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The effect of trunk training on muscle thickness and muscle activity : a systematic review

Reference:

Van Crielinge Tamaya, Truijen Steven, Verbruggen Chelsea, Van de Venis Lotte, Saeys Wim.- The effect of trunk training on muscle thickness and muscle activity : a systematic review
Disability and rehabilitation - ISSN 1464-5165 - 5(2018), p. 1-9
Full text (Publisher's DOI): <https://doi.org/10.1080/09638288.2018.1445785>
To cite this reference: <https://hdl.handle.net/10067/1493770151162165141>

The effect of trunk training on muscle thickness and muscle activity after stroke: A systematic review

ABSTRACT

OBJECTIVE: A systematic review to examine the effect of static or dynamic trunk training compared to standard care or control therapy on muscle activity and muscle thickness of the trunk and lower limb muscles in stroke survivors.

MATERIALS AND METHODS: This review was registered on PROSPERO (No: CRD42017063771) and was written according to the PRISMA guidelines. The search strategy included studies from the first indexed article until September 2017 and was performed in the electronic databases PubMed, Web of Science, Cochrane Library, Ovid Medline and PEDro. Two independent reviewers screened, assessed risk of bias by means of the PEDro scale and extracted data.

RESULTS: Eight studies were included of which three investigated the effects of trunk training on muscle thickness, the remaining five investigated muscle activity. The following muscles were investigated: erector spinae, multifidi, paravertebralis, transversus abdominis, internal and external oblique abdominis, rectus abdominis, quadriceps femoris, hamstrings, soleus and tibialis anterior. Trunk exercises significantly improved the muscle activity of the internal oblique abdominis and increased muscle thickness of transversus abdominis.

CONCLUSIONS: Trunk training is effective in restoring symmetry in muscle thickness to improve muscle strength. The gain in muscle thickness is specific to the applied exercise program, suggesting that therapeutic goal setting is of great importance. However, no conclusion could be made concerning changes in muscle activity due to a high risk of bias.

Keyterms: stroke, cerebrovascular disorder, trunk, muscle thickness, muscle activity, cross-sectional area

INTRODUCTION

Motor deficits resulting from a stroke consist of a disruption in neural pathways affecting contralateral extremities and bilateral trunk motor functions [1]. Studies investigating trunk motor function after stroke reported reduced muscle activity levels, such as delayed onset times, and diminished synchronization between muscles [2-4]. Moreover, increased trunk asymmetry and instability, decreased antiphase rotation of the upper and lower trunk and enhanced trunk motion in the lateral and sagittal plane have been reported during walking after stroke [5]. These dysfunctions result in reduced functional independence, gait and balance performance [6,7].

Since trunk impairments are often seen in stroke patients, retraining of the trunk should be incorporated in standard care. Trunk training can be defined as both a hands on and off therapy using weight-shifting [8], reaching [9] or trunk muscle strengthening exercises [10,11] depending on the patients ability to execute exercises independently. The latter specifically targeted abdominal and back muscles of the trunk, performed on either a stable or unstable surface. Rehabilitation programs that incorporate specific trunk training have proven to be beneficial in stroke patients in improving sitting balance, standing balance and gait [12]. These improvements might possibly be explained by changes in muscle thickness or activity. Muscle activity measures the relative timing and amplitude of muscle contractions which is mainly assessed by electromyography (EMG). Muscle thickness, also known as the cross-sectional area of the muscle which is the area of the cross section of a muscle perpendicular to its fibers. The underlying mechanisms of these therapeutic effects should be further explored.

Thus, the aim of this study is to systematically review the effect of static or dynamic trunk training compared to standard care or control therapy on muscle activity and muscle thickness of the trunk and lower limb muscles in stroke survivors.

