Universidad Miguel Hernández de Elche
Programa de Doctorado en Deporte y Salud

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# EFFECTS OF TRUNK-FOCUSED EXERCISE PROGRAMS AND HOW THE TRAINING PROGRAM AND THE INDIVIDUALS' CHARACTERISTICS MODULATE THEIR IMPACT

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Doctoral thesis

A dissertation presented by
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La presente tesis doctoral, titulada "*Effects of trunk-focused exercise programs and how the training program and the individuals' characteristics modulate their impact"*, es un compendio de 1 artículo publicado y 1 artículo aceptado en revistas indexadas en el *Journal Citation Reports* de la *Web of Science*:

- Prat-Luri A, Moreno-Navarro P, García JA, Barbado D, Vera-Garcia FJ, Elvira JLL. Do initial trunk impairment, age, intervention onset, and training volume modulate the effectiveness of additional trunk exercise programs after stroke? A systematic review with meta-analyses. *Int. J. of Environ. Res. Public Health.* 2020; 17(23):8714. doi: 10.3390/ijerph17238714
- Prat-Luri A, de los Rios-Calonge J, Moreno-Navarro P, Manresa-Rocamora A, Vera-Garcia, FJ, Barbado D. Effect of trunk-focused exercises on pain, disability, quality of life and trunk physical fitness in low back pain and how potential effect modifiers modulate the improvement on pain and disability: a systematic review with meta-analyses. Accepted in the *Journal of Orthopaedic & Sports Physical Therapy.*

Además de los artículos previamente publicados o aceptados para su publicación, la presente tesis doctoral incluye un artículo que se ha enviado a revisión a una revista indexada en el *Journal Citation Reports* de la *Web of Science*:

- Prat-Luri A, Vera-Garcia FJ, Moreno-Navarro P, Juan-Recio C, Rios-Calonge J, Heredia-Elvar JR, Elvira JLL, Barbado D. Effect of two core stability training programs on core performance and whole-body balance based on smartphone-accelerometry monitorization: a double-blind randomised controlled trial. Submitted to the *Journal of Sport and Health Sciences.*

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**INFORMAN:**

Que Dña. *Amaya Prat Luri* ha realizado bajo nuestra supervisión el trabajo titulado "*Effects of trunk-focused exercise programs and how the training program and the individuals' characteristics modulate their impact*" conforme a los términos y condiciones definidos en su Plan de Investigación y de acuerdo con el Código de Buenas Prácticas de la Universidad Miguel Hernández de Elche, cumpliendo los objetivos previstos de forma satisfactoria para su defensa pública como tesis doctoral.

Lo que firmamos para los efectos oportunos,

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| Director de la tesis | Codirector de la tesis |
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El Dr. *Francisco Javier Moreno Hernández*, Coordinador del Programa de Doctorado en **Deporte y Salud**

**INFORMA:**

Que Dña. *Amaya Prat Luri* ha realizado bajo la supervisión de nuestro Programa de Doctorado el trabajo titulado "*Effects of trunk-focused exercise programs and how the training program and the individuals' characteristics modulate their impact*" conforme a los términos y condiciones definidos en su Plan de Investigación y de acuerdo con el Código de Buenas Prácticas de la Universidad Miguel Hernández de Elche, cumpliendo los objetivos previstos de forma satisfactoria para su defensa pública como tesis doctoral.

