Alterations in intermuscular coordination underlying isokinetic exercise after a stroke and their implications on neurorehabilitation

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Research

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Abstract

Background: Abnormal intermuscular coordination limits the motor capability of stroke-affected upper limbs. By evaluating the intermuscular coordination in the affected limb under various biomechanical task constraints, the impact of a stroke on motor control can be analyzed and intermuscular coordination-based rehabilitation strategies can be developed. In this study, we investigated upper limb intermuscular coordination after a stroke during isokinetic movements.

Methods: Sixteen chronic stroke survivors and eight neurologically intact individuals were recruited. End-point forces and electromyographic activities of the shoulder and elbow muscles were measured while the participants performed isokinetic upper limb movements in a three-dimensional space. Intermuscular coordination of the stroke survivors and the control participants was quantified in the form of muscle synergies. Then, we compared the number, composition, and activation coefficients of muscle synergies and the end-point force between the groups. The correlation between the alteration of muscle synergies and the level of motor impairment was investigated.

Results: Four and five muscle synergies in the stroke and control groups were observed, respectively. The composition of muscle synergies was comparable between the groups, except that the three heads of the deltoid muscle were co-activated and formed one synergy in the stroke group, whereas those muscles formed two synergies in the control group. When the number of muscle synergies between the groups matched, the comparable composition of muscle synergies was observed in both groups. Alternatively, the modulation of synergy activation coefficients was altered after a stroke. The severity of motor impairments was negatively correlated with the similarity of the post-stroke synergies with respect to the mean control synergies.

Conclusions: Stroke-affected upper limbs seemed to modularize the activation of the shoulder and elbow muscles in a fairly similar way to that of neurologically intact individuals during isokinetic movements. Compared with free (i.e., unconstrained) movement, exercise under biomechanical constraints including the isokinetic constraint might promote the activation of muscle synergies independently in stroke survivors. We postulated the effect of biomechanical constraints on the intermuscular coordination and suggested a possible intermuscular coordination-based rehabilitation protocol that provides the biomechanical constraint appropriate to a trainee throughout the progress of rehabilitation.

Full Text

This preprint is available for download as a PDF.