METHODS

Search strategy

A systematic search strategy was conducted using the electronic databases of PubMed, Web of Science, Cochrane Library, Ovid Medline and the Physiotherapy Evidence Database (PEDro). The following free texts words and Medical Subject Headings were used: “stroke” or “cerebrovascular disorder”, “trunk training” and “muscle activity” or “muscle thickness” or “cross-sectional area”. The following filters were applied: clinical trials (PEDro) and trials (Cochrane Library). This review was conducted according to the Preferred Reporting Items for Systematic Review and Meta-Analysis Statement (PRISMA) [13] and was registered in the PROSPERO database (no. CRD42017063771). The search strategy can be found as supplementary material (supplementary table 1). The final literature search was performed in September 2017 and included all studies since the first indexed article.

Eligibility criteria

Studies were included if they met the following criteria: 1) randomized controlled trial or clinical controlled trial study designs; 2) population consisting of adult patients (age 18 years or older) diagnosed with an ischaemic or haemorrhagic stroke; 3) interventions consisting of a specific trunk training program, separate or complementary to conventional physiotherapy; 4) outcome was described as muscle activity or muscle thickness for trunk and/or lower extremities; 5) studies written in English, Dutch, German or French. Studies were excluded when interventions were not adequately specified or when training involved exercises while standing and/or walking. Subsequently, trunk training protocols consisting of aquatic therapy or using trunk restraints were excluded since observed changes cannot be solely attributed to the trunk as there is potentially lots of interference of other muscles. No limitations were applied regarding time post-stroke, length of intervention, and follow-up assessment.

Study collection

The screening procedure was performed by two independent researchers (CV, LV). To collect potentially relevant studies, eligibility was screened based on title and abstract. Full texts were retrieved and evaluated based on the a-priori provided inclusion and exclusion criteria. Reference lists of the included studies were manually screened to identify additional relevant studies. After evaluations were pooled, a consensus was reached by a third reviewer (TVC) when discrepancies occurred between the first two researchers.

Risk of bias

The risk of bias was assessed by two independent reviewers (CV, LV) on eleven criteria as instructed by the PEDro Scale [14]. The PEDro scale has been shown to be reliable and valid (ICC= 0.68; 95% CI: 0.57-0.76; $r = 0.31$ to 0.69) [15,16]. The criteria were each given a score of "1" if clearly satisfied, or "0" if not clearly stated or satisfied. The total score was determined by the summation of criteria clearly met. The first item 'eligibility criteria' was not scored. Studies with a score of at least six were considered having a moderate to low risk of bias [17]. In addition, level of evidence was determined by two reviewers (CV, LV) using the guidelines provided by Harbour et al 2011 [18]. Criteria consisted of study design and the amount of risk of bias. A score of 1+ was rewarded for randomized controlled trials with a low risk of bias, whereas a 1- was given for randomized controlled trials with a high risk of bias. In case of uncertainty at any point during the scoring process, consensus was sought by a third reviewer (TVC).

Variables of interest

First, muscle activity measures the relative timing and amplitude of muscle contractions which is mainly assessed by electromyography (EMG). The second variable measures is muscle thickness, also known as the cross-sectional area (CSA) of the muscle which is the area of the cross section of a muscle perpendicular to its fibers. Assessment can be performed by several outcome measures such as ultrasound and computed tomography. Only muscles of the trunk, e.g. back and abdominal, and lower extremities, e.g. quadriceps, hamstrings and calf were included in this study.

Data extraction

Extracted data consisted of subject characteristics (age and time post-stroke), outcome measures (muscle activity or muscle thickness), experimental interventions which were defined as either static or dynamic trunk training and the comparison interventions including standard care, placebo intervention, etc. (type, duration and frequency), results and conclusions.

