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The effects of body orientation on maximum voluntary arm torques

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Abstract

INTRODUCTION—Increased reliance on bulbospinal motor systems has been implicated in individuals with chronic stroke during maximum voluntary arm joint torque generation.

METHODS—Maximum isometric single-joint and multi-joint arm strength were observed in two body orientations (sitting & supine) while maintaining identical head/neck/trunk/extremity joint configurations in order to identify bulbospinal contributions to maximum joint torque generation in 11 individuals with stroke and 10 individuals without stroke.

RESULTS—During sitting, shoulder flexion was greater for both groups, while shoulder extension and elbow flexion, part of the “flexion synergy,” were greater only in individuals with stroke.

CONCLUSIONS—The results demonstrate that body orientation influences isometric arm strength, notably the constituents of flexion synergy in individuals with stroke, suggesting bulbospinal motor pathway involvement. From a practical perspective, clinical evaluation of single joint strength in the supine position may underestimate strength available during activities of daily living that are performed in an upright orientation.

Keywords

stroke; body orientation; upper extremity; isometric; torque

Introduction

There is a long standing clinical observation of stereotypical patterns of arm movement in individuals with stroke.¹ Initially, Signe Brunnstrom defined the impairment broadly as “flexion synergy” and “extension synergy,”² and later, Dewald and colleagues referred to the impairment as the “loss of independent joint control.”³ Foundational quantitative work attributed the impairment to abnormal co-activations of shoulder and elbow muscles and suggested a common neural mechanism of increased reliance on bulbospinal motor systems

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following the loss of corticofugal projections.⁴ Bulbosplinal motor pathways, such as reticulospinal and vestibulospinal pathways, project bilaterally largely to motoneuron pools of axial and proximal limb muscles and exhibit widespread branching, innervating neurons over many spinal segments.⁵ The extensive branching of bulbospinal neurons may explain the preferential co-activation patterns of muscles and subsequent loss of independent joint control following stroke-induced disruption of corticospinal pathways. Recent primate research has provided supportive evidence for reticulospinal involvement by demonstrating that neurons in the pontomedullary reticular formation make concurrent connections to multiple ipsilateral upper extremity muscles,⁶ including intrinsic hand muscles.⁷ This finding is identical to the “flexion synergy” muscles reported by our laboratory in humans over the last 16 years.^{4,8-10} Additionally, the reticulospinal system has been implicated in individuals with stroke who have enhanced startle reflex¹¹ and enhanced tonic vibration reflex¹² on the affected side.

While previous work pointed toward the involvement of corticoreticulospinal pathways in stroke, we attempted to determine if another brainstem system, the vestibular system, might influence upper extremity torque generation in individuals with stroke. To investigate the potential contribution of the vestibular system, the effect of total body orientation on single-joint and multi-joint isometric upper extremity strength was measured. This study stimulated the vestibular system naturally by altering the orientation of the body/head to vertical.¹³ By altering the position of the whole body with respect to gravity without changing neck, trunk, or extremity joint configurations the confounding influences of ascending proprioceptive input were minimized. This sensory feedback is thought to influence upper extremity torque production in individuals with stroke such as axial neck rotation^{14,15} or changes in arm configuration.¹⁰ Keeping the cervical spine segments in the same configuration across body orientations was of paramount importance, as tonic labyrinthine reflexes (vestibulospinal reflex) are known to act in an opposite direction to asymmetric tonic neck reflexes (neck reflex) in man¹⁶ as well as in the cat.¹⁷ The isometric setup and seating/positioning system allowed for exact replication of joint configurations when the body was in either a sitting or supine orientation. Therefore, the isolated effects of body orientation were observed to determine if the vestibular system, like corticoreticulospinal pathways, influences the generation of upper extremity joint torque. The hypothesis was that upper extremity joint torques, specifically constituents of the flexion synergy, would increase in the seated position, suggesting a facilitatory influence of the vestibular system possibly via reticulospinal pathways. Understanding the neural mechanisms underlying the loss of independent joint control following stroke will lead clinicians to more accurate movement diagnoses and the development of more targeted and effective interventions.

Materials and Methods

Eleven individuals with chronic stroke (see *table 1* for description) and a comparison group of 10 right-handed individuals without stroke or other motor impairment (22-28 yrs; 6 female/4 male) participated in this research study. Individuals with stroke were recruited from an inter-institutional research registry at Rehabilitation Institute of Chicago and Northwestern University while the comparison group was recruited through advertising within the Department of Physical Therapy and Human Movement Sciences. Unimpaired individuals served as a convenience sample with the initial hypothesis that no change in arm torque would be observed. The possibility that differences in age influenced the results is explored in the discussion section. Prior to the experiment, all participants gave informed consent to participate in the study. It was approved by the Institutional Review Board of Northwestern University in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki for research involving human subjects.