Figures

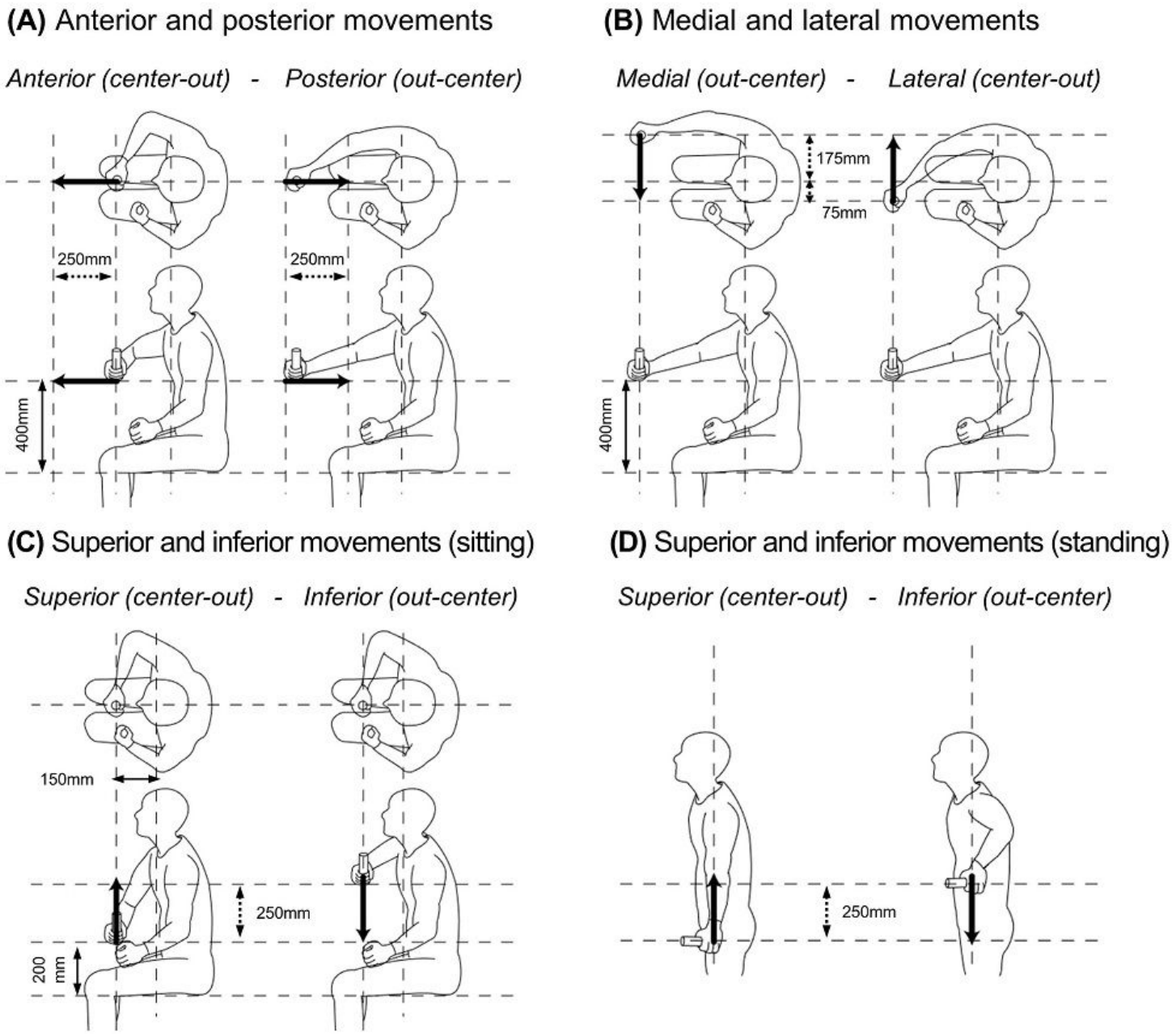

Figure 1

Upper limb movements examined in this study. The participants moved their hands 250 mm (see red arrows) in one direction and returned to the initial position after a rest of two seconds. The numbers with the black double-headed arrows represent key dimensions to determine the initial positions of the handle relative to the participants.