Data synthesis and analysis

Due to the great variety of outcome measures, data was recalculated to the mean rate of change (ROC) and associated standard deviations. ROC describes the percentage of change over a period of time, whereby pre-intervention is set at 100% and post-intervention data shows the percentage of change. Statistical heterogeneity, performed by I^2 test, was calculated to assess the level of heterogeneity. Cochrane guidelines were used to interpret the heterogeneity: 0–40% might not be important; 30–60% may represent moderate heterogeneity; 50–90% may represent substantial heterogeneity; 75–100% considerable heterogeneity [19]. However, to invigorate the qualitative interpretation of the results, several forest plots were provided. Outcome measures which showed a considerable amount of heterogeneity ($I^2 > 75\%$), were not further analysed with forest plots. A partial meta-analysis could be performed if similar outcome measure and muscles were used in at least two studies and if a complete dataset of the two studies was present. A complete dataset consisted of between-group differences, rate of change, and standard deviations. Authors were contacted concerning missing data. If no data has been provided in the tables, no information concerning missing data was received from the contacted authors. In the case of missing data from a third study, standard deviation was borrowed from the trials that reported them. This method has been proven to be reliable for performing meta-analyses [19,20]. Effect sizes were calculated using Z scores by the Review Manager version 5.3 software (The Nordic Cochrane Centre, Copenhagen, Denmark) and presented on pooled forest plots for muscle activity and muscle thickness. Confidence intervals were set at 95%.

RESULTS

Study selection

The search resulted in 287 possible relevant studies. After deduplication, 221 studies remained. Manual reference list screening did not result in additional studies. Eligibility was screened and 24 studies were included for further examination. Subsequently, full texts were retrieved and evaluated. Finally, 8 studies that met the a-priori established inclusion and exclusion criteria were included (Figure 1).

[Insert figure 1: Flow Chart]

Figure 1. Flow Chart

Risk of bias

The included studies [21-28] had a median score of 4/10 which corresponds with a moderate to high risk of bias (Table 1). Most studies did not meet the criteria of blinding the subjects and therapist as this does not seem possible with respect to treatment. Additionally, blinding of assessors was not reported in the majority of cases, therefore, no score could be given. One study received a particular low score, due to the lack of clarity regarding the amount and final allocation of subjects [29].

[Insert Table 1. Risk of Bias assessed by PEDro scale]

Table 1. Risk of Bias assessed by PEDro scale

Study characteristics

The characteristics of the included population are described in table 2. The included population consisted of 174 patients of which 43 patients (25%) received unstable trunk training, 84 patients (48%) received stable trunk training, 37 patients (21%) received only standard care, 10 patients received a control training (6%). The participant's median age of the unstable, stable and standard care group was 61, 60 and 55 years, respectively. Moreover, the median time post-stroke was 18.1, 17.9 and 21.7 months, respectively.

Three studies compared the effect of a trunk training program to standard care [25,26,28] and one to control therapy [22]. Four studies examined the effect of trunk training programs on unstable support surfaces compared to stable ones [21,23,24,27]. Trunk training was additional to standard care in four studies [21,25,26,28]. The other studies did not receive

standard care [23,24], there was no information about standard care [27] or received a control therapy [22]. The unstable support surfaces used in the studies were a physio ball [21], a sling [24], a balance pad [27] and a tilting board [23]. The majority of exercises consisted of core stability exercises such as bridging, dead bug position, upper and lower trunk flexion, extension and rotation, for the trunk training groups on both stable and unstable surfaces [21,23-27]. Another study implemented a sitting training protocol consisting of weight-shift or reaching exercises [22]. A final study used proprioceptive neuromuscular facilitation techniques to enhance trunk function [28]. The amount of therapy varied from a total of 5 hours [22] to 30 hours [21] between studies.

Concerning outcome measures, three studies reported on muscle thickness [21,23,25], whereas five studies reported on muscle activity [22,24,26-28]. Muscle thickness was assessed by means of ultrasound [23,25] and computed tomography [21]. All studies used surface electromyography to assess muscle activity [22,24,26-28]. The following muscles were investigated: erector spinae, multifidi, paravertebralis, transversus abdominis (TrA), internal and external oblique abdominis (IO/EO), rectus abdominis, quadriceps femoris, hamstrings, soleus and tibialis anterior.

