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Review Article

Do trunk exercises improve trunk and upper extremity performance, post stroke? A systematic review and meta-analysis

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Abstract.
Background: Post-stroke trunk control is reported to be associated with trunk performance and recovery of the upper limb, but the evidence for the influence of trunk exercise on both of these is unclear.
Objective: To evaluate the effect of trunk exercises on trunk performance post-stroke, and to determine if these exercises result in improved upper limb function.
Methods: A comprehensive search of the literature published between January 1990 and February 2017 was conducted using the following electronic databases; AMED, CINAHL, Cochrane Library, EMBASE, MEDLINE, PsychInfo and SPORTDiscus. Only randomized, controlled trials, published in English, evaluating the effect of trunk exercises on trunk performance and/or upper limb function post-stroke, were included.
Results: A total of 17 studies involving 599 participants were analysed. Meta-analysis showed that trunk exercises had a large significant effect on trunk performance post-stroke. This effect varied from very large for acute stroke to medium for subacute and chronic stroke. None of the included studies had measured the effect of trunk exercise on upper limb impairment or functional activity.
Conclusions: Trunk exercises improve trunk performance for people with acute, subacute and chronic strokes. As yet there is no evidence to support the effect of trunk exercise on upper limb function.

Keywords: Meta-analysis, systematic review, stroke, trunk exercise, trunk, upper limb

1. Introduction

The trunk is the central, key point of the body; it plays a postural role in holding the body upright and in performing selective trunk movements, during static and dynamic postural adjustments (Davies and Klein-Vogelbach 2012; Edwards 1996). Trunk performance is an important predictor for outcomes of balance, gait and activity of daily living (ADL), after a stroke (Franchignoni et al. 1997; Hsieh et al. 2002; Verheyden et al. 2007). The percentage of the variance of functional recovery after a stroke is explained by trunk control ranges from 45% to 71% (Hsieh et al. 2002; Verheyden et al. 2007). One study has shown an overall functional independency evaluated in the

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early acute phase, post-stroke; it has been shown to be highly correlated to levels of trunk impairment, followed by upper extremity impairments but not lower extremity impairments (Likhi et al. 2013).

Studies measuring trunk performance after a stroke have used various clinical tools, including the Trunk Control Test (TCT), the Trunk Impairment Scale by Fujiwara (TIS-F) and the Trunk Impairment Scale by Verheyden (TIS-V) (Collin et al. 1990; Verheyden et al. 2004; Fujiwara et al. 2004). These three tools exhibit good psychometric properties and are suitable for use within the clinical setting; they do not require specialised equipment. The TCT measures trunk control in static positions, giving relatively minimal information. The TIS-V measures during selective movements of the trunk, in both static and dynamic positions, including flexion, extension, lateral flexion and rotation (Verheyden et al. 2004). The TIS-F has only been used in two studies to assess the impairment of the trunk in people with a stroke, neither of which applied trunk exercises (Likhi et al. 2013; Fujiwara et al. 2004). The trunk impairment scale (TIS) that will be referred to throughout the rest of this paper is the TIS-V. Rasch analysis of the TIS led to the elimination of the static sitting balance subscal (Verheyden & Kersten, 2010).

People with strokes can have trunk impairments (weakness, loss of selective coordinated muscle action, overactive muscles and stiffness) that lead to insufficient trunk control. This might interfere with their ability to carry out ADL (Verheyden et al. 2007). The Barthel Index measures the degree of independence in performing ADL, such as feeding, transfer, toilet use, bathing, walking, climbing stairs, dressing, bowel and bladder control (Verheyden et al. 2007). It has been reported that the static sitting balance subscale of TIS predicted 50% of the variance in the Barthel Index score, six months after a stroke (Verheyden et al. 2007). Moreover, a recent cross-sectional study has reported that there is a relationship between trunk control, as measured by the TIS, and the ability to use the upper extremities in functional activities amongst people with chronic strokes (Wee et al. 2015).

Trunk control is considered to be a vital component in many facets of stroke recovery, such as balance, gait and functional ability (Verheyden et al. 2004). Several studies emphasize the importance of including trunk training exercises to improve trunk performance and functional recovery after a stroke (Langhorne et al. 2009). The UK Royal College of Physicians (RCP) National Clinical Guidelines for Stroke recommends, “People with impaired sitting balance after stroke should receive trunk training exercises” (National clinical guideline for stroke 2016; p.73). A systematic review conducted in 2013 explored the effects of focused trunk exercise programmes on trunk impairment (Cabanas-Valdes et al. 2013). Efficacy results from a total of 11 RCTs, included in the systematic review, demonstrated that there was moderate evidence for using trunk training exercises, on stable and unstable surfaces, as a method of improving dynamic sitting, balance and trunk performance in both sub-acute and chronic strokes. However, the intensity of trunk exercise and the best trunk training strategies are still unclear. Although a recent study reported that trunk control has an association with the recovery of the upper extremities, the influence of trunk exercise on both trunk impairment and upper extremity function is still unclear (Wee et al. 2015). Therefore, the aim of this systematic review is to evaluate the effects of trunk training or sitting balance exercises on trunk control and upper extremity function, following strokes.

2. Methodology

This systematic review was conducted in accordance with the Cochrane Handbook for Systematic Reviews and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Higgins & Green 2011, Moher et al. 2009).

2.1. Literature search procedure

A comprehensive search of the literature published between January 1990 and February 2017 was conducted, using the following electronic databases; AMED, CINAHL, Cochrane Library, EMBASE, MEDLINE, Physiotherapy Evidence Database (PEDro), PsychInfo and Sport Discus. The following keywords were used; stroke, cerebrovascular accident, paresis, trunk, balance, equilibrium, physical therapy, exercise, motion therapy, rehabilitation, upper limb, upper extremity, reach, reach-to-grasp, grasp. Truncations were used where deemed appropriate. A secondary search of hand-searching of reference lists was also performed to identify additional relevant studies. An example search strategy for MEDLINE is found in Appendix 1.

The title and abstract of the retrieved search results were examined to identify potential eligible publications. If the title and abstract fitted the inclusion criteria, the full text articles were retrieved. The inclusion criteria were the following:

1. Randomised controlled trials (RCT) published in the English language.
2. Involving adults with strokes (age 18 years or older).
3. Intervention involved any form of balance exercise, trunk strength training and/or any form of trunk exercise with or without conventional physiotherapy (CPT). Trunk exercises (TE) were defined as any form of exercises regimens consist of selective movements of the upper and lower part of the trunk with or without raising the upper extremities in supine and/or sitting position (Cabanas-Valdes et al. 2013).
4. Interventions not performed with robotics or functional electrical stimulation alone
5. The studies include a minimum of one of the following primary outcomes:
    a. Trunk performance as measured by Trunk Control Test (TCT) or the Trunk Impairment Scale (TIS).
    b. Upper extremity function as measured by valid and reliable upper extremity outcome measures.

The following data were extracted from included studies: author, year, participant's age, sample size, stroke stage, outcome measures, treatment characteristics and main findings (Tables 1 and 2). The main author (AN) assessed the methodological quality of all the included studies using the Cochrane risk of bias tool and the PEDro scale (Table 3), which uses a cut-off score of six points to distinguish high from low quality studies (Higgins & Green 2011)· The papers were split between two other reviewers (AMH, RT) to independently assess the methodological quality using the same tools. The authors discussed any inconsistencies related to the quality criteria until a consensus was reached.

2.2. Data synthesis

A meta-analysis was conducted where suitable data were available, to examine the effect of trunk exercise on trunk performance and upper extremity function. For the outcome measure of trunk performance, the numbers of each group, means and standard deviations were extracted from the corresponding measures. The overall effect size was calculated by using standardised mean differences (SMD) with 95% Confidence Intervals (CI) using Review Manager Software 5.1((http://ims.cochrane.org/revman/download). The SMD was chosen because of the different measurement tools used to measure the same outcome (trunk performance) (Higgins & Green 2011).The effect size was categorized as; 0.2, 0.5, 0.8, and 1.3, considered as small, medium, large and very large, respectively (Turner et al. 2013).