The inclusion criteria for individuals with chronic stroke required: 1) Hemiparetic stroke with moderate to severe impairment of the upper limb and 2) Capacity to provide informed consent. The exclusion criteria for the sample population of individuals with stroke eliminated anyone with: (1) abnormalities in muscle tone, gross motor impairment, and/or sensory impairment in the nonparetic limb; (2) severe wasting or contracture of the paretic upper limb; (3) significant sensory deficits in the paretic upper limb; (4) severe cognitive or affective dysfunction; (5) severe concurrent medical problems; (6) brainstem lesions as determined from participant report or clinical/radiological reports; or 7) pacemakers.

Participants were randomly assigned to either sitting or supine starting orientation and strapped into a Biodex (Biodex Medical Systems, Inc., Shirley, New York, USA) chair with shoulder and waist nylon belts configured such that the participant was firmly pressed against the back of the chair (figure 1). The straps were used to constrain movement of the scapula and trunk during the experiment. Each participant's forearm, wrist, and hand of either the impaired arm (individuals with stroke) or right arm (comparison group) were secured with a fiberglass cast coupled to a 6-degrees-of-freedom load cell (JR3 Inc., Woodland, CA, USA; Model #45E15A). In sitting and supine, the arm position relative to the torso was duplicated using manual goniometric measurement. The arm position (shoulder, elbow), as defined by the International Society of Biomechanics recommendation¹⁸ is:

Plane of elevation rotation = 65 degrees

(Negative) elevation = 50 degrees

Axial rotation = 0 degrees

Elbow angle = 90 degrees

Limb segment lengths and joint angles were measured for the calculation of joint torques using a two-link model. The load cell was calibrated, i.e. set to zero, to remove the effects of gravity on limb and apparatus mass prior to collecting data in each body orientation. For the zeroing procedure, the participant was asked to remain at rest, and a reading was collected from the load cell for a 250-ms time window. The mean values from the zeroing time frame were subsequently subtracted from load cell recordings for that individual in that body position session. Therefore, the orientation of each joint to gravity (vertical) had no impact on the magnitude of joint torque production. Orthogonal forces and torques were measured at the load cell, used to calculate joint torques online, and saved for future offline analysis.⁸

Isometric maximum voluntary torque

Each volunteer generated an isometric maximum voluntary torque (MVT) for each of 6 directions: shoulder flexion, shoulder extension, shoulder abduction, shoulder adduction, elbow flexion, and elbow extension, in randomized order, for each body orientation similar to previous experiments.^{10,4} Each trial began with a 0.5-second recording of the participant at rest, continued with a “go” signal indicating to the individual to push/pull as strong as possible, while researchers provided verbal encouragement, and ended after 5 seconds. Participants observed real-time joint torque feedback visually in the form of a dial for the intended direction. Strict criteria were enforced in order to obtain the most accurate representation of maximum voluntary torque. These criteria required that a minimum of 3 trials be within 10% of the largest and that the last trial collected not be the largest.⁸ This minimized the likelihood of additionally collected trials being larger and ensured accurate representation of MVT for each condition.

Body orientation indices (BOIs) were calculated from MVTs in order to normalize the data between subjects in the two groups. The BOI was defined as the change in MVT between

sitting and supine over the average of the MVT from both orientations ($BOI = (MVT^{sit} - MVT^{supine}) / [1/2(MVT^{sit} + MVT^{supine})]$). A negative BOI indicates greater strength in supine, and a positive BOI represents greater strength in sitting for a given task direction.

All data were checked for normality of distribution with the Lilliefors Test and homogeneity of variance with two-sample F-test for equal variance. MVT comparisons between sitting and supine were conducted for the stroke group with paired t-tests for each torque direction. MVT comparisons between sitting and supine were conducted for individuals without stroke with paired t-tests for the torque directions of shoulder abduction and shoulder flexion while Wilcoxon Paired-Sample Sign-Rank Tests were used for the remaining torque directions due to lack of normal distribution. Wilcoxon Rank-Sum Tests were used to assess differences between groups in BOI for each torque direction. The Wilcoxon Rank-Sum Tests were used due to the lack of normal distribution and homogeneity of variance in several of the sample means.