[Insert Table 2. Data extraction of the included studies]

Table 2. Data extraction of the included studies

Data synthesis and analysis

A detailed overview of the evidence table can be found as supplementary material (supplementary table 2 and 3). However, after reviewing the results of the selected studies, it was decided that no meta-analysis could be performed since the outcome measures and treatment protocols varied substantially. The high degree of variation was a result of differences in outcome measures, intervention modalities and time post-stroke.

Muscle thickness

Trunk training appears to enhance the size of the muscle thickness of the abdominal and back muscles [21,23,25]. Exercises on unstable surfaces resulted in an even greater increase compared to stable surfaces for some muscle groups [21,23]. Concerning the CSA of the paravertabralis and multifidi, a significant increase was reported on both the contralesional and ipsilesional side after trunk training on stable and unstable surfaces (ROC [105%-125%])

[21]. Regarding TrA, IO and EO, a significant increase of the TrA (ROC [118%-135%]) and IO (ROC [119%-133%]) on the contralesional and ipsilesional side was reported after trunk training, whereas no significant differences were found concerning EO (ROC [115%-119%]) [23,25]. Although improvements were present at both stable and unstable surfaces in the majority of studies [21,25], one study reported no significant differences after trunk training on stable surfaces [23]. The CSA of the TrA, IO and EO muscles in the group receiving standard care did not improve significantly (ROC [102.17%-109.09%], [101.41%-105.36%], [97.44%-109.38%]) [25]. Unfortunately, no studies reported on muscle thickness of lower extremity muscles following trunk training.

In summary, trunk exercises, especially performed on unstable support surfaces, significantly increased muscle thickness of TrA ($Z=2.22$, $p=0.03$). Muscle thickness of the IO ($Z=1.33$, $p=0.018$) and EO ($Z=0.36$, $p=0.72$) did not significantly differ between the experimental and control group. However, there was a tendency towards an increase in muscle thickness after trunk training since some studies compared stable to unstable surfaces which resulted in smaller differences presented in the forest plots. The overall effect size, as shown in Figure 2, was $Z=2.38$ ($p=0.02$) which suggest an overall increase in muscle thickness after trunk training. The heterogeneity is very low, suggesting that the observed variance reflects true effect size and is not due to sampling error. However, the low percentage of heterogeneity might be due to the duplication of the studies in the forest plots.

[Insert Figure 2. Forest Plot: Muscle Thickness]

Figure 2. Forest Plot: Muscle Thickness

Muscle activity

Three studies examined the effect of trunk training on the amplitude of muscle activity in the abdominal and back muscles [24,26,27]. Muscle activity of the erector spinae (ROC [110.59%-127.9%]), EO (ROC [107.4%-184.5%]), IO (ROC [112.5-254.58%]) and rectus abdominis (ROC [104.7%-107.5%]) increased after trunk training on both stable and unstable surfaces [24,26,27]. The group receiving standard care did not show any significant differences in muscle activity for the rectus abdominis, IO, EO and erector spinae (ROC 107.33%, 90.95%, 105.04%, and 97.1%) [26].

Concerning the lower limb muscles, two studies examined the effect of trunk training on the amplitude in muscle activity and concluded that improvements in the soleus and quadriceps muscle were most apparent [22,28]. After trunk training, muscle activity of the soleus (ROC [111.5%-133.3%]), quadriceps (ROC 116.2%) and hamstrings increased significantly (ROC 119.50 %), in contrast to a significant decrease in the ipsilesional soleus (ROC [79.5%-96.6%]) and quadriceps (ROC [76.4%-87.5%]). No significant differences were reported in the ipsilesional hamstrings. In addition, the contralesional tibialis anterior muscle activity increased significantly following reaching exercises [22], though following proprioceptive neuromuscular facilitation, no significant differences are reported contralesional or ipsilesional [28]. Therefore, no consensus was reached concerning tibialis anterior. The group receiving standard care did not show any significant differences in contralesional tibialis anterior, soleus, quadriceps and hamstrings muscle activity (ROC 97.94%, 100.4%, 95.6%, and 105.5%). Significant differences were reported in ipsilesional soleus and quadriceps muscle activity in the standard care group (ROC 96.6%, 87.5%).