Further subgroup analysis explored the effect of trunk exercise on trunk performance, relative to the stroke stage (time from stroke), and duration of the intervention ($\geq$16 hours, or $<$16 hours). The stroke stage was divided, according to the subject inclusion criteria of the studies included, into three stages; the acute stage for subjects who were less than one month post-stroke duration; the sub-acute stage for subjects who were more than one month and less than six months since the onset, and the chronic stage for subjects who were at more than six months' post-stroke duration (Bae et al. 2013, Buyukavci et al. 2016, Cabanas-Valdes et al. 2016, Chan et al. 2015, de Sèze et al. 2001, Fujino et al. 2016, Haruyama et al. 2017, Jung et al. 2014, Jung et al. 2016, Karthikbabu et al. 2011, Kilinc al. 2016, Kumar et al. 2011, Lee et al. 2012, Saeys et al. 2012, Shine et al. 2016, Verheyden et al. 2009, Yoo et al. 2010). The choice of a 16 hours cut-off duration for the exercise time was based upon the last systematic review, which reported that a study which used 16 hours of specific trunk exercise resulted in the highest improvement in trunk performance (Cabanas-Valdes et al. 2013). When the data were not suitable to be included in the pooled analysis, a descriptive analysis was performed. The heterogeneity was measured using the I^2 statistic; when the heterogeneity was $\leq 50\%$, the fixed-effect model was used, otherwise the random-effect model was used for the meta-analysis (Higgins & Green 2011).

3. Results

The search procedure is presented in the PRISMA flowchart in Fig. 1. A total of 224 studies were retrieved (after the removal of duplicates). Of these, 87 studies were excluded, after screening the titles and abstracts, because they did not meet the inclusion criteria. Full-text copies were obtained for the remaining 22 studies and reviewed independently by the author (NA). Five articles were excluded because they did not meet the inclusion criteria (Appendix 2).

Table 1
Included studies characteristics

Author, year	N	Age (yr) Mean (SD)	Stroke stage
Bae et al. 2013	16	E1 : 53.4 (5.8) E2 : 52.4 (7.6)	Chronic
Buyukavci et al. 2016	65	E : 62.6 (10.5) C : 63.6 (10.4)	Acute
Cabanas-Valdés et al. 2016	80	E: 74.92 (10.70) C: 75.69 (9.40)	Sub-acute
Chan et al. 2015	37	E1 : 58.2 (10.7) E2 : 56.3 (7.4) C: 59.3 (10.4)	Chronic
de Sèze et al. 2001	20	E:63.5 (17) C: 67.7 (15)	Sub-acute
Fujino et al. 2016	43	E: 67.9 (7.8) C: 64.4 (7.5)	Acute
Haruyama et al.2017	32	E: 67.56 (10.11) C: 65.63 (11.97)	Sub-acute
Jung et al. 2014	18	E: 51.9 (10.3) C: 57.9 (8.5)	Chronic
Jung et al. 2016	24	E: 58.9 (11) C: 60.7 (7.8)	Chronic
Karthikbabu et al. 2011	30	E: 59.8 (10.5) C: 55 (6.5)	Acute
Kilinc et al. 2016	22	E: 55.91 (7.92) C: 54 (13.64)	Chronic
Kumar et al. 2011	20	E: 59.5 (12.09) C: 57.8 (13.49)	Acute
Lee et al., 2012	28	E: 59 (11) C: 62.3 (4.2)	Chronic
Saeys et al. 2012	33	E: 61.04 (13.83) C: 61.07 (9.01)	Sub-acute
Shin et al. 2016	30	EG: 60 (8.4) CG: 57.4 (10.3)	Chronic
Verheyden et al. 2009	33	E: 55 (11) C: 62 (14)	Sub-acute
Yoo et al. 2010	59	E:59.61(18.16) C:61.77(12.58)	Sub-acute

E = experimental group, *C* = control group, Acute = less than one month since onset, Subacute = more than 1 month and less than 6 months since onset, Chronic = more than 6 months since onset.

Finally, 17 full-text articles met the inclusion criteria and were included in this study (Bae et al. 2013, Buyukavci et al. 2016, Cabanas-Valdes et al. 2016, Chan et al. 2015, de Sèze et al. 2001, Fujino et al. 2016, Haruyama et al. 2017, Jung et al. 2014, Jung et al. 2016, Karthikbabu et al. 2011, Kilinc al. 2016, Kumar et al. 2011, Lee et al. 2012, Saeys et al. 2012, Shine et al. 2016, Verheyden et al. 2009, Yoo et al. 2010).

The sample size of the studies included ranged from 16 to 80 participants, totalling 590 stroke patients, with a mean age range from 51.9 to 75.69 years. The stroke patients were also at different stages, from acute through to chronic phases, post-stroke.

Trunk performance was assessed using the Trunk Impairment Scale (TIS) in 15 studies and in three studies using the Trunk Control Test (TCT). The outcome measures and key findings of the studies are summarized in Table 2.

The total intervention time of the exercise regime ranged from a minimum of 1.5 hours to a maximum of 36 hours, and the duration ranged from 1 to 12 weeks. The dose of the intervention ranged from 15 minutes per day, five days a week, to 120 minutes per day, five days a week. The type of exercise ranged from exercises related to the trunk impairment scale tasks, use of technology (e.g. Functional Electrical Stimulation (FES), Smartphone-Based Visual Feedback Trunk Training), to those using training on a stable or unstable surface (Table 2).

3.1. Risk of bias assessment

The assessment of methodological quality and risk of bias presented in bias are presented in Fig. 2 and Table 3.

3.2. Meta-Analysis

A meta-analysis of the 17 clinical trials, using the TIS and TCT as a common outcome measure, was undertaken. The meta-analysis was made between the trunk exercise group and the conventional therapy group.

The meta-analysis of the TCT and total TIS score, pooled the data from 17 studies with a total of 320 participants in the trunk exercise group and 317 in the control group. The results demonstrated that trunk exercises had a large, significant effect on improving trunk performance, as measured by TCT and/or TIS, in favour of the experimental group (SMD = 0.85; 95% CI = 0.58 to 1.12; $P < 0.00001$; I2 = 59%, random effect model; Figure 3).

The meta-analysis of the TCT score only pooled data from three studies with a total of 53 participants in a trunk exercise group and 56 in the control group. The results showed that trunk exercise had a small, non-significant effect on improving trunk performance as measured by TCT, in favour of the experimental group (SMD = 0.34; 95% CI=–0.04 to 0.72; $P = 0.08$; I2 = 0%, fixed effect model; Figure 4).

