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Research Report

Impact of Trunk Support on Upper Extremity Function in People With Chronic Stroke and Healthy Controls

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ABSTRACT

Background

Trunk control is thought to contribute to upper extremity (UE) function. However, this common assumption has not been validated.

Objective

To investigate the effect of providing an external trunk support on trunk control and UE function, and examine the relationship between trunk control and UE function in people with chronic stroke and healthy controls.

Design

A cross-sectional study was conducted.

Methods

Twenty-five participants with chronic stroke and 34 age and sex-matched healthy controls were recruited. Trunk control was assessed using the Trunk Impairment Scale (TIS), UE impairment and function were assessed with Fugl-Meyer (FMA-UE) and Streamlined Wolf Motor Function Test (SWMFT) respectively. The TIS and SWMFT were evaluated, with and without an external trunk support; the FMA was evaluated without trunk support.

Results

With trunk support, participants with stroke demonstrated improvement in TIS from 18 to 20 points ($p<0.001$); reduction in SWMFT performance time (SWMFT-Time) of the affected UE from 37.20 to 35.37 seconds ($p<0.05$); and improvement in the affected UE function (SWMFT-Functional Ability Scale) from 3.3 to 3.4 points ($p<0.01$). With trunk support, SWMFT-Time of healthy controls was reduced from 1.61 to 1.48 seconds ($p<0.001$) for the dominant, and from 1.71 to 1.59 seconds ($p<0.001$) for the non-dominant UE. Significant moderate correlation was found between TIS and FMA-UE ($r = 0.53$) in participants with stroke.

Limitations

The limitations include a non-blinded assessor and a standardized height of the external trunk support.

Conclusions

External trunk support improved trunk control in people with chronic stroke; and had a statistically significant effect on UE function in both people with chronic stroke and healthy controls. The findings suggest an association between trunk control and UE when an external trunk support was provided. This supports the hypothesis that the provision of lower trunk and lumbar stabilization from an external support enables an improved ability to use the UE for functional activities.

INTRODUCTION

Stroke affects control of the trunk muscles and therefore ability to remain upright, adjust to weight shifts and perform selective trunk movements to maintain stability during static and dynamic postural adjustments [1,2]. The trunk is thought to play an integral role in postural stabilization supporting controlled movement of the extremities during task performance [2,3]. The development of trunk stability and control is considered to be a prerequisite to upper extremity (UE) function and use of the hand [4]. It is hypothesized that proximal stability allows for independent use of the arms and hands in manipulative and purposeful activity [4]. However, this common assumption in neurorehabilitation has not been validated in clinical trials.

There is strong evidence that trunk control is an important predictor of overall functional outcome following stroke [5-9]. The reported variance of functional recovery after stroke explained by trunk control ranges from 45% [5,8] to 71% [10]. These studies [5-10] clearly illustrate that trunk control impacts on many facets of the recovery in people with stroke, such as activities of daily living (ADL), balance and gait. However, there is no research currently which builds upon these findings to investigate the impact of trunk control on recovery of UE function in people with stroke specifically, even though the UE plays a vital role in the performance of ADL [11,12].

Several studies on the use of trunk restraint in people with chronic stroke [13-20] have demonstrated that stabilizing the trunk to restrict compensatory trunk movements leads to improved shoulder and elbow movement resulting in improvements in reach-to-grasp. Our recent systematic review and meta-analysis revealed that trunk restraint has a moderate effect on the reduction of UE impairment, increased shoulder flexion and reduction in excessive anterior trunk movement during reaching in people with chronic stroke [21]. Taken together, the findings suggest a possible relationship between trunk and UE function. However, in previous studies [13,14,17,18], the trunk has been restrained with a chest harness, thus eliminating the need for trunk control.