Isometric multi-joint strength

A specific measurement of multi-joint strength was administered to both groups in both body orientations. The measurement of elbow extension MVT during a standardized abduction level provided a measure of “task dependent weakness” or ability to generate a torque pattern outside of the abnormal flexion synergy.⁸ The task required individuals to hold a set amount of shoulder abduction at 50% of his or her MVT. A tolerance of plus/minus 15% around 50% was permitted due to the difficulty of the task. While abducting the shoulder, the participant was required to generate an elbow extension MVT without allowing the shoulder abduction torque to change or surpass the tolerance. The value recorded from each 10-second trial was the peak elbow extension torque that occurred while shoulder abduction was within the 50±15% range (for example see figure 2). Up to 15 trials were recorded with visual feedback and verbal encouragement. Experimenters terminated this portion of the experiment after performance reached a plateau and results were consistent across 5 trials.

Peak elbow extension torque during 50±15% shoulder abduction was determined utilizing a 6th-order 4-Hz low pass Butterworth filter. Elbow extension torques were normalized to elbow extension MVT for each body orientation. A univariate (normalized elbow extension torque) 2-factor (group, body orientation) ANOVA was used to determine the effect of body orientation and group on normalized maximal elbow extension during 50% shoulder abduction.

Visual feedback

Real-time visual feedback was provided via computer monitor of the torque produced at the shoulder and/or elbow joint (figure 3). During the single-joint task, only feedback in the instructed direction (for example, shoulder extension) was provided to the participant. In the multi-joint task, feedback was provided for both shoulder abduction and elbow extension simultaneously, similar to previous work.¹⁰

Electromyography Processing for the Isometric Multi-Joint Task

Muscle activity data in the form of electromyographs (EMGs) were recorded for the brachioradialis, biceps brachii, triceps brachii lateral head, and triceps brachii long head for use in interpreting the results of the isometric multi-joint task. The elbow flexor with the largest physiological cross sectional area, brachialis,¹⁹ was not included because it has been shown to be tightly coupled to activation of brachioradialis⁴ and would require the use of invasive intramuscular recording. A multichannel Delsys system (Delsys, 16-channel Bagnoli EMG System, Boston, MA, USA) with active (1000x amplification) differential

electrodes was used to record surface activity (spacing 1cm, parallel bars, 6-Hz single-pole high pass Butterworth filter at the electrode) and low pass filter the signals at a 500-Hz cutoff through 8th order Butterworth filters (Frequency Devices Model 9016, Haverhill, MA, USA). The amplification provided by the low pass filters was adjusted for each channel to maximize recording precision without clipping the signal. Data were sampled at 1 kHz on a National Instruments data acquisition board. Data were post-processed to determine maximum EMG values temporally offset by 50 ms to the corresponding joint torque to account for the electromechanical delay.²⁰ Post-processing steps included full-wave rectification and a 2-way (zero-phase) 4-Hz 6th-order digital Butterworth filter. Additional processing included weighting of each muscle's EMG by its unit action vector and its physiological cross-sectional area in order to calculate the muscle vector via methods described by Yao et. al.²¹ Muscle vectors for the four elbow joint muscles were then used to calculate a muscle selectivity index²¹ to quantify elbow extensor and flexor co-contraction as a function of body orientation for each group.

A univariate (absolute EMG) 2-factor (group, body orientation) ANOVA was used to determine the effect of group and body orientation on absolute EMG for each of the four elbow muscles. Four *a priori* comparisons (four elbow joint muscles) were made for each group using the Student paired t-test with a Bonferroni correction to determine the difference between body orientations on absolute EMG. A univariate (muscle vector) 2-factor (group, body orientation) ANOVA was used to determine the effect of group and body orientation on muscle vector for each of the four elbow muscles. Four *a priori* comparisons (four elbow joint muscle vectors) were made for each group using the Student paired t-test with a Bonferroni correction to determine the difference between body orientations on muscle vector. A univariate (muscle selectivity index) 2-factor (group, body orientation) ANOVA was used to determine the effect of group and body orientation on muscle selectivity index.

Results

Nine individuals with chronic hemiparetic stroke and a comparison group of 10 individuals without stroke completed all single-joint maximum voluntary torque tasks in sitting and supine. One participant only completed the supine portion of the experiment and could not return due to scheduling conflicts. Another participant experienced pain near the styloid process of the radius and the first metacarpal during shoulder extension and thus could not generate a maximum voluntary effort in that direction. Eight individuals with chronic stroke were able to hold 50±15% of shoulder abduction for greater than 250 ms to be included in the multi-joint task analysis.