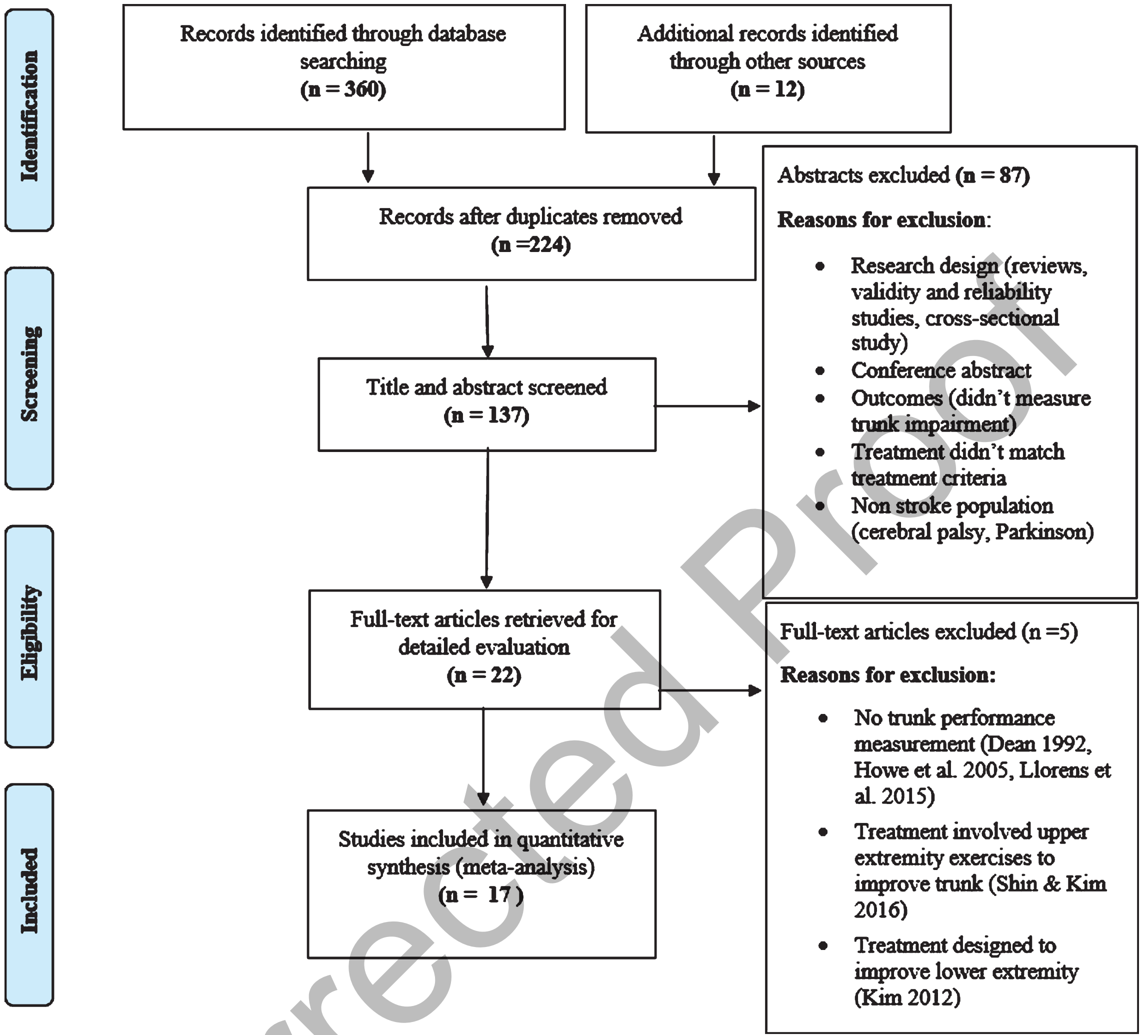


Fig.1. Prisma Flow chart.

The meta-analysis of the total TIS score only pooled data from 14 studies with a total of 227 participants in the trunk exercise group and 222 in the control group. The results showed that trunk exercise had a large, significant effect upon improving trunk performance as measured by TIS, in favour of the experimental group (SMD = 0.98; 95% CI = 0.65 to 1.32; $P < 0.001$; I2 = 61%, random effect model; Figure 5).

The subgroup analysis of trunk impairment subscales revealed a medium, non-significant effect size in the pooled data of the static subscale (SMD = 0.45; 95% CI=–0.06 to 0.95; $P = 0.08$; I2 = 64%, random effect model; Figure 6), a large, significant effect in pooled data of the dynamic subscale (SMD = 0.99; 95% CI = 0.76 to 1.21; $P < 0.001$; I2 = 45%, fixed effect model; Figure 6) and a large, significant effect in pooled data of the coordination subscale (SMD = 0.76; 95% CI = 0.41 to 1.12; $P < 0.001$; I2 = 58%, random effect model; Figure 6).

The subgroup analysis of the TCT and total TIS pooled data at different stroke stages demonstrated a very large, significant effect on improving trunk performance in favour of the experimental group at the acute stroke stage (SMD = 1.57; 95% CI = 0.76 to 2.47; $P = 0.0006$; I2 = 79%, random effect model; Figure 7). In the sub-acute stage, trunk exercise had a medium, significant effect on improving trunk performance in favour of the experimental group (SMD = 0.67; 95% CI = 0.44 to 0.90; $P < 0.00001$; I2 = 42%, fixed effect model; Figure 7). In the chronic

Table 2
Treatment characteristics of the included studies

Author, year	Experimental group intervention	Control group intervention	Follow-up	Outcome measures	Results
Bae et al. 2013	E1: Trunk stabilization exercises on a stable support surface - 12 wk (30 min./d,5X/wk) E2: Trunk stabilization exercises on an un-stable support surface - 12 wk (30 min./d,5X/wk)	—	NO	TIS	* Total TIS E1 ** Total TIS E2
Buyukavci et al. 2016	Conventional rehabilitation for 2–3 hours+additional trunk balance exercise - 3 wk (120 min./d,5X/wk)	Conventional rehabilitation includes group-neurodevelopmental facilitation techniques and OT - 3 wk (120 min./d,5X/wk)	NO	TIS	¬Total TIS,static sitting, dynamic, coordination subscales
Cabanas-Valdéset al 2016	1 hour of patient specific conventional physiotherapy+Additional core strengthening exercise - 5 wk (15 min./d,5X/wk)	1 hour of patient specific conventional physiotherapy - 5 wk (15 min./d,5X/wk)	No	TIS	** Total TIS, dynamic, coordination subscales
Chan et al. 2015	E1: transcutaneous electrical nerve stimulation (TENS)+task-related trunk training (TRTT) - 6 wk (60 min./d,5X/wk) E2: placebo-TENS+(TRTT) - 6 wk (60 min./d,5X/wk)	Placebo-TENS - 6 wk (60 min./d,5X/wk)	Yes	TIS	* TIS dynamic subscale in all groups) * TIS coordination subscale in E1 group ¬Total TIS,static sitting subscale in all groups
de Sèze et al. 2001	Phase1 : 1 hour conventional rehabilitation+1 hour on Saint Come Device - 4 wk (60 min./d,5X/wk) Phase 2: conventional rehabilitation	Phase1 : 2 hours of conventional rehabilitation - 4 wk(120 min./d,5X/wk) Phase 2:conventional rehabilitation	NO	TCT	*
Fujino et al. 2016	1 hour of conventional rehabilitation+lateral sitting exercise on plinth tilted 10 degree in the paretic side - 1 wk (15 min./d,6X/wk)	1 hour of conventional rehabilitation+lateral sitting exercise on flat plinth - 1 wk (15 min./d,6X/wk)	NO	TCT	**
Haruyama et al. 2017	Conventional PT includes 20 min. of core stabilization exercises - 4 wk (60 min./d,5X/wk)	Conventional PT- 4 wk (60 min./d,5X/wk)		TIS	** Total TIS, dynamic subscale ¬TIS static sitting, coordination subscales
Jung et al. 2014	Weight-shift training on an unstable surface - 4 wk (30 min./d,5X/wk)	patient-specific and consisted physiotherapy including stretching, strengthening, and stationary bicycle - 4 wk (30 min./d,5X/wk)	NO	TIS	** Total TIS * TIS dynamic subscale ¬TIS static sitting, coordination subscales

(Continued)

Table 2
(Continued)

Author, year	Experimental group intervention	Control group intervention	Follow-up	Outcome measures	Results
Jung et al. 2016	Trunk exercise include weight shifting and arm flexion from sitting position on unstable surface - 4 wk (30 min./d,5X/wk)	Trunk exercise include weight shifting and arm flexion from sitting position on stable surface - 4 wk (30 min./d,5X/wk)	NO	TIS	* Total TIS, dynamic, coordination subscales ¬TIS static sitting subscale
Karthikbabu et al. 2011	task-specific trunk exercises on an unstable surface from supine and sitting - 3 wk (60 min./d,4X/wk)	task-specific trunk exercises on an stable surface from supine and sitting- 3 wk (60 min./d,4X/wk)	NO	TIS	** TIS total scale, dynamic, coordination subscales ¬TIS static sitting subscale
Kilinc et al. 2016	Trunk exercises according to the Bobath concept - 12 wk (60 min./d,3X/wk)	Functional activities, strengthening, stretching and ROM exercises - 12 wk (60 min./d,3X/wk)	NO	TIS	¬Total TIS, static sitting, dynamic, coordination subscales
Kumar et al. 2011	Conventional rehabilitation+additional exercise consisted of selective movements of the upper and lower part of the trunk in supine and sitting - 3 wk (45 min./d,6X/wk)	Conventional patient-specific rehabilitation - 3 wk (45 min./d,6X/wk)	NO	TIS	** Total TIS, dynamic, coordination subscales ¬TIS static sitting subscale
Lee et al. 2012	1 hour of conventional exercise+dual motor training in the sitting position - 6 wk (30 min./d,3X/wk)	1 hour of conventional exercise – 6 wk (4X/wk)	NO	TIS	* Total TIS
Saeys et al. 2012	Trunk muscle strength, coordination, and selective trunk movement exercise - 8 wk (30 min./d,4X/wk)	passive mobilization of the upper extremity and TENS for hemiplegic shoulder- 8 wk (30 min./d,4X/wk)	NO	TIS	** Total TIS, dynamic, coordination subscales ¬TIS static sitting subscale
Shin et al. 2016	Conventional rehabilitation+Smartphone-Based Visual Feedback Trunk Control Training (SPVFTCT) System - 4 wk (20 min./d,3X/wk)	Conventional rehabilitation consisted of PT, OT and ES - 4 wk (20 min./d,3X/wk)	NO	TIS	** Total TIS
Verheyden et al. 2009	Conventional rehabilitation+additional trunk exercise from supine and sitting - 5 wk (30 min./d,4X/wk)	Patient-specific Conventional treatment (PT, OT and nursing care) – 5 wk (30 min./d,4X/wk)	NO	TIS	** TIS dynamic subscale ¬TIS total scale, static sitting, coordination subscales
Yoo et al. 2010	Control treatment+additional core strengthening - 4 wk (30 min./d,3X/wk)	Neuro-developmental technique, walking, and OT - 4 wk (30 min./d,3X/wk)	NO	TIS TCT	** Total TIS ¬TCT

*Statistically significant difference between groups at $p \leq 0.05$ from pre-post; **Statistically significant difference between groups at $p \leq 0.01$ from pre-post; ¬No significant difference at $p > 0.05$ between groups.