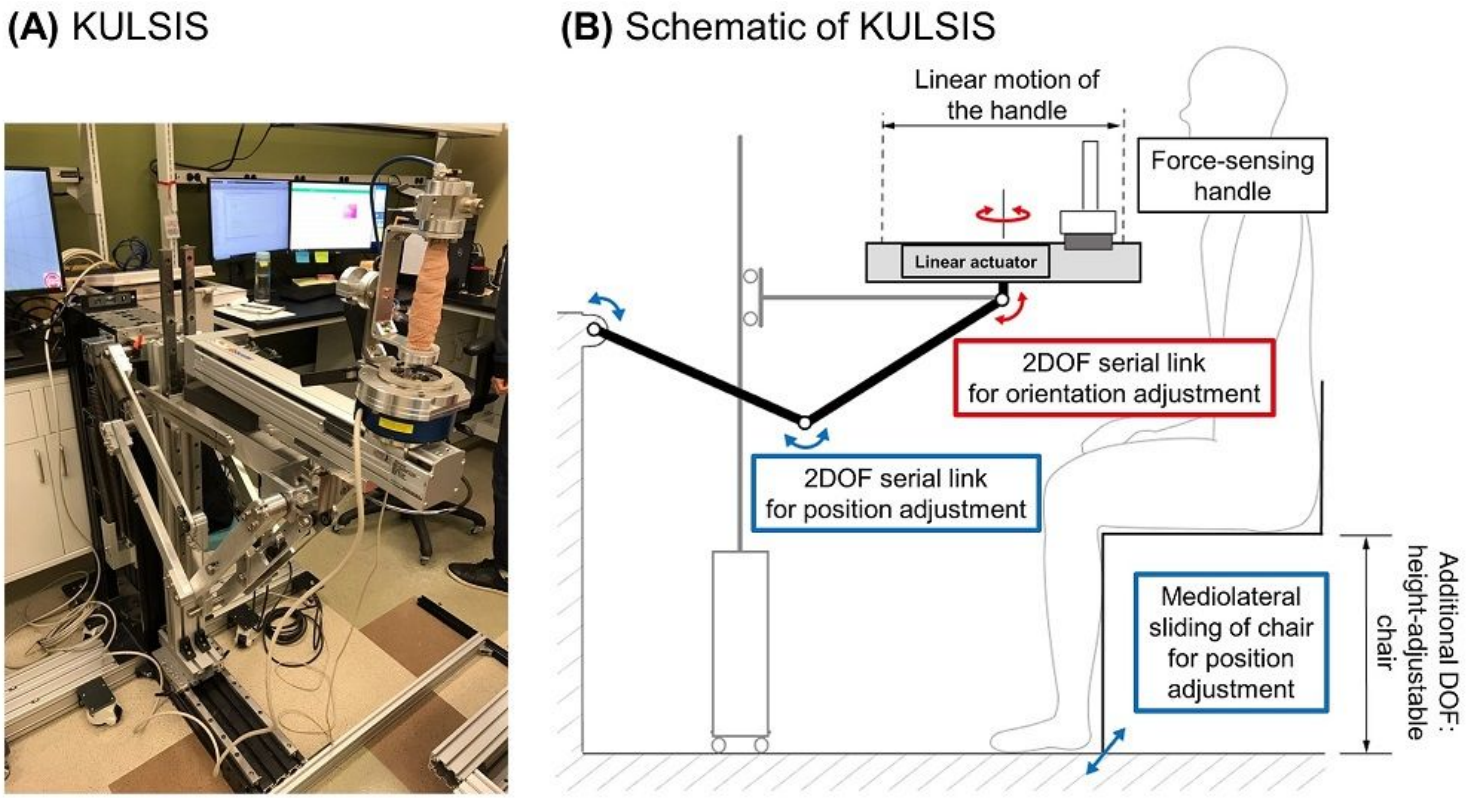

Figure 2

(A) Experimental setup, KULSIS, and (B) its schematic. The linear actuator is aligned to a participant using the 3DOF mechanism for position adjustment (blue arrows) and the 2DOF mechanism to adjust its orientation (red arrows).