Our aim was therefore to investigate the effect of an external trunk support on trunk control and UE function, and examine the relationship between trunk control and UE function in people with chronic stroke and healthy controls. The trunk support that we used, unlike the trunk restraints used in other studies [13,14,17,18], provided stability to the trunk without restricting normal movement. We hypothesized that a more stable trunk enables improved dissociation of the UE from the trunk for function. Our findings could advance understanding of how trunk control impacts on UE function in people with stroke and subsequently inform the design of targeted rehabilitation programs for the trunk and UE to optimize functional outcomes post stroke.

METHODS

Sample size calculation

Sample size was determined by a power calculation based on the between-group (stroke versus healthy) difference for the Wolf Motor Function Test (WMFT) performance time, the primary UE function outcome measure. The mean WMFT has been recorded for healthy individuals (1.20 seconds with a standard deviation (SD) of 0.20 seconds [22]) and for people with chronic stroke (7.05 seconds with SD 6.85 seconds [23]). To detect a difference of 5.85 seconds in the WMFT performance time between groups, 25 participants per group were required to achieve an 85% power in a 2-sided test at 5% significance level.

Participants

For this cross-sectional study, participants were recruited between November 2013 and March 2014 via paper and electronic advertisements and talks at seven local stroke clubs. Participants were matched for age and sex. Inclusion criteria for participants with chronic stroke were: i) aged 18 years or over; ii) more than 6 months post stroke; iii) able to understand the purpose of the study and follow simple instructions; and iv) able to sit unsupported for ten seconds. Exclusion criteria were i) people with brainstem or cerebellar stroke and ii) presence of neurological or orthopedic pathology or acute low back pain. Inclusion criteria for healthy controls were: i) aged 18 years or over; and ii) able to understand the purpose of the study and follow simple instructions; and the exclusion criteria were: history of neurological injury or disease, orthopedic spinal pathology, and orthopaedic UE pathology. The Institutional Review Board of the University of Southampton, United Kingdom, approved the study (Ethics number 7547), and all participants provided written informed consent.

Outcome measures

The Trunk Impairment Scale (TIS) was used to evaluate trunk control in the participants[1]. The TIS consists of three subscales that assess static sitting balance, dynamic sitting balance, and trunk coordination on a scale ranging from 0 to 23 points. A higher score indicates better trunk control.

Post stroke UE motor impairment was measured with the UE subsection of the Fugl-Meyer Assessment (FMA-UE) [24]. Each of the 33 items of FMA-UE was rated on a 3-point scale. The maximum score is 66 points. The UE motor function was measured with the Streamlined Wolf Motor Function Test (SWMFT) [25]. The six SWMFT tasks appropriate for people with chronic stroke were lifting hand from the table to a box, lifting a can to mouth, lifting a pencil with 3-jaw chuck grasp, folding towel, turning key in lock, and extending elbow against a one-pound weight [26]. The performance time (SWMFT-Time) of the tasks was measured with a stopwatch and a 6-point Functional Ability Scale (SWMFT-FAS) was used to rate the quality of movement during performance of the tasks [26]. The TIS, FMA-UE and SWMFT have all demonstrated good psychometric properties and good clinical utility that are appropriate for people with subacute and chronic stroke [27].

Procedures

All assessments were conducted in the research laboratory of the University of Southampton. The participants sat unsupported on a height-adjustable plinth with their thighs fully supported on the plinth, knees at 90 degrees and feet flat on the ground as the starting position. Assessment of UE impairment (FMA-UE) was only conducted for the participants with stroke. Trunk control was then assessed using the TIS; once with no external trunk support, and once with a 'size adjustable' high-density foam support around the trunk (Figure 1). By using the appropriate size trunk support to fit snugly at the posterior and lateral aspects of the trunk (up to the level between 10th and 12th thoracic vertebrae), the trunk was supported whilst allowing free forward movement and minimal movement posteriorly and laterally.