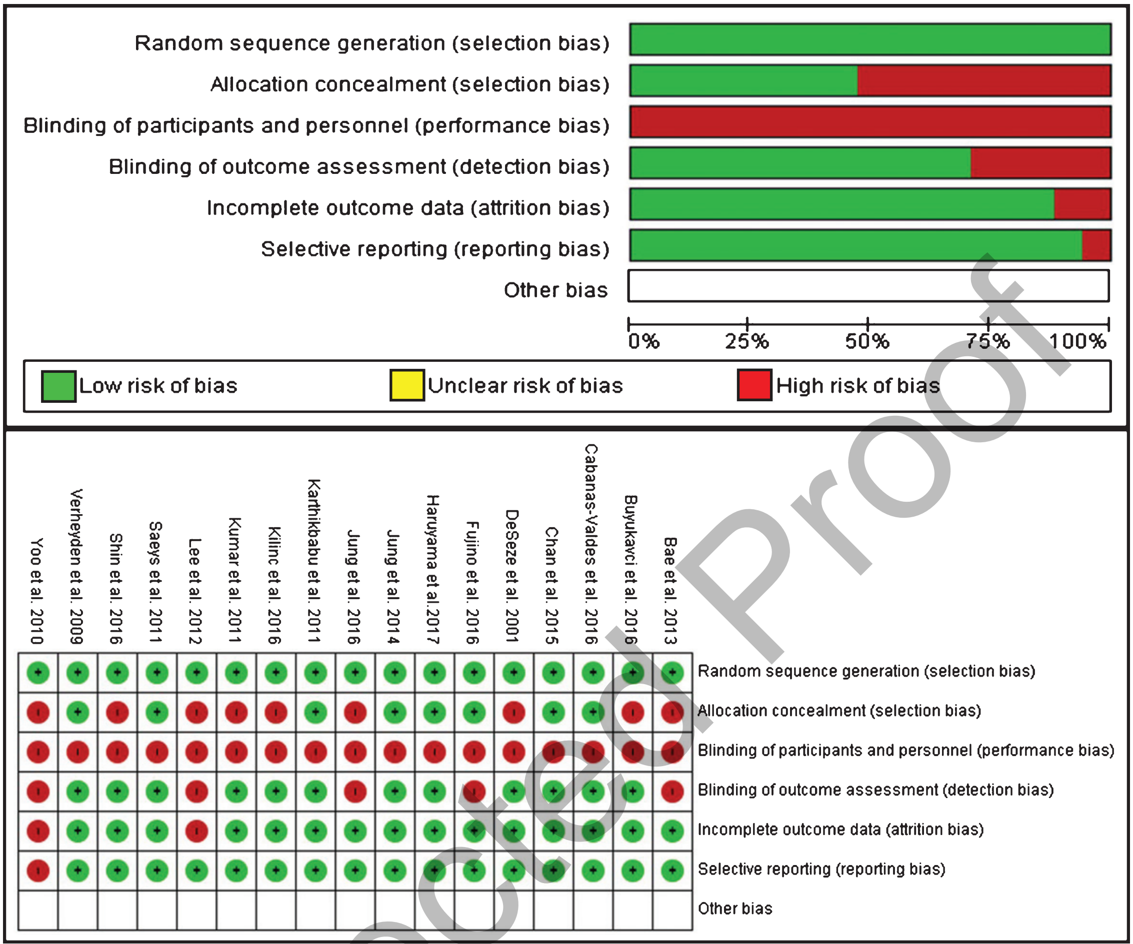


Fig. 2. Cochrane risk of bias summary.

stage, trunk exercise had a medium, significant effect on improving trunk performance in favour of the experimental group (SMD = 0.74; 95% CI = 0.42 to 1.05; P < 0.00001; I2 = 37%, fixed effect model; Figure 7).

The subgroup analysis based upon the treatment duration demonstrated that the trunk exercise had a large, significant effect on improving trunk performance in the studies that applied ≥16 hours of trunk exercise in favour of the experimental group (SMD = 0.77; 95% CI = 0.32 to 1.22; P = 0.0007; I2 = 56%, random effect model; Figure 8). Likewise, the pooled data from the studies that applied <16 hours of trunk exercise also showed a large, significant effect on trunk performance in favour of the experimental group (SMD = 0.90; 95% CI = 0.55 to 1.26; P < 0.00001; I2 = 64%, random effect model; Figure 8).

4. Discussion

The aim of this review was to evaluate the effects of trunk exercises on trunk performance following a stroke, as well as other secondary outcomes, such as upper extremity function after a stroke. In this review, we included 17 trials with a total of 599 people with strokes and found high evidence that the inclusion of trunk training in rehabilitation sessions may improve trunk performance after a stroke. None of the included and excluded studies assessed upper extremity impairment or function, though there were studies which considered trunk exercise in relation to a lateral reach test, reach distance (both measures of dynamic sitting balance or stability) and reaching time.

The results from 17 RCTs suggest a large, significant effect from trunk exercises on trunk performance, as measured by TCT and TIS. However,

Table 3
PEDro score for included studies

Authors, year	Bae 2013	Buyukavci 2016	Cabans Valdes 2016	Chan 2015	deSèze 2001	Fujino 2016	Haruyama 2017	Jung 2014	Jung 2016	Karthikbabu 2011	Kilinc 2016	Kumar 2011	Lee 2012	Saeys 2011	Shin 2016	Verheyden 2009	Yoo 210
Random allocation	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Concealed allocation	NO	NO	YES	YES	NO	YES	YES	YES	NO	YES	NO	NO	NO	YES	NO	NO	NO
Groups similar at baseline	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Participants blinding	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Therapists blinding	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Outcome assessor blinding	NO	YES	YES	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO	YES	YES	YES	NO
Less than15% dropouts	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Intention- to treat analysis	NO	NO	NO	YES	NO	NO	YES	YES	NO	YES	NO	NO	NO	NO	YES	YES	NO
Between groups statistical comparison	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Point measures and variability data	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Total PEDro score	5	6	7	8	6	6	8	8	5	8	6	6	5	7	7	7	5

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bae et al. 2013	17.6	3.24	8	17.9	2.88	8	4.2%	-0.09 [-1.07, 0.89]
Buyukavci et al. 2016	18.7	2.7	33	14.3	4.1	32	6.9%	1.26 [0.72, 1.79]
Cabanas-Valdes et al. 2016	9.38	3.9	40	6.3	3.7	39	7.4%	0.80 [0.34, 1.26]
Chan et al. 2015	19	5.2	12	15.2	2.8	12	4.9%	0.88 [0.03, 1.72]
Chan et al. 2015	18.4	5.2	13	15.2	2.8	12	5.1%	0.73 [-0.08, 1.55]
DeSeze et al. 2001	70.3	24.2	10	70.4	21.7	10	4.8%	-0.00 [-0.88, 0.87]
Fujino et al. 2016	59.5	15.2	15	52.7	14.8	15	5.6%	0.44 [-0.28, 1.17]
Haruyama et al.2017	19.63	2.45	16	16.69	3.72	16	5.6%	0.91 [0.18, 1.64]
Jung et al. 2014	18.7	1.5	9	14.6	3.2	8	3.6%	1.59 [0.46, 2.72]
Jung et al. 2016	18.58	1.98	12	15.92	2.84	12	4.8%	1.05 [0.19, 1.91]
Karthikbabu et al. 2011	19.2	1.56	15	16.34	1.11	15	4.6%	2.06 [1.15, 2.96]
Kilinc et al. 2016	15.6	4.14	10	16.56	4.16	9	4.6%	-0.22 [-1.12, 0.68]
Kumar et al. 2011	18.43	1.1	10	14.2	1.5	10	2.7%	3.08 [1.70, 4.46]
Lee et al. 2012	12.6	5.2	14	9.1	2.8	14	5.3%	0.81 [0.04, 1.59]
Saeys et al. 2011	18.78	3.53	18	13.27	3.79	15	5.3%	1.47 [0.69, 2.26]
Shin et al. 2016	15.33	1.97	12	12.42	2.57	12	4.7%	1.23 [0.34, 2.11]
Verheyden et al. 2009	19	2.78	17	18.5	3.12	16	5.9%	0.17 [-0.52, 0.85]
Yoo et al. 2010	18.57	5.32	28	14.03	5.58	31	6.9%	0.82 [0.29, 1.35]
Yoo et al. 2010	86.14	18.17	28	75.94	28.7	31	7.0%	0.41 [-0.10, 0.93]
Total (95% CI)			**320**			**317**	**100.0%**	**0.85 [0.58, 1.12]**