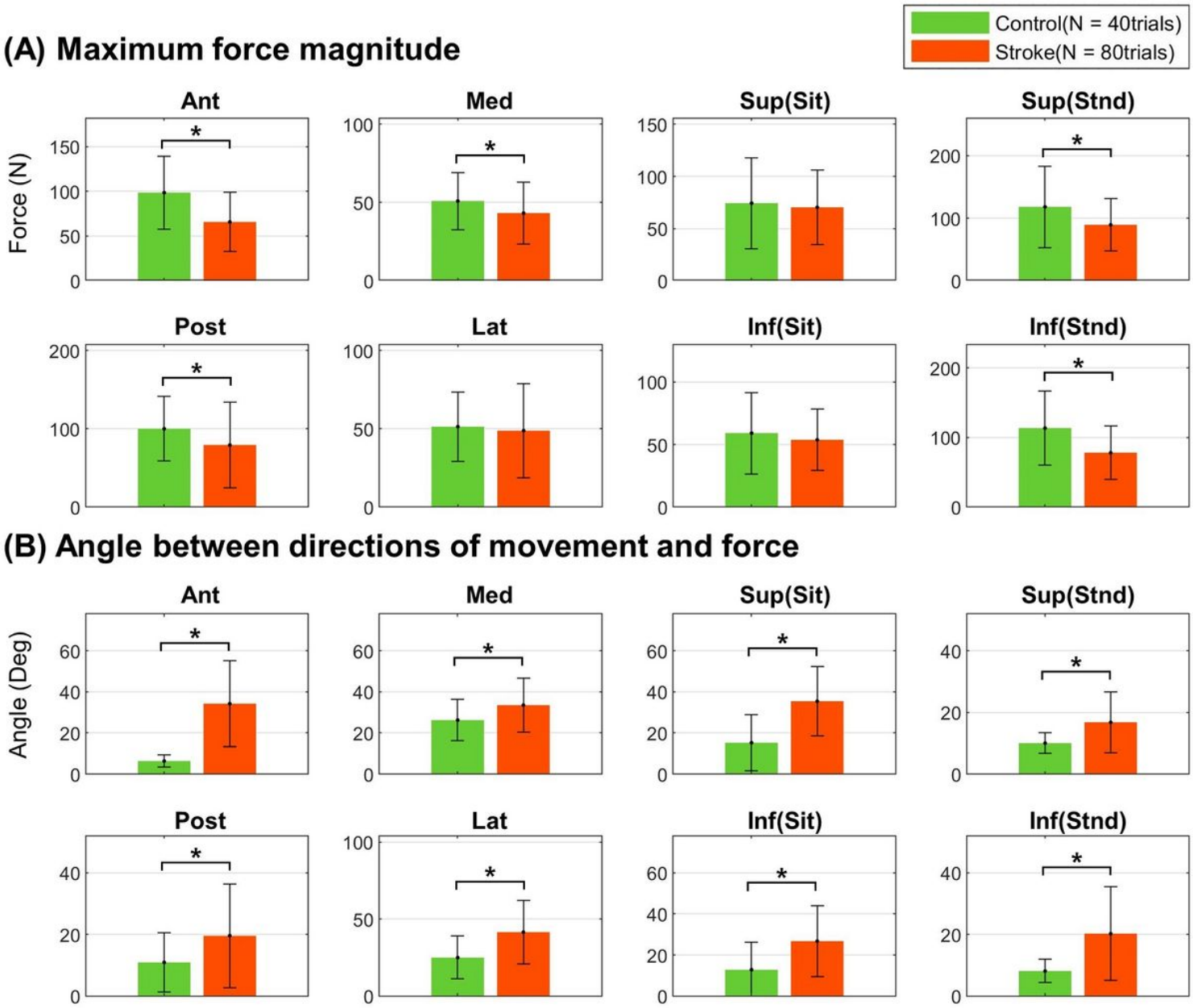

Figure 3

Inter-group difference of end-point force. (A) The mean maximum force magnitude and (B) the mean angle between the directions of the movement and the force. The error bars represent one standard deviation. Asterisks represent the statistical difference between control and stroke groups (Wilcoxon rank-sum test, $p<0.050$). Ant, anterior movement; Post, posterior movement; Med, medial movement; Lat, lateral movement; Sup, superior movement; Inf, inferior movement; Sit, in a sitting posture; Stnd, in a standing posture.