Following the trunk assessment, the UE function (SWMFT) of participants was assessed with and without trunk support. Participants with stroke performed the tasks with the unaffected UE, followed by the affected UE. The order of testing with and without the trunk support was randomized using blocked randomization [28], with a block size of four, to avoid possible order bias due to practice or fatigue, while ensuring equal numbers in each order-protocol. Healthy controls performed the tasks of SWMFT with the dominant, followed by the non-dominant UE. Hand dominance was determined by the Edinburgh Handedness Inventory–Short Form [29].

Statistical analysis

Data analysis was performed using the IBM SPSS Statistics 20 software. The level of statistical significance was set at $p < 0.05$ for all tests. The Shapiro-Wilk test was used to confirm normal data distribution.

In view of the comparison between two groups (chronic stroke and healthy groups) under two support conditions (with and without trunk support), the split plot analysis of variance (SPANOVA) was used to analyse the results of the TIS and SWMFT-Time as they are interval variables. The affected UE of participants with stroke was compared with the non-dominant UE of the healthy controls. This allowed participants with hemiparesis in the non-dominant arm to be at less of a comparative disadvantage [30]. The main effect of group, the main effect of support, and the interaction effect between group and support conditions were analysed. The SWMFT-FAS (ordinal scale) under the two support conditions was analyzed using the Wilcoxon signed rank test.

The SPANOVA was used to compare the difference in SWMFT-Time based on sex, hand dominance, the order of testing of trunk support, type of stroke and the side of affected UE for the participants with stroke, and healthy controls.

Association between TIS and SWMFT-Time, under the condition of no trunk support, was determined by the Pearson correlation coefficient as the data were normally distributed. Spearman's rho (*ρ)* was used to determine the relationship between TIS and SWMFT-FAS as SWMFT-FAS is an ordinal scale. Based on normal distribution of FMA-UE data, the Pearson correlation coefficient was used to determine the relationship between TIS and FMA-UE.

RESULTS

Participants

Twenty-five participants with chronic stroke (age 65.3 ± 12.0 years) and 34 age and sex-matched healthy controls (age 60.4 ± 12.4 years) were recruited (Table 1). There was no significant difference in the age between the participants with stroke and healthy controls. All the participants could participate in the SWMFT tasks.

Clinical outcomes

Participants with stroke demonstrated a significant improvement in the TIS score, from 18 points to 20 points ($p < 0.001$); SWMFT-FAS, from median 3.3 points to 3.4 points ($p <$

0.01); and significant reduction in the SWMFT-Time, from 37.20 seconds to 35.37 seconds ($p < 0.05$) for the affected UE with trunk support as compared to no support (Table 2).

With trunk support, SWMFT-Time of the healthy controls was reduced significantly from 1.61 to 1.48 seconds ($p < 0.001$) for the dominant UE; and from 1.71 to 1.59 seconds ($p < 0.001$) for the non-dominant UE (Table 2).

Comparison of clinical outcomes between participants with chronic stroke and healthy controls

Results from the SPANOVA showed a statistically significant difference ($F_{(1,57)} = 44.39$, $p < 0.001$) in the TIS scores between the participants with stroke and healthy controls, regardless of the support conditions (Table 3). The partial Eta-squared (η_p^2), a measure of effect size, was found to be 0.44 (large effect size). By convention, η_p^2 of 0.01, 0.06, and 0.14 is considered small, moderate, and large effect size respectively [31,32]. Participants with stroke had significantly lower TIS scores (mean 18.00 points) compared to healthy controls (mean 22.62 points). The difference in the TIS score with and without trunk support regardless of the groups, was significant ($F_{(1,57)} = 33.06$, $p < 0.001$) with a large effect size ($\eta_p^2 = 0.37$) (Table 3). Further analysis revealed a large significant interaction effect between the group and support conditions ($F_{(1,57)} = 20.60$, $p < 0.001$, $\eta_p^2 = 0.27$).