Heterogeneity: Tau² = 0.20; Chi² = 44.40, df = 18 (P = 0.0005); I² = 59%
Test for overall effect: Z = 6.13 (P < 0.00001)

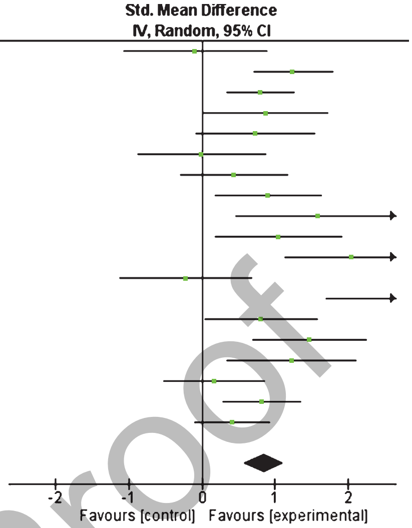


Fig. 3. Forest plot for the effect of trunk exercise on trunk performance (TCT and TIS scales).

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
DeSeze et al. 2001	70.3	24.2	10	70.4	21.7	10	18.7%	-0.00 [-0.88, 0.87]
Fujino et al. 2016	59.5	15.2	15	52.7	14.8	15	27.3%	0.44 [-0.28, 1.17]
Yoo et al. 2010	86.14	18.17	28	75.94	28.7	31	53.9%	0.41 [-0.10, 0.93]
Total (95% CI)			**53**			**56**	**100.0%**	**0.34 [-0.04, 0.72]**

Heterogeneity: Chi² = 0.75, df = 2 (P = 0.69); I² = 0%
Test for overall effect: Z = 1.77 (P = 0.08)

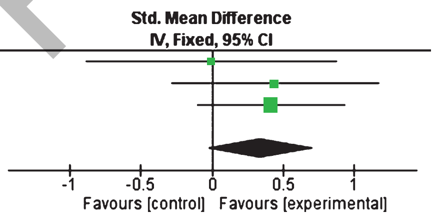


Fig. 4. Forest plot for the effect of trunk exercise on TCT.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bae et al. 2013	17.6	3.24	8	17.9	2.88	8	5.8%	-0.09 [-1.07, 0.89]
Buyukavci et al. 2016	18.7	2.7	33	14.3	4.1	32	8.8%	1.26 [0.72, 1.79]
Chan et al. 2015	18.4	5.2	13	15.2	2.8	12	6.8%	0.73 [-0.08, 1.55]
Chan et al. 2015	19	5.2	12	15.2	2.8	12	6.6%	0.88 [0.03, 1.72]
Haruyama et al.2017	19.63	2.45	16	16.69	3.72	16	7.4%	0.91 [0.18, 1.64]
Jung et al. 2014	18.7	1.5	9	14.6	3.2	8	4.9%	1.59 [0.46, 2.72]
Jung et al. 2016	18.58	1.98	12	15.92	2.84	12	6.5%	1.05 [0.19, 1.91]
Karthikbabu et al. 2011	19.2	1.56	15	16.34	1.11	15	6.2%	2.06 [1.15, 2.96]
Kilinc et al. 2016	15.6	4.14	10	16.56	4.16	9	6.2%	-0.22 [-1.12, 0.68]
Kumar et al. 2011	18.43	1.1	10	14.2	1.5	10	3.9%	3.08 [1.70, 4.46]
Lee et al. 2012	12.6	5.2	14	9.1	2.8	14	7.1%	0.81 [0.04, 1.59]
Saeys et al. 2011	18.78	3.53	18	13.27	3.79	15	7.0%	1.47 [0.69, 2.26]
Shin et al. 2016	15.33	1.97	12	12.42	2.57	12	6.3%	1.23 [0.34, 2.11]
Verheyden et al. 2009	19	2.78	17	18.5	3.12	16	7.7%	0.17 [-0.52, 0.85]
Yoo et al. 2010	18.57	5.32	28	14.03	5.58	31	8.8%	0.82 [0.29, 1.35]
Total (95% CI)			**227**			**222**	**100.0%**	**0.98 [0.65, 1.32]**

Heterogeneity: Tau² = 0.25; Chi² = 35.99, df = 14 (P = 0.001); I² = 61%
Test for overall effect: Z = 5.78 (P < 0.00001)

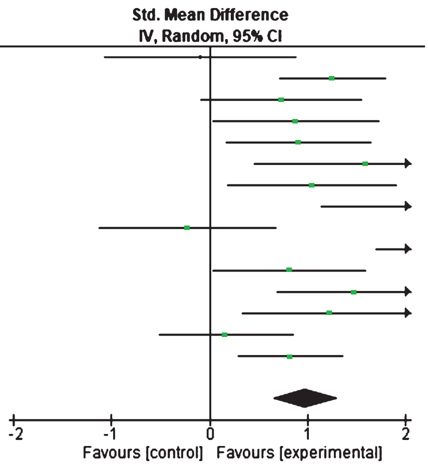
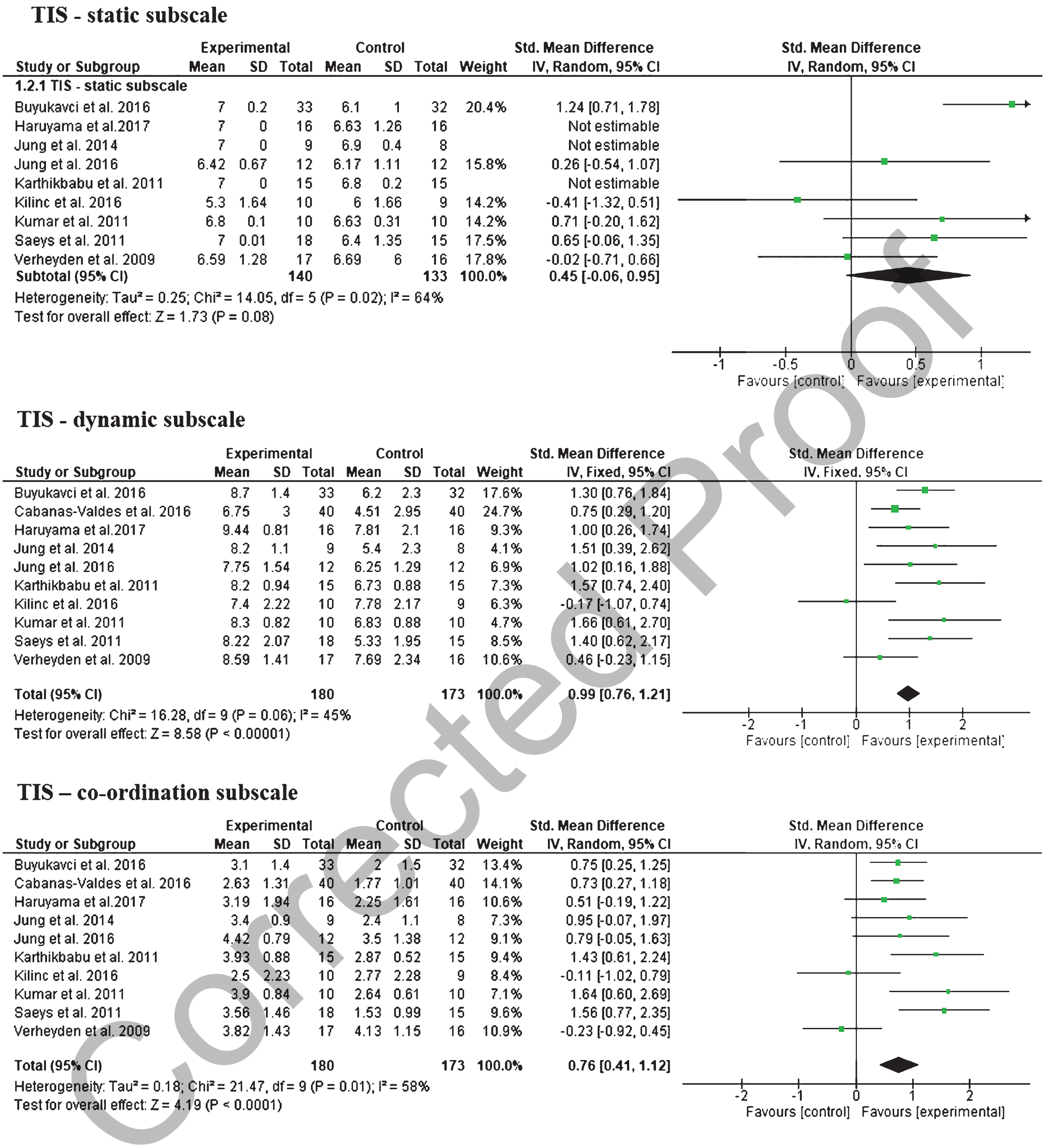