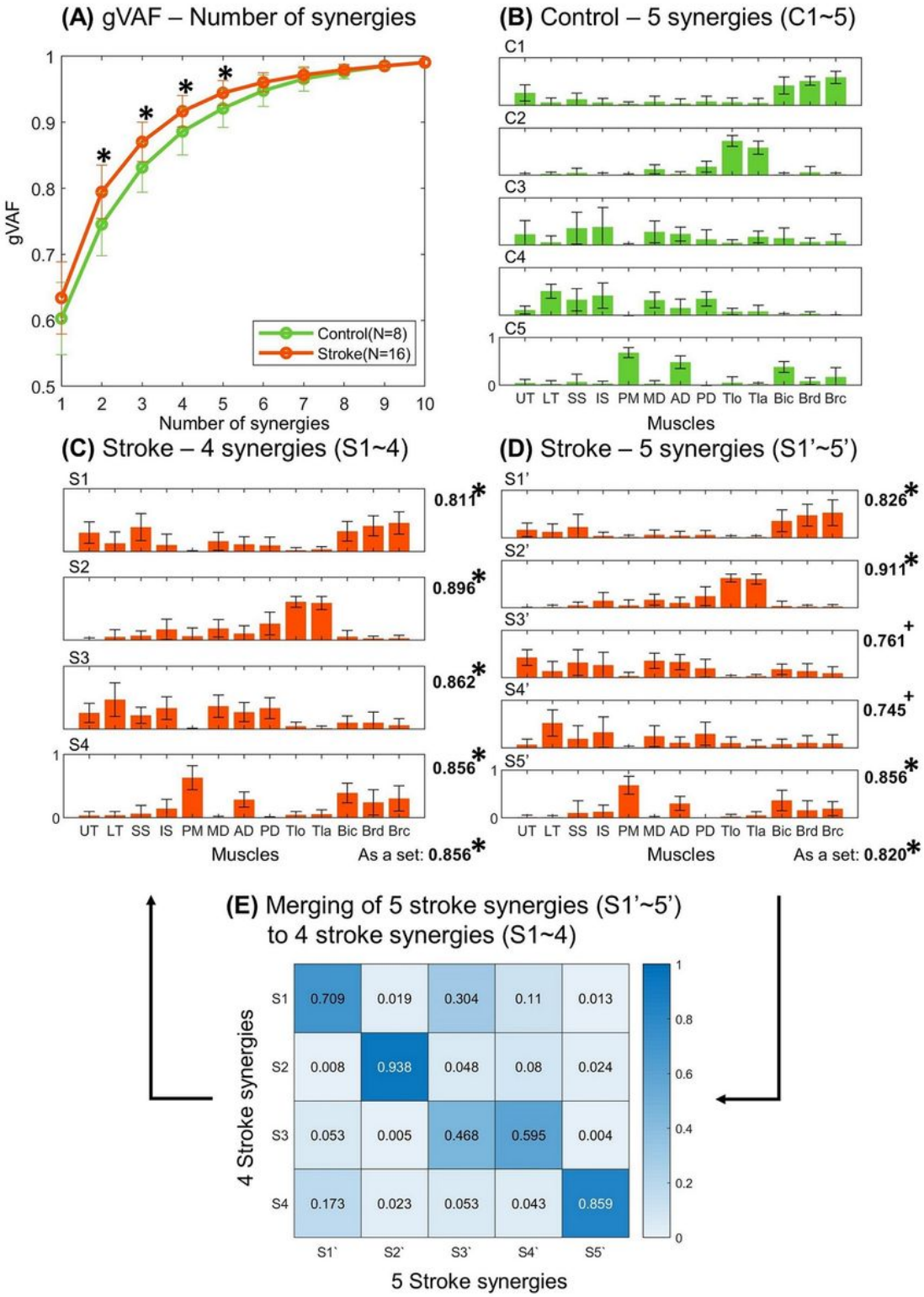

Figure 4

Number and composition of muscle synergies. (A) The gVAF values (mean ± SD) of the stroke (orange) and the control (green) groups. An asterisk represents a statistical difference between the two groups (Wilcoxon rank-sum test, p<0.050). The mean composition of (B) five synergies (C1~C5) of the control group, (C) four synergies (S1~S4) of the stroke group, and (D) five synergies (S1'~S5') of the stroke group. Standard deviations are represented as error bars. The numbers to the right of the graphs

represent the mean similarity of the individual synergy vector and the similarity of the set of synergy vectors of stroke participants to the mean synergy vectors of the control group. An asterisk represents a statistical difference between each similarity value and its corresponding similarity by chance (Sign test, p<0.050). (E) Mean merging coefficients of five to four stroke synergy vectors. The merging coefficients above 0.2 are considered as a significant merging of synergies.