Isometric maximum voluntary torques

Mean absolute MVTs for each group and torque direction are shown in figure 4. MVTs were greater in sitting than in supine for both groups for shoulder flexion ($p=0.01$ non-stroke; $p=0.04$ stroke). Additionally, elbow flexion ($p=0.03$) and shoulder extension ($p=0.05$) MVTs were greater in sitting in individuals with stroke. Changes between MVTs in supine and sitting are shown in figure 5 in the form of BOIs from the paretic arms of individuals with stroke and dominant arms of individuals without stroke for the torque directions where individual group MVT differences were significant. The relative change in strength between orientations as represented by BOI was greater in individuals with stroke for elbow flexion ($p=0.04$) and shoulder extension ($p=0.03$) but not for shoulder flexion.

Isometric multi-joint task

Maximal voluntary elbow extension values were recorded over a 250-ms window while participants maintained 50% MVT of shoulder abduction for each orientation. There was a significant effect of group ($p=0.002$) but not body orientation ($p=0.59$) on the ability to extend the elbow while maintaining 50% MVT shoulder abduction (figure 6). There was no interaction effect of group by body orientation ($p=0.62$).

Electromyographic data recorded during the maximal elbow extension demonstrates strong triceps activity and minimal biceps activity in both groups (figure 7). However, there was a main effect of group in that individuals with stroke showed greater activation of the brachioradialis ($p=0.03$), which was consistent with the lower output extension torque in both body orientations and the flexion synergy pattern.^{22,4,23} While biceps activity appeared to be greater in individuals with stroke, it did not reach statistical significance to show an effect of group. There was no main effect of body orientation or interaction effect of group by body orientation for any of the four measured muscles ($p>0.05$) that was consistent with joint torque findings. *A priori* comparisons of absolute EMG found no significant differences between body orientations for either group.

Calculation of muscle vectors similarly demonstrates strong activation of the extensors, specifically lateral head of the triceps, in both groups (figure 8). Similar to absolute EMGs, there was a significant effect of group on the brachioradialis muscle vector ($p=0.003$) demonstrating increased activation in individuals with stroke. There was no main effect of body orientation or interaction effect of group by body orientation for any of the four measured muscle vectors ($p>0.05$) that was also consistent with joint torque findings. *A priori* comparisons of muscle vectors found no significant differences between body orientations for the four muscles in each group.

The muscle selectivity index demonstrates that individuals with stroke have impaired ability to selectively activate elbow extensors during the multi-joint task without abnormal co-contraction of the elbow flexors (figure 9). There was an effect of group ($p=0.03$) but not body orientation ($p>0.05$) for the muscle selectivity index.

Discussion

In this experiment, the effect of body orientation on maximum voluntary upper limb isometric torque was investigated in individuals with moderate-to-severe chronic hemiparetic stroke and a comparison group of individuals without stroke. While all participants generated greater maximal voluntary torque in shoulder flexion in a seated position, only individuals with stroke had greater elbow flexion and shoulder extension MVTs in sitting. Correspondingly, there were larger BOIs in individuals with stroke than in individuals without stroke for elbow flexion and shoulder extension. Notably, the torque directions of elbow flexion and shoulder extension are part of the *flexion synergy*² suggesting that torque generation following stroke may be influenced by the vestibular system and that constituent torques of the flexion synergy may be amplified in sitting. This conclusion is inconsistent with recent related work. Jankelowitz and Colebatch investigated galvanic stimulation evoked vestibulocollic (sternocleidomastoid) and vestibulospinal (soleus) reflexes in individuals with stroke and reported no difference between affected and unaffected sides.²⁴ However, of the individuals tested, only 5 demonstrated increased startle reflex, which the same authors have reported to be enhanced following stroke.¹¹ The lack of enhanced vestibular reflexes on the affected side along with the lack of increased startle reflex could have been explained by the presence of substantial residual corticospinal pathways. In this study, individuals with moderate to severe upper extremity impairment

were recruited. These individuals have substantial loss of descending corticospinal pathways and are hypothesized to have increased reliance on bulbospinal pathways.^{8,4}