Fig. 5. Forest plot for the effect of trunk exercise on trunk performance measured by total TIS.

the sub-group analysis of each outcome measure demonstrated that the TIS was more sensitive and showed a large, significant effect of trunk exercise, favouring the experimental group compared to only a small (SMD = 0.34), non-significant effect on TCT sub-group analysis. This finding was in line with that of one of the studies included (Yoo et al., 2010) which used both the TIS and TCT. Yoo et al. (2010) identified a statistically significant change between groups ($P < 0.01$) as measured by the TIS, whilst the TCT failed to show any difference ($p > 0.05$) between groups. This finding has also been



TIS - static subscale

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
1.2.1 TIS - static subscale								
Buyukavci et al. 2016	7	0.2	33	6.1	1	32	20.4%	1.24 [0.71, 1.78]
Haruyama et al.2017	7	0	16	6.63	1.26	16		Not estimable
Jung et al. 2014	7	0	9	6.9	0.4	8		Not estimable
Jung et al. 2016	6.42	0.67	12	6.17	1.11	12	15.8%	0.26 [-0.54, 1.07]
Karthikbabu et al. 2011	7	0	15	6.8	0.2	15		Not estimable
Kilinc et al. 2016	5.3	1.64	10	6	1.66	9	14.2%	-0.41 [-1.32, 0.51]
Kumar et al. 2011	6.8	0.1	10	6.63	0.31	10	14.2%	0.71 [-0.20, 1.62]
Saeys et al. 2011	7	0.01	18	6.4	1.35	15	17.5%	0.65 [-0.06, 1.35]
Verheyden et al. 2009	6.59	1.28	17	6.69	6	16	17.8%	-0.02 [-0.71, 0.66]
Subtotal (95% CI)			**140**			**133**	**100.0%**	**0.45 [-0.06, 0.95]**

Heterogeneity: $Tau^2 = 0.25$; $Chi^2 = 14.05$, df = 5 (P = 0.02); $I^2 = 64\%$
Test for overall effect: Z = 1.73 (P = 0.08)

TIS - dynamic subscale

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Buyukavci et al. 2016	8.7	1.4	33	6.2	2.3	32	17.6%	1.30 [0.76, 1.84]
Cabanas-Valdes et al. 2016	6.75	3	40	4.51	2.95	40	24.7%	0.75 [0.29, 1.20]
Haruyama et al.2017	9.44	0.81	16	7.81	2.1	16	9.3%	1.00 [0.26, 1.74]
Jung et al. 2014	8.2	1.1	9	5.4	2.3	8	4.1%	1.51 [0.39, 2.62]
Jung et al. 2016	7.75	1.54	12	6.25	1.29	12	6.9%	1.02 [0.16, 1.88]
Karthikbabu et al. 2011	8.2	0.94	15	6.73	0.88	15	7.3%	1.57 [0.74, 2.40]
Kilinc et al. 2016	7.4	2.22	10	7.78	2.17	9	6.3%	-0.17 [-1.07, 0.74]
Kumar et al. 2011	8.3	0.82	10	6.83	0.88	10	4.7%	1.66 [0.61, 2.70]
Saeys et al. 2011	8.22	2.07	18	5.33	1.95	15	8.5%	1.40 [0.62, 2.17]
Verheyden et al. 2009	8.59	1.41	17	7.69	2.34	16	10.6%	0.46 [-0.23, 1.15]
Total (95% CI)			**180**			**173**	**100.0%**	**0.99 [0.76, 1.21]**

Heterogeneity: $Chi^2 = 16.28$, df = 9 (P = 0.06); $I^2 = 45\%$
Test for overall effect: Z = 8.58 (P < 0.00001)

TIS – co-ordination subscale

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Buyukavci et al. 2016	3.1	1.4	33	2	1.5	32	13.4%	0.75 [0.25, 1.25]
Cabanas-Valdes et al. 2016	2.63	1.31	40	1.77	1.01	40	14.1%	0.73 [0.27, 1.18]
Haruyama et al.2017	3.19	1.94	16	2.25	1.61	16	10.6%	0.51 [-0.19, 1.22]
Jung et al. 2014	3.4	0.9	9	2.4	1.1	8	7.3%	0.95 [-0.07, 1.97]
Jung et al. 2016	4.42	0.79	12	3.5	1.38	12	9.1%	0.79 [-0.05, 1.63]
Karthikbabu et al. 2011	3.93	0.88	15	2.87	0.52	15	9.4%	1.43 [0.61, 2.24]
Kilinc et al. 2016	2.5	2.23	10	2.77	2.28	9	8.4%	-0.11 [-1.02, 0.79]
Kumar et al. 2011	3.9	0.84	10	2.64	0.61	10	7.1%	1.64 [0.60, 2.69]
Saeys et al. 2011	3.56	1.46	18	1.53	0.99	15	9.6%	1.56 [0.77, 2.35]
Verheyden et al. 2009	3.82	1.43	17	4.13	1.15	16	10.9%	-0.23 [-0.92, 0.45]
Total (95% CI)			**180**			**173**	**100.0%**	**0.76 [0.41, 1.12]**

Heterogeneity: $Tau^2 = 0.18$; $Chi^2 = 21.47$, df = 9 (P = 0.01); $I^2 = 58\%$
Test for overall effect: Z = 4.19 (P < 0.0001)

Fig. 6. Forest plot for the effect of trunk exercise on trunk performance measured by TIS - Subscales.

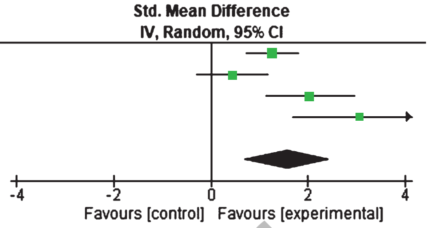
validated in a report (Sullivan et al., 2013) to develop recommendations for outcome measures following strokes. The consensus document recommended using the TIS in all practice settings as it had good sensitivity, specificity and reliability (ICC = 0.96), whilst the TCT was not recommended (Sullivan et al., 2013,Verheyden et al. 2008, Verheyden et al. 2004, Bohannon et al. 1995).

The sub-group analysis of TIS revealed that trunk exercise had a large effect (SMD = 0.98) on improving trunk performance for the experimental group, as measured by the TIS. More specifically, the TIS dynamic sub-scales significantly improved ($p < 0.05$ and/or $p < 0.01$) in nine out of 15 studies (Buyukavci et al. 2016, Cabanas-Valdes et al. 2016, Haruyama et al. 2017, Jung et al. 2014, Jung et al. 2016, Karthikbabu et al. 2011, Kilinc al. 2016, Kumar et al. 2011, Saeys et al. 2012, Verheyden et al. 2009). However, the results of the TIS static subscale were negative in ten out of 14 studies (Buyukavci et al.