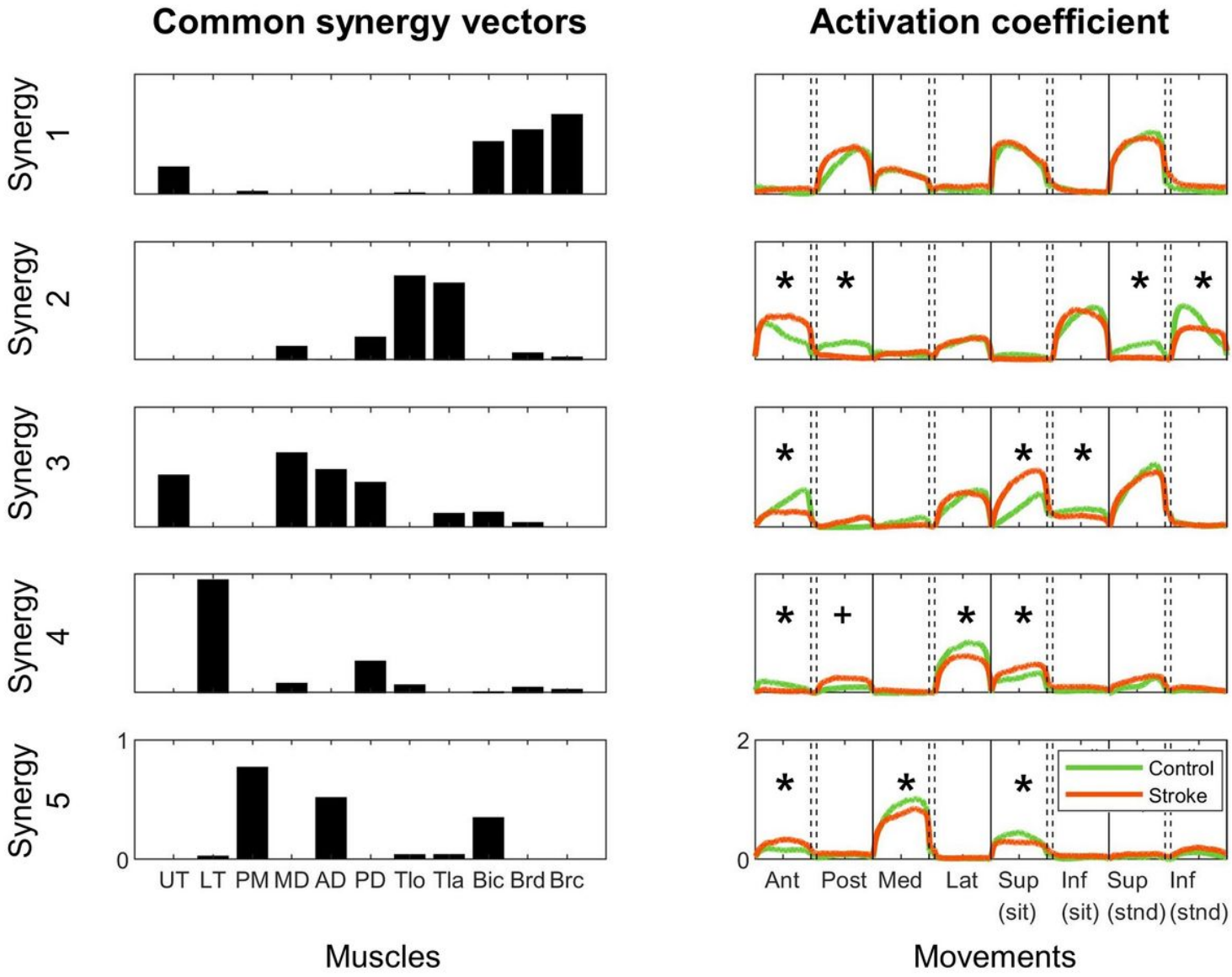

Figure 5

Common synergy vectors (left) and their activation coefficients (right). Activation coefficients of the common synergy vectors were compared between the stroke survivors (orange) and the control participants (green). Asterisks represent the statistically significant difference in the activation coefficient between the groups (Wilcoxon rank-sum test, p<0.05). Cross implies the difference in which statistical significance was marginal (p=0.05). Ant, anterior movement; Post, posterior movement; Med, medial movement; Lat, lateral movement; Sup, superior movement; Inf, inferior movement; Sit, in the sitting posture; Stnd, in the standing posture.