The specific amplification of flexion synergy torque constituents in sitting in individuals with stroke was significant and could be explained by excitatory vestibulospinal and/or vestibuloreticular connections. Although there is little evidence of direct monosynaptic influence of the vestibulospinal tract on upper extremity motor neurons, polysynaptic changes in response to posture may modulate upper limb control.²⁵ In our study, vestibulospinal input to the cord may have acted to facilitate specific joint torques. A more likely contribution from the vestibular system would be through vestibuloreticular connections. There is a complex, likely polysynaptic or disynaptic, connectivity between vestibular neurons and reticulospinal neurons.²⁶ Vestibuloreticular projections connect Deiters' nucleus to reticular nuclei to distribute vestibular afferent information to the reticular formation.²⁷⁻³¹ Excitatory input from vestibular nuclei may have facilitated the predominant reticulospinal pathways to the affected arm of individuals with stroke. This explains the increases in torques that are constituents of the reticulospinal-mediated flexion synergy.

The ability to generate a multi-joint torque pattern outside of the flexion synergy did not change as a function of body orientation, suggesting that direct vestibulospinal or vestibular projections to reticulospinal motor pathways are unlikely to be the primary mechanism of abnormal joint torque coupling and loss of independent joint control following stroke. Instead, mounting evidence points toward cortico-reticulospinal motor pathways as the most likely neural mechanism.^{32,33,3,10,7,34,4} This neural mechanism is supported by the multi-joint task in this study, as individuals with stroke generated far less normalized elbow extension torque than controls in both body orientations. The torque data was reinforced not only by the increased absolute EMG and muscle vector of brachioradialis during shoulder abduction, but also by the reduced muscle selectivity in individuals with stroke. Presumably, brachialis was co-activated with brachioradialis⁴ contributing to an overwhelming abnormal flexion torque production in individuals with stroke. The reduction in ability to selectively activate elbow extensors without co-contraction of the flexors ultimately impairs elbow extension production during shoulder abduction.

Considering the mechanism of increased reliance on cortico-reticulospinal motor pathways following stroke, facilitatory output from vestibular nuclei to reticulospinal neurons would be expected to scale-up the flexion synergy; thus, the lack of findings for an effect of body orientation on the multi-joint task was unexpected. A reduced ability to generate elbow extension in the presence of shoulder abduction would have occurred if the reticulospinal pathway was facilitated in sitting. The lack of changes in the multi-joint task between body orientations could be explained by age-related morphological changes of the vestibular system. Both click- and galvanic-evoked vestibulocolic responses reduce steeply after the seventh decade of life.³⁵ Although 50% of individuals with stroke included in this study were over the age of 60, it is unlikely that declining vestibular functioning accounts for the reason that sitting did not enhance the expression of flexion synergy. Considering the well-studied enhanced reliance on bulbospinal pathways following stroke and the changes observed in the single joint task, the more likely explanation is that the reticulospinal pathway was indeed facilitated in individuals with stroke while sitting upright. In the multi-joint task, two attributes of the task may have hindered the ability to detect facilitatory influences of the vestibular system in sitting. First, 50% maximum shoulder abduction may have been too demanding, activating the reticulospinal pathway to near full capacity and correspondingly, near maximal abnormal co-activation of elbow flexors and inhibition of elbow extensors.¹⁰ A more submaximal task may have increased the sensitivity to detect a change in response to altered body orientation. Second, the task involved generating a torque

pattern outside of the flexion synergy. A task that generated a torque pattern within the flexion synergy (shoulder abduction/shoulder extension/elbow flexion) may also have been more sensitive to detect facilitatory influences of the vestibular system in response to altered body orientation, since the impact on elbow flexors (activation) is far more robust than the impact on elbow extensors (inhibition) during shoulder abduction.¹⁰ Exclusion of the other shoulder/elbow multi-joint combinations was a limitation of this study and should be investigated in future work. Finally, the inability to detect a difference in the multi-joint task may have simply been due to the small sample size limiting the power of the statistical test and increasing the likelihood of a type-II error.

Clinical Implications

Regardless of the limitations of the multi-joint task, the results from the single-joint task were significant and carry important implications for clinical practice. What must be questioned when considering these results, is the reliability and validity of strength testing in individuals with stroke. Previous work has highlighted the importance of testing strength, such as elbow extension, additionally in combination with standardized levels of shoulder abduction in order to account for the influence of abnormal joint torque coupling on torque generation.^{10,36} Similarly, tests of reaching function in both a supported condition and in combination with standardized levels of abduction loading remains an essential portion of assessment.^{37,38} This study demonstrates a closely related confounding factor that must also be considered during the assessment of strength in patients with stroke: the influence of the vestibular system on joint torque generation. For example, evaluation of strength in the supine position before an intervention and evaluation of strength in the sitting position after the intervention could provide an invalid representation of strength gains. Mounting emphasis on the use of reliable and valid outcomes in rehabilitation mandates the consideration of all factors, such as body orientation, that may influence the measured gains in response to rehabilitation.

