upper limb function following stroke exists,[23,24] the importance of focusing on early activation and frequent movement repetition for motor rehabilitation of the paretic hand has therefore been stressed in the stroke literature.[25,26] The repetition of functional relevant movements, including all types of hand and finger actions, of the paretic side may thereby decrease the negative effects of depression in perilesional brain areas via discontinuation of the disuse that normally follows stroke.[27] In addition, regaining muscle strength of the paretic arm and hand should be emphasized as this may improve the odds of meeting the inclusion criteria for certain interventions. For example, one of the most studied and successful forms of upper limb rehabilitation in chronic stroke patients, constraint-induced movement therapy,[28-34] often has strict mobility and strength requirements for participation.[30,35] Therefore, effective hand exercises to improve the grip strength and hand function in chronic stroke patients are warranted, as these will function as a necessary precursor for the successful addition of more functional rehabilitation practices.

In this study, we evaluate muscle activity of the forearm musculature during finger flexion and extension exercises using elastic resistance. The main purpose was to clarify whether these exercises hold the potential for not only highly repetitive use but also sufficient muscle activation. Furthermore, we test the dose-response relationship of 3 different resistances in each exercise to clarify if graded loading is initially necessary in this population and to determine whether a reliance on the flexor musculature is evident in this population. We hypothesize that the flexion and extension exercises will selectively activate the musculature of the flexors and extensors, respectively, and that a dose-response relationship of muscle activity exists between the 3 resistances of increasing resistance.

Methods

Subjects

A total of 18 (11 men and 7 women) community-dwelling participants with cerebrovascular injuries in the chronic stage (> 6 months after injury) at the Center for Rehabilitation of Brain Injury, Copenhagen, Denmark, participated in 2 sessions, consisting of (1) familiarization and (2) an experimental protocol. A priori power analysis based on another study population suggested that 16 subjects in this paired design were sufficient to obtain a statistical power of 80% at a minimal relevant difference of 10%, a type I error probability of 1%, assuming a standard deviation of 10% based on previous research in our laboratory.[36]

All referrals to the study were made by physiotherapists at the Center for Rehabilitation of Brain Injury, having screened the patients for eligibility at admission. All participants were medically stable, motivated for rehabilitation, taking part in ongoing gait, cognitive, and conventional machine-based resistance training for the lower extremities at least twice a week. All training modalities were individualized and performed in a progressive manner, and all participants were cleared for strenuous physical exercise. The participants did not perform resistance exercises for the upper extremities before this study. Gait function had to be moderately to severely impaired, defined as a maximum walking distance of less than 50% of the normal walking speed for age-, height-, weight-, and sex-matched healthy individuals. Further criteria for inclusion were a chronicity of more than 6 months and a moderate to severe hemiparesis with unilateral weakness, which, in addition to gait function, was based on the physiotherapists' evaluation of side-side differences in strength and function. Exclusion criteria were alcohol or substance abuse, resting blood pressure above 160/100 mmHg, psychiatric diseases, and any progressive diseases. Table 1 shows the demographics of the participants.

Electromyography (EMG) signal sampling

Before placing the electrodes (Blue Sensor N-00-S; Ambu A/S, Ballerup, Denmark), the skin was cleaned, shaved, and prepared with scrubbing gel (Acqua gel; Meditec, Parma, Italy) to lower skin impedance.[37] Our laboratory has previously found strong correlations between normalized EMG and perceived exertion during dynamic resistance exercises,[38] and EMG is generally accepted as a proxy measure for force in nonfatigued states.[39] EMG signals were recorded from the flexor digitorum superficialis (FDS) and extensor digitorum (ED) muscles.[17,40,41] A bipolar surface EMG configuration (Neuroline 720 01-K; Medicotest A/S, Ølstykke, Denmark) with an interelectrode distance of 2 cm was used.[42,43] The EMG electrodes were connected directly to wireless probes that preamplified the signal (gain 400) and transmitted data in real time to a nearby 16-channel PC-interface receiver (TeleMyo DTS Telemetry; Noraxon, AZ). The sampling rate was set to 1500 Hz with a bandwidth of 10-500 Hz to avoid aliasing. The resolution of the signals was 16 bit. The common mode rejection ratio was >100 dB.

Familiarization and experimental protocol

At the first session, the participants were familiarized with the exercises used in the experimental protocol. At the second session, the participants arrived at the Center for Rehabilitation of Brain Injury after breakfast. The EMG apparatus was applied on one side at a time and fixated with adhesive tape (Fixomull; BSN medical GmbH, Hamburg, Germany), after which the subject was asked to perform various movements to confirm comfort and

Table 1
Demographics, mean (SD)

Variable	Combined	Men	Women
	Mean (SD)		
Age (y)	56.8 (7.6)	56 (8.8)	57 (6)
Weight (kg)	71.1 (16.5)	80.4 (13.4)	56 (9)
Height (cm)	174.4 (8.9)	179 (5.7)	165 (7.7)
Blood pressure, systolic/diastolic (mmHg)	129/81 (11/11)	128/80 (9/11)	134/85 (12/11)
Sex (men/women)	11/7		
Side of lesion (left/right)	8/10	5/6	3/4
Time since injury (y)	3 (3)	4 (4)	2 (1)
Grip strength, paretic side (kg)	7.8 (9.4)	10.5 (11)	3.4 (2.3)
Grip strength, nonparetic side (kg)	39.2 (12.5)	46 (9)	28.7 (10)

SD = standard deviation.