Acute stroke stage

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Buyukavci et al. 2016	18.7	2.7	33	14.3	4.1	32	29.5%	1.26 [0.72, 1.79]
Fujino et al. 2016	59.5	15.2	15	52.7	14.8	15	27.2%	0.44 [-0.28, 1.17]
Karthikbabu et al. 2011	19.2	1.56	15	16.34	1.11	15	24.7%	2.06 [1.15, 2.96]
Kumar et al. 2011	18.43	1.1	10	14.2	1.5	10	18.6%	3.08 [1.70, 4.46]
Total (95% CI)			**73**			**72**	**100.0%**	**1.57 [0.67, 2.47]**

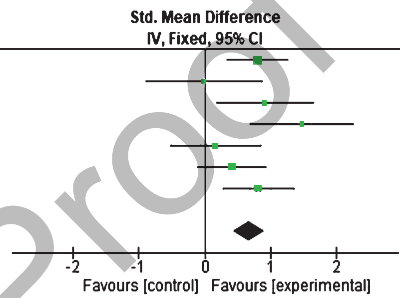
Heterogeneity: Tau² = 0.64; Chi² = 14.46, df = 3 (P = 0.002); I² = 79%
Test for overall effect: Z = 3.42 (P = 0.0006)



Sub-acute stroke stage

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Cabanas-Valdes et al. 2016	9.38	3.9	40	6.3	3.7	39	25.0%	0.80 [0.34, 1.26]
DeSeze et al. 2001	70.3	24.2	10	70.4	21.7	10	6.9%	-0.00 [-0.88, 0.87]
Haruyama et al.2017	19.63	2.45	16	16.69	3.72	16	9.8%	0.91 [0.18, 1.64]
Saeys et al. 2011	18.78	3.53	18	13.27	3.79	15	8.6%	1.47 [0.69, 2.26]
Verheyden et al. 2009	19	2.78	17	18.5	3.12	16	11.3%	0.17 [-0.52, 0.85]
Yoo et al. 2010	86.14	18.17	28	75.94	28.7	31	19.8%	0.41 [-0.10, 0.93]
Yoo et al. 2010	18.57	5.32	28	14.03	5.58	31	18.6%	0.82 [0.29, 1.35]
Total (95% CI)			**157**			**158**	**100.0%**	**0.67 [0.44, 0.90]**

Heterogeneity: Chi² = 10.38, df = 6 (P = 0.11); I² = 42%
Test for overall effect: Z = 5.71 (P < 0.00001)



Chronic stroke stage

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Bae et al. 2013	17.6	3.24	8	17.9	2.88	8	10.2%	-0.09 [-1.07, 0.89]
Chan et al. 2015	19	5.2	12	15.2	2.8	12	13.7%	0.88 [0.03, 1.72]
Chan et al. 2015	18.4	5.2	13	15.2	2.8	12	14.7%	0.73 [-0.08, 1.55]
Jung et al. 2014	18.7	1.5	9	14.6	3.2	8	7.6%	1.59 [0.46, 2.72]
Jung et al. 2016	18.58	1.98	12	15.92	2.84	12	13.1%	1.05 [0.19, 1.91]
Kilinc et al. 2016	15.6	4.14	10	16.56	4.16	9	12.0%	-0.22 [-1.12, 0.68]
Lee et al. 2012	12.6	5.2	14	9.1	2.8	14	16.3%	0.81 [0.04, 1.59]
Shin et al. 2016	15.33	1.97	12	12.42	2.57	12	12.5%	1.23 [0.34, 2.11]
Total (95% CI)			**90**			**87**	**100.0%**	**0.74 [0.42, 1.05]**

Heterogeneity: Chi² = 11.08, df = 7 (P = 0.14); I² = 37%
Test for overall effect: Z = 4.62 (P < 0.00001)

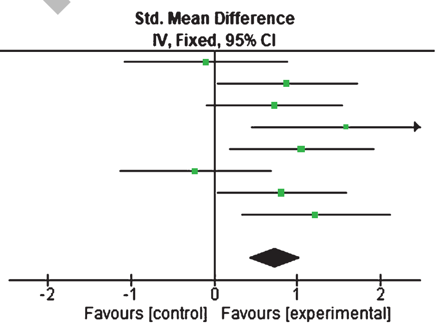


Fig. 7. Forest plot for the effect of trunk exercise on trunk performance at different stroke stages.

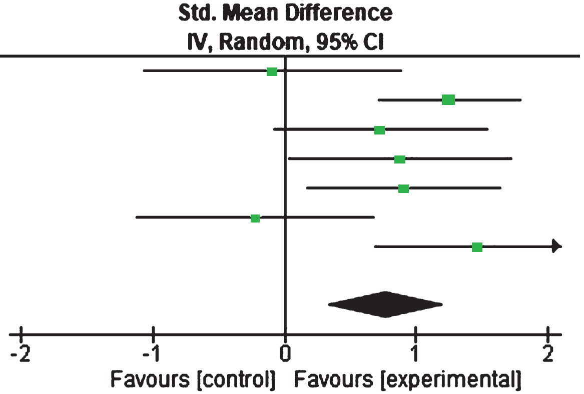
2016, Haruyama et al. 2017, Jung et al. 2014, Jung et al. 2016, Karthikbabu et al. 2011, Kilinc al. 2016, Kumar et al. 2011, Saeys et al. 2012, Verheyden et al. 2009). A likely explanation for the latter point may relate to the inclusion criteria for the study participants; only one study (Cabanas-Valdes et al., 2016) recruited participants who couldn't tolerate a sitting position, whilst the remaining studies recruited participants who were able to sit unsupported for at least ten seconds (Buyukavci et al. 2016, Haruyama et al. 2017, Jung et al. 2014, Jung et al. 2016, Karthikbabu et al. 2011, Kilinc al. 2016, Kumar et al. 2011, Saeys et al. 2012, Verheyden et al. 2009). Consistent with our findings, Cabanas-Valdes et al. (2013), in their systematic review of 11 studies with 317 participants, reported a significant improvement in trunk performance, especially in terms of the dynamic subscale ($P < 0.01$) with no effect on the static sitting subscale after a trunk exercise rehabilitation programme.

For people post-stroke, trunk exercise programmes result in a very large, (SMD = 1.57) statistically significant improvement ($P < 0.0001$) in trunk performance in the acute stage, whilst only having a medium effect in the sub-acute and chronic stages (SMD = 0.67 and 0.74, respectively). These findings are not surprising; the recovery pattern of the trunk was explored at different time points following stroke, by Verheyden et al. in 2008. They reported that trunk recovery followed an exponential pattern, with the most pronounced recovery (21.74%) occurring in the first month post-stroke and these changes in TIS (2.17%) subsequently, gradually, levelled off, between 3 to 6 months. Trunk exercise seems to lead to positively improved trunk performance at all

Exercise duration ≥ 16 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bae et al. 2013	17.6	3.24	8	17.9	2.88	8	11.5%	-0.09 [-1.07, 0.89]
Buyukavci et al. 2016	18.7	2.7	33	14.3	4.1	32	18.9%	1.26 [0.72, 1.79]
Chan et al. 2015	18.4	5.2	13	15.2	2.8	12	13.9%	0.73 [-0.08, 1.55]
Chan et al. 2015	19	5.2	12	15.2	2.8	12	13.4%	0.88 [0.03, 1.72]
Haruyama et al.2017	19.63	2.45	16	16.69	3.72	16	15.3%	0.91 [0.18, 1.64]
Kilinc et al. 2016	15.6	4.14	10	16.56	4.16	9	12.6%	-0.22 [-1.12, 0.68]
Saeys et al. 2011	18.78	3.53	18	13.27	3.79	15	14.4%	1.47 [0.69, 2.26]
Total (95% CI)			**110**			**104**	**100.0%**	**0.77 [0.32, 1.22]**

Heterogeneity: Tau² = 0.20; Chi² = 13.69, df = 6 (P = 0.03); I² = 56%
Test for overall effect: Z = 3.39 (P = 0.0007)



Exercise duration < 16 hours

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Cabanas-Valdes et al. 2016	9.38	3.9	40	6.3	3.7	39	11.4%	0.80 [0.34, 1.26]
DeSeze et al. 2001	70.3	24.2	10	70.4	21.7	10	7.6%	-0.00 [-0.88, 0.87]
Fujino et al. 2016	59.5	15.2	15	52.7	14.8	15	8.9%	0.44 [-0.28, 1.17]
Jung et al. 2014	18.7	1.5	9	14.6	3.2	8	5.8%	1.59 [0.46, 2.72]
Jung et al. 2016	18.58	1.98	12	15.92	2.84	12	7.7%	1.05 [0.19, 1.91]
Karthikbabu et al. 2011	19.2	1.56	15	16.34	1.11	15	7.4%	2.06 [1.15, 2.96]
Kumar et al. 2011	18.43	1.1	10	14.2	1.5	10	4.5%	3.08 [1.70, 4.46]
Lee et al. 2012	12.6	5.2	14	9.1	2.8	14	8.4%	0.81 [0.04, 1.59]
Shin et al. 2016	15.33	1.97	12	12.42	2.57	12	7.5%	1.23 [0.34, 2.11]
Verheyden et al. 2009	19	2.78	17	18.5	3.12	16	9.3%	0.17 [-0.52, 0.85]
Yoo et al. 2010	86.14	18.17	28	75.94	28.7	31	10.8%	0.41 [-0.10, 0.93]
Yoo et al. 2010	18.57	5.32	28	14.03	5.58	31	10.7%	0.82 [0.29, 1.35]
Total (95% CI)			**210**			**213**	**100.0%**	**0.90 [0.55, 1.26]**