Results from the SPANOVA showed significant difference ($F_{(1,57)} = 17.63$, $p < 0.001$) in the SWMFT-Time between the participants with stroke and healthy controls, regardless of the support conditions (Table 3). The effect size was large ($\eta_p^2 = 0.24$). The difference in the SWMFT-Time between the two support conditions, regardless of the groups, was significant ($F_{(1,57)} = 5.59$, $p < 0.05$) with moderate effect size of 0.09. There was a moderate significant interaction effect between the group and support conditions ($F_{(1,57)} = 4.37$, $p < 0.05$; $\eta_p^2 = 0.07$). While the SWMFT-Time was significantly reduced with the trunk support in both groups, the reduction was significantly more in the participants with stroke (from 37.20 to 35.37 seconds) as compared to the healthy controls (from 1.71 to 1.59 seconds) (Figure 2).

There was no significant difference in the SWMFT-Time for both the participants with stroke and healthy controls based on sex ($F_{(1,57)} = 0.08$, $p = 0.78$), hand dominance ($F_{(1,57)} = 0.52$, $p = 0.48$), and the order of testing of trunk support ($F_{(1,57)} = 2.32$, $p = 0.14$). For the participants with stroke, there was no significant difference in the SWMFT-Time based on the type of stroke ($F_{(1,23)} = 0.95$, $p = 0.34$), and side of affected UE ($F_{(1,23)} = 0.07$, $p = 0.80$).

Association between TIS and the clinical variables

There were no significant correlations between TIS and SWMFT-Time (Pearson correlation coefficient $r = -0.31$, $p > 0.05$), and between TIS and SWMFT-FAS (Spearman's $\rho = 0.38$, $p > 0.05$) in the participants with stroke without trunk support. Significant moderate correlation was found between TIS and FMA-UE ($r = 0.53$, $p < 0.01$) in the participants with stroke without trunk support.

No association was found between TIS and SWMFT-Time in the healthy controls without trunk support ($r = -0.08$, $p > 0.05$). The correlation coefficient between TIS and SWMFT-FAS for the healthy controls was not calculated as all achieved the maximum score of 5 on SWMFT-FAS.

DISCUSSION

This study investigated the effect of providing an external trunk support on trunk control and UE function and also examined the relationship between trunk control and UE function in people with chronic stroke and healthy controls using clinical scales.

With trunk support, there were significant improvements in trunk control (TIS) in the participants with stroke; significant improvements in the performance of UE tasks (SWMFT-Time) and UE function (SWMFT-FAS) in both participants with stroke and healthy controls. The significant reduction in SWMFT-Time of 1.83 seconds with trunk support in participants with chronic stroke is considered a clinically important difference. The minimal clinical important difference (MCID) for the Wolf Motor Function Test time was reported to be between 1.5 seconds to 2 seconds for people with chronic stroke [23]. However, it is important to recognize that the SWMFT does not distinguish between tasks accomplished by UE movements versus those accomplished by UE movements assisted by trunk movement as no kinematic analysis was conducted in this study. We planned to conduct kinematic analysis of the trunk and UE during performance of the SWMFT tasks to understand the underlying mechanisms behind the change in outcome measures in a future study. Significant interaction effect between the group and support conditions was demonstrated for TIS and SWMFT-Time. The findings demonstrated that a higher TIS score was associated with better UE function and supports the common assumption that a stable trunk enables the dissociation of the UE from the trunk for function.

In this study, we have not investigated the mechanisms associated with the improved UE function. However, we propose possible explanations for the significant reduction in the SWMFT-Time and improvement in SWMFT-FAS when the trunk was supported. With the trunk stabilized, it enables improved movement of the proximal and distal segments of the UE to occur against a background of stabilized core muscles of the body. This is supported by a study that demonstrated significant improvement in functional reach ability of the UE in people with stroke after an intervention consisting of trunk stability exercise [33]. This suggests that trunk stability has an effect on the stability of the shoulders, and that in turn improves the movement of the elbow, wrist and fingers [34]. A stable trunk provides a solid foundation for the torque generated by the extremities [35]. Performing reaching movement on a stable surface is different from the challenges faced when attempting to reach out for objects while balancing on an unstable surface. Studies have demonstrated that unstable conditions can lead to decreased force output and muscle activation of the extremities [36,37].