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Abbreviations

EMG	Electromyographs
MVT	Maximum voluntary torque
BOI	Body orientation index

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Figure 1.

The experimental setup is shown in sitting (*center*) and supine (*left*) positions. A fiberglass cast bonds the participant's arm to the six degrees-of-freedom load cell (*lower right*). The load cell is mounted on a rigid frame, which may be fixed in a variety of configurations (*left*). Careful goniometric measurements ensure accurate reproduction of arm position in the sitting and supine body orientations. A mobile visual display is used to provide feedback to the individual in both orientations.

Figure 2.

A multi-joint task trial example displays the $50 \pm 15\%$ abduction (*dashed line*) required while voluntarily generating maximum elbow extension (*star* near 9.5 seconds on the elbow flexion/extension (EF/EE) torque trace) (*lower trace*). The grayed region indicates the times during which shoulder abduction (SAB) (*upper trace*) was outside the required range. Normalized (*left y-axis*) and absolute values (Nm, *right y-axis*) are listed on the vertical axes.

Figure 3.

The feedback display for the two-joint task incorporates two elements: shoulder abduction controls rotation (*thick gray bar*) and elbow extension moves the entire cursor circle (*on the right*) leftward. The target shoulder abduction (*long dashed pie wedge on the right cursor*) is $50 \pm 15\%$ of the individual's maximum voluntary shoulder abduction torque in a given body orientation. Individuals attempt to move the cursor to the left toward maximum elbow extension (*dashed circle*) while maintaining the shoulder abduction needle within the pie wedge.

Figure 4.

Mean maximum voluntary torque and standard errors are shown for both groups for the torque directions of shoulder flexion (SF), shoulder extension (SE), shoulder abduction (SAB), shoulder adduction (SAD), elbow flexion (EF), and elbow extension (EE). Significant paired comparisons are indicated with an asterisk.

Figure 5.

Mean body orientation index (BOI) and standard errors for individuals with stroke (*gray*) and individuals without stroke (*black*) are displayed for only the torque directions that had significant changes in MVT (shoulder flexion, SF; shoulder extension, SE; and elbow flexion, EF). There was a significant increase in BOI for individuals with stroke for the SE and EF torque directions indicated with an asterisk.

Figure 6.

Mean normalized elbow extension torque and standard errors during 50% abduction MVT in sitting and supine for individuals with stroke (*gray*) and individuals without stroke (*black*) demonstrate a significant effect of group but not body orientation or interaction effect of group and body orientation on elbow extension torque during 50% abduction MVT.

Figure 7.

Mean absolute EMGs and standard errors for brachioradialis, biceps brachii, lateral head of triceps brachii, and long head of triceps brachii are presented for the individuals without stroke and individuals with stroke. An asterisk indicates a significant effect of group for brachioradialis. There was no effect of body orientation or interaction effect of group and body orientation on EMG. *A priori* paired comparisons found no significant difference between body orientations for each muscle in both groups.

Figure 8.

Mean muscle vectors and standard errors for brachioradialis, biceps brachii, lateral head of triceps brachii, and long head of triceps brachii are shown for the individuals without stroke and individuals with stroke. The significant effect of group for brachioradialis is indicated with an asterisk. No effect of body orientation or interaction effect of group and body orientation on EMG was observed. In both groups, *a priori* paired comparisons found no significant difference between body orientations for each muscle.

Figure 9.

Mean muscle selectivity index and standard errors for each body orientation in both groups are presented, and an asterisk indicates a significant effect of group. There was no effect of body orientation or interaction effect of group and body orientation on muscle selectivity index.

Table 1

Demographic information for the participants with chronic stroke.

Age	Time since stroke (year, month)	Gender	Affect side	Fugl-Meyer (x/66)
60yr	4, 11	F	R	14
62	12, 2	M	R	18
53	13, 11	M	L	10
71	7, 3	F	L	10
39	4	M	L	37
58	2, 6	M	L	43
65	1, 1	F	L	21
49	4, 3	F	R	37
61	6, 11	M	L	35
53	8	M	R	18
64	6, 2	M	L	37