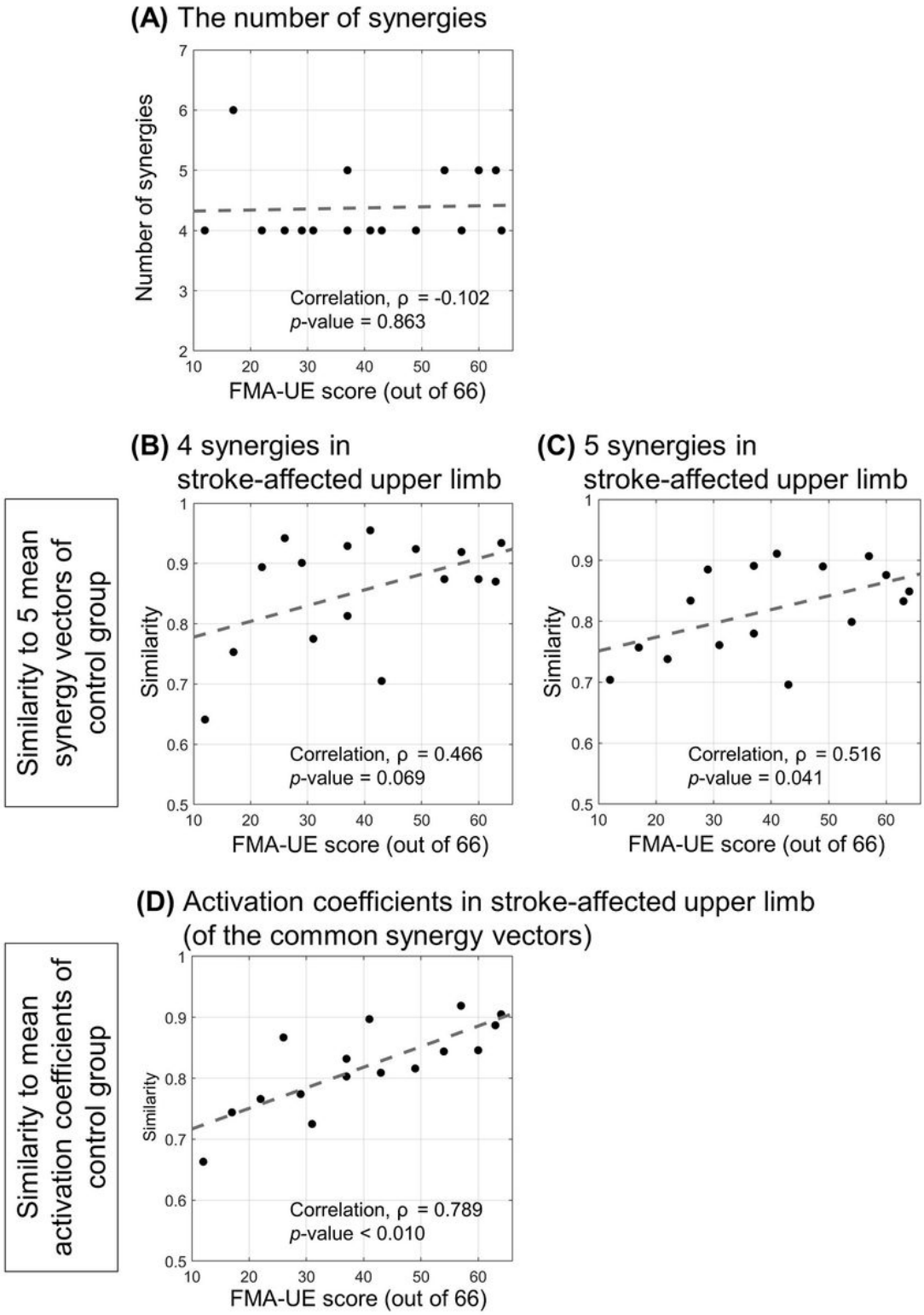

Figure 6

Correlation of muscle synergies post stroke and the FMA-UE score. (A) the number of synergies, the similarity scores of (B, C) synergy vector, and (D) activation coefficient of stroke participants with respect to mean synergy vectors and activation coefficient of the control group. The grey broken lines represent the lines of linear regression.