Previous trunk restraint studies [13-21] have demonstrated that restriction of compensatory trunk movements by a physical restraint can lead to improved shoulder and elbow movement resulting in improvements in reach-to-grasp. Our study demonstrated an improvement in UE function (SWMFT-Time and SWMFT-FAS) with an external trunk support that was non-constraining. Taken together, stablizing or physically restricting the trunk improves UE function. This may be explained by considering the concept of “degrees of freedom” (DOF).

There are a minimum of 26 DOF for UE movement [38] and 3 DOF in each of the upper and lower trunk [39]. In other words, the motor system has to deal with at least 32 DOF of an individual during reaching task in an unsupported seated condition. Our external trunk support aids in the stabilization of the trunk, limiting trunk excursion and/or reducing the number of DOF especially in the lower trunk. This can lead to a decrease in overall demand on the motor system to reorganize the DOF of the UE into a coordinated pattern of reaching movement and thus may lead to improvements in SWMFT-Time and SWMFT-FAS. This is congruent with the findings of a recent systematic review that manipulation of the mechanical DOF of the trunk via trunk restraint during reaching enhances recovery of UE function after stroke [40].

Another possible explanation for the improvement in SWMFT-Time and SWMFT-FAS could be due to the design ("C-shaped") of the trunk support and its height (up to approximately T10-T12 vertebral level). The external support may have assisted the pelvis to tilt more anteriorly, thus facilitating the lower lumbar into a more extended position. This alteration may lead to postural improvement for UE task performance. This postulation is supported by studies that demonstrated trunk posture and alignment affect UE performance [3,41]. A neutral trunk posture and alignment significantly improved UE performance as compared to a flexed [3,41] and laterally flexed trunk postures [3]. Taken together, the findings of our study and previous studies [3,41] support the hypothesis that a stable trunk with good postural alignment enables the dissociation of the UE from the trunk for function.

No association was found between TIS and SWMFT-Time, and between TIS and SWMFT-FAS in the participants with stroke, which may be due to the relatively small sample size. However, observation of improvement in UE function with trunk support demonstrates a link between trunk control and UE. This is supported by a significant moderate correlation between trunk control and UE impairment (FMA-UE).

Based on our results, it could be suggested that incorporating external trunk support may offer opportunity for better movement re-education and facilitate better retraining of the upper extremity. However, this concept needs further exploration and appropriately designed intervention studies to examine the effect of providing external trunk support on UE function during rehabilitation following stroke.

The results of our study must be considered in the light of methodological limitations. All the assessments of the TIS, FMA-UE and SWMFT were administered by the principal investigator. This may present an element of observer bias in the study. Another potential limitation in this study was the standardized height of the trunk support; the superior part of the trunk support was at different contact points on the posterior and lateral aspects of the trunk for the participants. However, the height of the trunk support was designed so that no participants experienced restrictions as they performed lateral flexion of the trunk during the TIS assessment. To address this limitation however, future trunk supports could be created with different height dimensions. We acknowledged that the use of external trunk support would invalidate the administration of TIS. The reason for inclusion of trunk support in the experimental procedure was to simulate the situation of having someone with a "better" TIS score, i.e. with a better trunk control within the same session, and then investigated that effect on upper extremity function.

Another limitation that might confound the observed improvements in the outcome measures is the Hawthorne effect. To minimize any presence of Hawthorne effect and performance bias, the participants were not informed of the hypothesis of the study. It would be very difficult to eliminate the Hawthorne effect completely as providing a sham condition would be difficult in this study, but important for consideration in future studies.

As this was a cross-sectional study, a causal relationship cannot be drawn from the results unless future randomized controlled trials are conducted to verify the association reported in this study [42]. In this study, we did not measure trunk control from a kinematic perspective, but only from a clinical scale, based on the Trunk Impairment Scale. A future study that we planned to conduct include capturing the kinematic data to shed light on the mechanisms associated with the improved UE function with the external trunk support.