Heterogeneity: Tau² = 0.24; Chi² = 30.56, df = 11 (P = 0.001); I² = 64%
Test for overall effect: Z = 4.95 (P < 0.00001)

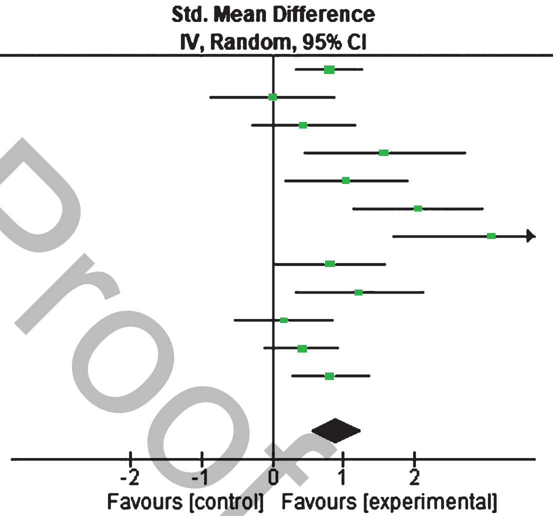


Fig. 8. Forest plot for the effect of duration of trunk exercises on trunk performance.

stroke-stages. This is probably due to a reduction of trunk control after a stroke, as a result of the loss of trunk muscle strength in acute as well as chronic stroke (Bohannon et al. 1995, Fujiwara et al. 2001). More specifically, a hand-held dynamometer measurement showed that strength in the lateral trunk flexors was reduced in people post-stroke to approximately 50% of age-matched healthy people (Fujiwara et al. 2001). Trunk exercises aimed at improving trunk performance are likely to change the strength of the trunk musculature. This may occur due to an increase in cross-sectional area of the muscles; one study included in this review measured the cross-sectional areas of trunk muscles (i.e., multifidus and paravertebral muscles) and found a statistical improvement ($P < 0.05$) after 12 weeks of trunk stabilization exercises (Bae et al. 2013).

The analysis from the studies included in this review did not provide details of the optimal intensity of trunk exercise intervention needed to improve trunk performance. Although the concept of a greater intensity of practice is widely accepted in stroke rehabilitation, the study that applied the greatest amount of exercise (36 hours) reported no significant difference ($p > 0.05$) in TIS between the groups at the end of the study (European Stroke Organisation Executive 2008, Kilinc et al. 2016). The results of our meta-analysis differ from those of the previous systematic review (11 RCTs) by Cabanas-Valdes et al. (2013), who identified that the best results in trunk performance were observed in a study that used 16 hours of trunk exercise over eight weeks on eighty subacute patients.The most noticeable improvement in trunk performance (SMD = 3.08) in our review was reported by Kumar et al. (2011), in which 13.5 hours of trunk exercise was provided over three weeks in twenty acute stroke patients. However, these findings should be interpreted with caution, due to the small sample size in the trunk exercise group and control group ($n = 10$ per group).

Although the sub-group analysis of the studies based on the time of intervention showed a large, significant effect on trunk performance across all the sub-groups, the studies that applied less than 16 hours of trunk exercise had a larger significant effect, compared to the studies that applied trunk exercise for 16 hours or more (Figure 8).

However, these findings should be interpreted with caution, due to the variation in the number of participants in each subgroup analysis. There were 214 participants in the subgroup analysis of the studies that applied < 16 hours of trunk exercise, as compared to 423 participants in the studies that applied > 16 hours of trunk exercise. As a result, the studies that applied > 16 hours of trunk exercise constitute 63.4% of the average weight of the meta-analysis of the trunk performance outcomes. Furthermore, five studies included in sub-group analysis (less than 16 hours of exercise) did not use a control for therapy time, giving the experimental group additional time for trunk exercises, which might account for the improvement in trunk performance (Cabanas-Valdes et al. 2016, Shin et al. 2016, Kumar et al. 2011, Yoo et al. 2010, Verheyden et al. 2009).

The studies included in this review varied, in terms of both the duration of the exercise sessions and the amount of repetition. The duration of trunk exercises ranged from 15 to 120 minutes. In terms of repetition, seven studies reported five sessions per week (Bae et al. 2013, Buyukavci et al. 2016, Cabanas-Valdes et al. 2016, Chan et al. 2015, Haruyama et al. 2017, Jung et al. 2014, Jung et al. 2016) with only one study reporting six sessions per week (Kumar et al. 2011). The meta-analysis to calculate comparisons in terms of treatment repetition and duration was not possible, due to heterogeneity in the intervention characteristics of the studies included. This finding is consistent with that reported in the systematic review by Cabanas-Valdes et al. (2013), which stated that the optimal frequency and duration of trunk exercises remains unclear.

4.1. Limitations of this review

There are several limitations to this review which will affect the generalizability of the results. The first is that the comprehensive search strategy considered only relevant publications in the English language. The small sample size of participants in the included studies ($n = 16$–80) may have affected the validity of the results in meta-analysis, as it has been shown that the inclusion of small studies might lead to Type-I error (Turner et al. 2013). Furthermore, the fact that four of the included studies were of poor methodological quality (PEDro score ≤ 5 points) is a significant limitation of this review (Bae et al. 2013, Jung et al. 2016, Lee et al. 2012, Yoo et al. 2010). Finally, the heterogeneity in the treatment characteristics and the lack of longer-term follow-up in the studies included may have affected the interpretation of the results.

Trunk exercises improve trunk performance as measured by the TIS for people with acute, subacute and chronic strokes. This is especially true for the dynamic sitting sub-scale of the TIS. The optimal intensity and duration of trunk exercises remains unknown, due to the heterogeneity of the included studies. There is currently no evidence for the effect of trunk exercise on upper extremity function in people with strokes.

4.2. Future research

Our understanding of the effects of trunk exercise following stroke will be enhanced if future studies with a large sample size at different levels of severity evaluate the long-term effects of trunk exercise on trunk performance at different stroke stages. Furthermore, it is recommended that an appropriate selection of standardised valid and reliable outcomes to measure trunk performance is used to facilitate data pooling in future meta-analyses. Nevertheless, a previous study found that trunk control has an association with the recovery of the upper extremities (Wee et al. 2015). Therefore, it is important that future studies should assess the upper extremity function, in addition to trunk performance. Understanding the underlying mechanisms of how trunk exercise is associated with upper extremity function may provide insights into a new therapeutic approach for the management of trunk control and upper extremity function following stroke.

5. Conclusion

Trunk exercises improve trunk performance as measured by the TIS for people with acute, subacute and chronic strokes. This is especially true for the dynamic sitting sub-scale of the TIS. The optimal intensity and duration of trunk exercises remains unknown, due to the heterogeneity of the included studies. There is currently no evidence for the effect of trunk exercise on upper extremity function in people with strokes.

Conflict of interest

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Appendix 1:
Search Strategy for MEDLINE

1. exp. stroke/or poststroke/or post-stroke/ or “cerebrovascular accident”
2. (hemipleg$ or hemipar$).tw.
3. (paresis or paretic).tw.
4. 1 or 2 or 3
5. trunk.tw
6. exp. exercise
7. exp. physical therapy
8. motion therapy
9. rehabilitat*
10. 6 or 7 or 8 or 9
11. 5 AND 10
12. “upper limb” /or “upper extremity”
13. (arm or shoulder or elbow or forearm or hand or wrist or finger or fingers).tw.
14. reach* /or grasp*/or “ reach to grasp
15. 12 or 13 or 14
16. 4 AND 11 AND 15

Appendix 2:
Excluded Studies

Study	Reason for Exclusion
Dean 1992	There is no trunk performance measurement
Howe et al. 2005	There is no trunk performance measurement
Llorens et al. 2015	There is no trunk performance measurement
Shin & Kim 2016	The treatment program involved upper extremity exercises to improve trunk
Kim et al. 2012	The treatment program designed to improve lower extremity (walking-related tasks)