In summary, trunk exercises only significantly improved the muscle activity of the IO ($Z=3.02$, $p=0.003$). Muscle activity of the EO ($Z=0.83$, $p=0.40$), erector spinae ($Z=0.68$, $p=0.49$) and rectus abdominis ($Z=0.07$, $p=0.94$) did not significantly improve after trunk training. The overall effect size, as shown in Figure 3, was $Z=1.55$ ($p=0.12$). Again, the majority of studies reported the differences between stable and unstable surfaces which resulted in smaller between-group differences. However, a tendency towards improvement in muscle activity was seen after trunk training. No analysis was performed for the lower limbs since no full dataset was present for at least two muscles. However, it appears that the contralesional soleus, quadriceps and hamstrings muscle activity increased and ipsilesional soleus and quadriceps muscle activity decreased after trunk training, partially restoring symmetry of muscle activity. Yet, the latter was also seen in the standard care group.

[Insert Figure 3. Forest Plot: Muscle Activity]

Figure 3. Forest Plot: Muscle Activity

DISCUSSION

The aim of this review was to evaluate the effects of trunk training on muscle activation and muscle thickness of the trunk and lower extremity. Scientific literature has shown that trunk training has positive effects on functional tasks, such as sitting balance and ambulation [10-12]. Yet, the clinical outcome measures used in these studies are not suitable to explain the underlying mechanisms of the therapeutic effects. Investigating the effects of trunk training on muscle activity and thickness might give us a better understanding in why improvements in balance and gait are seen.

Muscle thickness

In addition to skeletal muscle wasting after stroke, several studies also reported a significant hypertrophy of contralesional back muscles in almost half of the people suffering from stroke which results in an asymmetry of the back muscles in the majority of the patients [30, 31]. The included studies reported that these differences became non-significant after trunk training. Therefore, it appears trunk training interventions are effective in restoring the symmetry of the trunk musculature. Moreover, the abdominal and back muscles demonstrated greater improvements following unstable trunk training than stable support surfaces and is thereby believed to be most effective. Similar results have been reported by several authors [32,33]. However, some muscles seem unchanged after trunk training, differences in the EO thickness were not significant. This can be explained by the extension patterns of the performed exercises during the intervention, e.g. bridging exercises [21,23-27]. The EO is mostly involved in rotational movements whereas TrA is involved in all movements [34,35]. Moreover, TrA contracts prior to movement, known as anticipatory postural adjustments, and thereby acts as a local stabiliser [34]. Since training programs consisted mostly of exercises focusing on extension patterns, EO received less training in comparison to TrA. In addition, comparison of symmetric ratio, which is the difference between left and right muscle thickness, between healthy subjects and stroke patients showed significant differences for TrA and IO, but not EO [36]. It appears EO suffers less muscle mass wasting following stroke and has thereby less muscle mass to gain following trunk training.

Muscle activity

Although a tendency towards improvement of muscle activity was seen after trunk training, there are several important concerns regarding the included studies. Results should be interpreted with caution. Firstly, all studies examined trunk muscle activity unilaterally, although it is well known that the trunk is affected bilaterally after a stroke [1]. Moreover, in one study it is even unclear on which side data was collected [24].