The observed improvement in trunk control and UE function with the trunk support was an immediate effect; carry-over was not assessed as this was not the aim of the study. It remains unknown whether a period of UE training with the external trunk support for people with stroke will yield sustainable gains in the improvements observed in the trunk control or UE function. A randomized controlled trial may be conducted to investigate the effectiveness of trunk support in improving UE function in the future.

Future research may consider investigating the effect of trunk support on trunk control and UE in patients with trunk ataxia due to neurological disorders such as cerebellar stroke or brainstem stroke. Gaining a deeper understanding of the underlying mechanisms of trunk stability and trunk control may provide insights into a new therapeutic approach for the management of trunk ataxia and UE in neurorehabilitation.

CONCLUSION

An external trunk support improved trunk control of people with chronic stroke; and had a statistically significant effect on UE function in both people with chronic stroke and healthy controls. The findings suggest an association between trunk control and UE when an external trunk support was provided. This supports the hypothesis that the provision of lower trunk and lumbar stabilization from an external support enables an improved ability to use the UE for functional activities.

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Figure 1 Trunk support

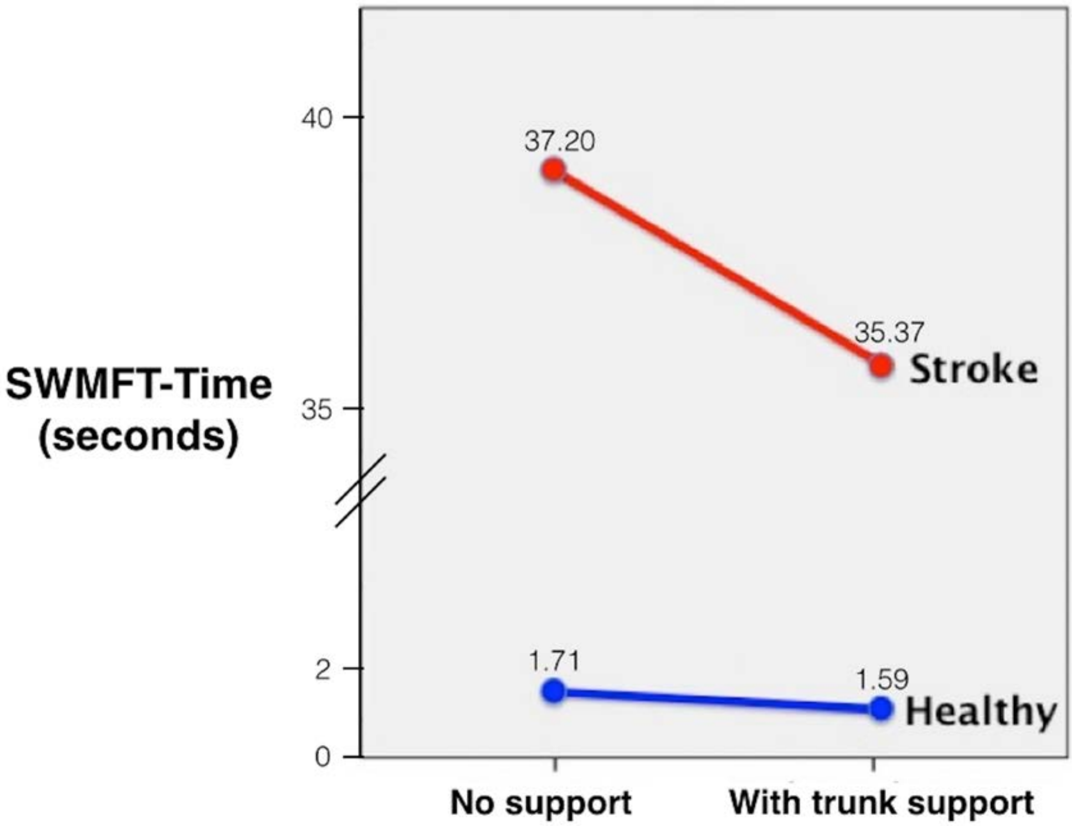

Figure 2 Moderate significant interaction effect between group and support conditions ($p < 0.05$; $\eta_p^2 = 0.07$)