Secondly, studies examined the amplitude of muscle activity without its relation to timing of activation. There are many factors affecting the EMG amplitude, such as noise of the equipment, electrode placement, cross-talk, muscle depth, subcutaneous fat tissue, etc. Therefore, looking solely at EMG amplitude might not be an appropriate method since it is dependent on many variables. For example, the presence of subcutaneous fat not only reduces EMG amplitude, but also enhances cross-talk which leads to greater noise of the signal [37]. The risk of subcutaneous fat is rather large in this populations since chronic stroke patients generally have a more sedentary lifestyle. This might be one of the reason why there are no conclusive results concerning this subject. As a result, there is a great need to investigate the effect of trunk training on muscle activity in a more standardized manner with regard to timing of muscle activation. Moreover, research intended to explore the underlying mechanisms of the therapeutic improvements should examine muscle activity during functional tasks, such as walking or standing. This might give us a better understanding towards why improvements in clinical measures are seen.

Regarding muscle activity, the high risk of bias of the included studies and the noise of the EMG signal may contribute to the great amount of heterogeneity (I^2) and the presence of large standard deviations presented in the forest plots. Therefore, no conclusion could be made regarding the effect of trunk training on muscle activity and this subject necessitates further study.

Implications for rehabilitation

In conclusion, there is a moderate amount of evidence to suggest that trunk training has positive effects on trunk muscle activity and thickness. More specifically, muscle thickness of the more affected trunk muscles increased after trunk training resulting in a decrease of asymmetry ratios. A gain in muscle thickness, which is directly related to a greater force

generation capacity, does not suffice to improve muscle strength [38]. Trunk muscles also need to contract harmoniously [39], emphasizing the importance of timing of muscle contractions in improving functional muscle strength.

Regarding the exercise modalities, interventions undertaken on unstable surfaces appeared to be more efficient in increasing muscle thickness and muscle activity. The postural perturbations require more trunk muscle activity as it is more difficult to control the center of gravity on an unstable surface which enhances therapeutic effects [32]. Also, it is important to consider the type of training since not all exercises induce changes in specific muscle groups. For example, chances to see improvement in EO muscle thickness are smaller when performing bridging exercises compared to rotational exercises [34, 35].

Lastly, it is reported that the greatest recovery of functionality is within the first six months after diagnosis of stroke and continues up till 18 months [40]. The included studies presented with a median time post-stroke of around 18 months. This implies, that even in the chronic phase, the trunk muscles are still capable of restoring motor functions and should be incorporated in the rehabilitation protocol during this phase.

Limitations

Some caution for these proposed recommendations is required. The included studies recruited small patient groups which added up to a total of only 174 patients. Moreover, the studies included high motor and cognitive functioning stroke patients, they were able to sit independently for at least 30 second, walked independently with or without walking aids and had a mini mental state score of at least 21 or 24 points. It is important to acknowledge that many people suffering from a stroke do not reach this level of functioning. In addition, most studies included patients with a time post-stroke of at least 6, 12 or 24 months. Therefore it remains unknown if the conclusions drawn from this study apply after an acute stroke or in patients with lower motor or cognitive abilities. In addition, the included studies had a moderate to high risk of bias which necessitates further research.

CONCLUSION

There is moderate evidence to suggest that trunk training is effective in restoring symmetry in trunk muscle thickness in patients suffering from a chronic stroke when receiving at least nine hours of additional therapy. Although increased symmetry of muscle thickness is of

importance in restoring muscle strength, harmonic co-contractions are also necessary. Therefore, future research should focus on investigating the effect of trunk training on both timing and amplitude of the EMG signal since the included studies concerning muscle activity showed a high risk of bias and a great chance towards noise of the EMG signal. Lastly, clinicians should clearly identify therapy goals and exercise protocols since not all muscles improve at the same rate when performing specific trunk exercises.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Declaration of Interest Statement

The authors report no conflicts of interest.

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Figures and Tables:

Tables:

Table 1. Risk of Bias assessed by PEDro scale
Table 2. Data extraction of the included studies

Figures

Figure 1. Flow Chart
Figure 2. Forest Plot: Muscle Thickness
Figure 3. Forest Plot: Muscle activity

Supplementary material

Supplementary Table 1. Search Strategy
Supplementary Table 2. Evidence table: the effect of trunk training on the trunk muscle thickness
Supplementary Table 3. Evidence table: the effect of trunk training on muscle activity of trunk and lower limb muscles

Tables

Author (Year)	Eligibility	Random allocation	Concealed allocation	Baseline comparability	Blinding subjects	Blinding therapist	Blinding assessors	Adequate follow-up	Intention-to-treat analysis	Between-group statistical comparison	Point measures and measures of variability	Score	Level
Bae 2013 [21]	No	1	0	1	0	0	0	0	0	1	1	4	1-
Dean 1997 [22]	No	1	0	1	0	0	1	1	1	1	1	7	1+
Jung 2016 [27]	Yes	1	0	1	0	0	0	1	0	1	1	5	1-
Kim 2011 [28]	No	1	0	1	0	0	0	0	0	1	1	4	1-
Lee 2014 [24]	Yes	1	0	1	0	0	0	0	0	1	1	4	1-
Seo 2012 [25]	Yes	1	0	1	0	0	0	0	0	1	1	4	1-
Yoo 2014 [23]	Yes	1	0	1	0	0	0	0	0	1	1	4	1-
Yu 2013 [26]	Yes	0	0	0	0	0	0	0	0	1	1	2	1-