η_p^2 partial Eta-squared

Table 1 Characteristics of participants

(mean ± standard deviation, and range)

Characteristics	**Healthy (N=34)**	**Stroke (N=25)**
Age (years)	60.4 ± 12.4 38 – 82	65.3 ± 12.0 38 – 84
Sex – Male Female	18 16	15 10
Time since stroke (months)	N/A	100.4 ± 107.1 12 – 432
Type of stroke – Ischemic Hemorrhagic	N/A	18 7
Hand dominance – Right Left	30 4	23 2
Affected upper extremity – Right Left	N/A	9 16
Fugl-Meyer Upper Extremity (FMA) score	N/A	41.4 ± 15.3 14 – 64
Number of participants with FMA		
≤ 20 (Severe impairment)		4
21-50 (Moderate impairment)		12
51-66 (Mild impairment)		9
Trunk Impairment Scale (TIS) score	22.6 ± 1.0 19 – 23	18.0 ± 3.8 10 – 23

Table 2 Clinical outcomes of healthy controls and participants with stroke

Outcome measure	Healthy controls (n=34)		Participants with stroke (n=25)	
	Without trunk support	**With trunk support**	**Without trunk support**	**With trunk support**
TIS (max score 23)	22.62 ± 1.02	22.85 ± 0.70	18.00 ±3.76**	20.00 ±2.80**
	95% CI [-0.10, 0.48]		95% CI [1.12, 2.88]	
SWMFT-Time Dominant UE for healthy / Affected UE for stroke (seconds)	1.61 ± 0.38**	1.48 ± 0.35**	37.20 ± 49.22#	35.37 ± 47.37#
	95% CI [0.08, 0.18]		95% CI [0.15, 3.80]	
SWMFT-Time Non-dominant UE for healthy / Unaffected UE for stroke (seconds)	1.71 ± 0.34**	1.59 ± 0.30**	8.12 ± 9.18	7.31 ± 8.82
	95% CI [0.04, 0.19]		95% CI [-0.59, 2.22]	
SWMFT-FAS Dominant UE for healthy / Affected UE for stroke (max score 5)	5	5	Median 3.3* (Q1-Q3: 1.8-4.3)	Median 3.4* (Q1-Q3: 1.9-4.4)
SWMFT-FAS Non-dominant UE for healthy / unaffected UE for stroke (max score 5)	5	5	5	5

TIS – Trunk Impairment Scale; SWMFT – Streamlined Wolf Motor Function Test; FAS – Functional Ability Scale;
UE – Upper extremity
mean ± standard deviation
Q1: first quartile
Q3: third quartile
CI –Confidence Interval
[note: the figures presented refer to the CI of difference in the two (without trunk support versus with trunk support) means.]

**p<0.001; *p<0.01; #p<0.05

Table 3 SPANOVA results of TIS and SWMFT-Time for healthy controls and participants with stroke

Clinical outcome	**Group**	**Without support** mean ± SD	**With support** mean ± SD	**Effect**	**F value**	***p* value**	**Partial Eta-squared** η_p^2
TIS	Stroke Healthy	18.00 ± 3.76 22.62 ± 1.02	20.00 ± 2.80 22.85 ± 0.70	Group	44.39	0.001	0.44
				Support	33.06	0.001	0.37
				Support x Group	20.60	0.001	0.27
SWMFT-Time	Stroke Healthy	37.20 ± 49.22 1.71 ± 0.34	35.37 ± 47.37 1.59 ± 0.30	Group	17.63	0.001	0.24
				Support	5.59	0.05	0.09
				Support x Group	4.37	0.05	0.07

Support x Group: interaction effect
SD: standard deviation