Table 1. Risk of Bias assessed by PEDro scale

Study	Participants			Interventions		Outcome Measures	Muscles	Results		Conclusion
	<i>N</i>	<i>Age (yrs)</i>	<i>TPS (months)</i>	<i>Experimental</i>	<i>Control</i>			<i>Experimental</i>	<i>Control</i>	
Bae 2013 [21]	16	TTs: 53.4 ± 5.8 TTu: 52.4 ± 7.6	TTs: 17.9 ± 4.3 TTu: 18.1 ± 4.2	SC + TTu (core stability, ball) 30h, 12 weeks, 5x/week, 30'	SC + TTs (core stability)	Muscle thickness, CT (μm)	*Paravertebral *Multifidus	PV ↑ CL and IL (p<0.05) MF ↑ CL (p<0.001) and IL (p<0.01)	MF ↑ CL (p<0.05). PV + MF ↑ IL (p<0.05)	*Both groups improved the CSA of PV and MF
Dean 1997 [22]	20	TTs: 68.2 ± 8.2 CT: 66.9 ± 8.2	TTs: 6.7 ± 5.8 CT: 5.9 ± 2.9	TTs (reaching) 5h, 2 weeks, 5x/week, 30'	CT (cognition)	Muscle activity, EMG (%)	*Vastus lateralis *Tibialis anterior *Soleus	Not reported	Not reported	*Exp group improved MA of AT, SM
Jung 2016 [27]	24	TTs: 60.7 ± 7.8 TTu: 58.9 ± 11	TTs: 8.4 ± 2.4 TTu: 8.0 ± 3.2	TTu (core stability, balance pad) 10h, 4 weeks, 5x/week, 30'	TTs (core stability)	Muscle activity, EMG (%)	*Erector spinae *External/Internal oblique abdominis	↑ MA ES, EO and IO (p< 0.05)	↑ MA ES (p< 0.05), ↑ MA EO and IO (p>0.05)	*Both groups improved MA of ES *Exp group improved MA of EO and IO
Kim 2011 [28]	40	TTs: 51.4 ± 5.7 SC: 53.5 ± 7.1	TTs: 22.9 ± 12.2 SC: 26.8 ± 12.8	TTs (PNF) 15h, 6 weeks, 5x/week, 30'	SC	Muscle activity, EMG (%RVC)	*Quadriceps *Tibialis anterior *Soleus *Hamstrings	↑ SM and QF on CL (p< 0.05) and ↓ on IL (p<0.05) ↑ hamstrings on CL (p<0.05)	SM and QF on CL (p>0.05) and ↓ on IL (p<0.05)	*Both groups improved MA of SM and QF *Exp group improved MA of AT, Hamstrings
Lee 2014 [24]	20	TTs: 62.50 ± 8.48 TTu: 63.40 ± 4.94	/	TTu (core stability, sling) 6h, 4 weeks, 3x/week, 30'	TTs (core stability)	Muscle activity, EMG (μV)	*Rectus abdominis *External oblique abdominis *Erector spinae	↑ RA, EO and ES (p< 0.05)	↑ RA, EO and ES (p< 0.05)	*both groups improved MA of RA, EO and ES
Seo 2012 [25]	12	TTs: 59.8 ± 12.8 SC: 57.8 ± 10.7	TTS: 7.3 ± 4.6 SC: 16.5 ± 15.4	SC + TTs (core stability) 12.5-25h, 5 weeks, 5x/week, 30'-60'	SC	Muscle thickness, US (cm)	*Transversus abdominis *External/Internal oblique abdominis	rest: ↑ TrA, EO and IO on CL&IL after training (p<0.05). contracted: ↑ TrA and IO on CL&IL after training (p<0.05), EO (p>0.05)	rest: ↑ IO on CL&IL after training (p<0.05), TrA & EO (p>0.05) contracted: p>0.05	*both groups improved CSA of IO *Exp group improved CSA o Tr and EO
Yoo 2014 [23]	24	TTs: 71.3 ± 8.42 TTu: 64.1 ± 9.6	TTs: 26.1 ± 12.9 TTu: 30.4 ± 13.5	TTu (core stability, tilting board) 9h, 6 weeks, 3x/week, 30'	TTs (core stability)	Muscle thickness, US (mm)	*Transversus abdominis *External/Internal oblique abdominis	↑ TrA and IO on CL&IL (p<0.05) after training, EO (p>0.05)	TrA, IO and EO (p>0.05)	*Exp group improved CSA of TrA and IO
Yu 2013 [26]	18	TTs: 50.0 ± 5.5 SC: 52.6 ± 4.6	TTs: 25.9 ± 10.0 SC: 31.0 ± 7.7	SC + TTs (core stability) 10h, 4 weeks, 5x/week, 30'	SC	Muscle activity, EMG (mV)	*Rectus abdominis *Internal oblique abdominis *Erector spinae	↑ RA, IO and ES after training (p<0.05)	RA, IO, ES (p>0.05)	*Exp group improved MA of RA, EO, IO and ES

Table 2. Data extraction of the included studies

TTu: trunk training on an unstable surface, TTs: trunk training on a stable surface, CP: standard care, CT: cognitive therapy, exp: experimental, PNF: proprioceptive neuromuscular facilitation N: total amount patients, TPS: time post-stroke, yrs: years, ': minutes, mm: millimetre, cm: centimetre, mV: millivoltage, μV: microvoltage, /: no data provided, RVC: reference voluntary contraction, CL: contralesional side, IL: ipsilesional side, CSA: cross-sectional area, US: ultrasound, MA: muscle activity, CT: computed tomography, EMG: electromyography, ES: erector spinae muscles, PV: paravertebral muscles, MF: multifidus muscles, TrA: transversus abdominal muscles, RA: rectus abdominal muscles, EO: external oblique abdominal muscles, IO: internal oblique abdominal muscles, LV: lateral vastus muscles, QF: quadriceps femoris muscles, SM: soleus muscles, AT: anterior tibial muscles

Figure 1. Flow Chart

Figure 2. Forest Plot: Muscle Thickness

SD: standard deviation, CI: confidence interval, with *: ipsilesional side, without *: contralesional side

Figure 3. Forest Plot: Muscle activity

SD: standard deviation, CI: confidence interval