Lo que firmo para los efectos oportunos,

en Elche a diciembre de 2022

Prof. Dr. *Francisco Javier Moreno Hernández*

Coordinador del Programa de Doctorado en Deporte y Salud

***A Pedro, por haber recorrido***

***esta parte del camino conmigo.***

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# List of abbreviations

**ANOVA:** analysis of variance.

**ATEP:** additional trunk-focused exercise programs.

**BMI:** body mass index.

**CSE:** core stability exercises.

**CI:** confidence interval.

**CG:** control group.

**ES:** effect size.

**$EG_{HI}$:** core stability exercise program with higher intensity and lower volume.

**$EG_{HV}$:** core stability exercise program with higher volume and lower intensity.

**GRADE:** grading of recommendations, assessment, development, and evaluation.

**GEP:** general exercise programs.

**$I^2$:** heterogeneity.

**$I^2_{res}$:** residual heterogeneity.

**LBP:** low back pain.

**MD:** mean difference.

**n:** number of participants.

**PEDro:** physiotherapy evidence database.

**ROM:** range of motion.

**$R^2$:** adjusted r-squared.

**SD:** standard deviation.

**SMD:** standardised mean difference.

**SPSS:** statistical package for social sciences.

**$TH_{ROM}$:** trunk and/or hip range of motion.

**TEP:** trunk-focused exercise programs.

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# Abstract

Trunk-focused exercise programs (TEP) refer to those training programs in which the main target of the exercises resides in the active and/or passive trunk/core structures. Although these programs have shown a positive impact in sport and health contexts throughout recent years, there are several limitations in the literature that hinder the understanding of TEP effect and their relationship to the individual and to the training load characteristics. In this sense, TEP are sometimes compared to exercise control groups and/or other exercise programs that include trunk-focused exercises. Furthermore, although the individual and the training program features are a basic aspect to optimize training programs, experimental TEP studies not always provide this information properly. To address these constraints, the present doctoral thesis includes two systematic reviews and an experimental study. The two systematic reviews aimed at an in-depth analysis of the literature on TEP both, to improve the knowledge about the trunk-focused exercise contribution to increase trunk physical fitness and ameliorate stroke and low back pain symptoms, and to better understand how the individuals and exercise programs characteristics modulate TEP effectiveness. Overall, although the quality of evidence was low, their results showed that TEP were effective to ameliorate stroke and patients' non-specific chronic low back pain condition, with positive effects in all the outcomes analysed. Furthermore, the analysis of moderator factors revealed that TEP effectiveness in stroke patients seems to be higher when the initial trunk impairment is greater, the patients are older, and the intervention starts earlier. Importantly, the TEP impact on low back pain symptoms (mainly pain reduction) seems higher when a greater improvement in trunk and/or hip range of motion is recorded after the training program and participants have a lower body mass index. These results reinforce the importance of paying close attention to the individuals and to the exercise programs characteristics when designing this type of interventions. On the other hand, the experimental study overcomes some of the problems found in the systematic reviews, especially the lack of experimental works that objectively controlled the training load intensity. This study aimed at the comparison of the effects of a higher intensity and a higher volume core stability exercise (CSE) program on core stability, core endurance and whole-body dynamic balance in young physically active males, using a smartphone-accelerometer to control the CSE intensity. These study results showed the specificity of the effects caused by the CSE programs, with a larger increase in the lumbopelvic postural control during the execution of isometric CSE for the higher intensity CSE program and a larger core endurance increase for the higher volume CSE program. Interestingly, the performance of conventional isometric CSE in lying and quadruped positions during the CSE programs did not have a significant impact on the unstable sitting test, a sudden loading protocol and several whole-body dynamic balance tests. Altogether, the results of the studies included in this doctoral thesis highlight the importance of performing TEP to improve trunk performance, functional capacity, and health status in different populations. Specifically, the two systematic reviews showed how moderator factors related to both, the individual and the training program characteristics can play an important role in modulating TEP effectiveness, which should be considered to maximize and tailor the TEP benefits in stroke and low back pain patients. However, the quality of the evidence for all the outcomes analysed in these systematic reviews was low, and thus, higher quality studies are required to strengthen the evidence on the impact of performing trunk-focused exercises in stroke and low back pain rehabilitation programs. Regarding the experimental study, the training load control performed through the smartphone-accelerometer allowed to describe the specificity of the effects caused by a higher intensity and a higher volume CSE program in young physically active males. Further research is needed to characterize the dose-response relationship of CSE programs in different populations properly.

**Keywords:** *trunk exercises, potential effect modifiers, rehabilitation, training load, wearable devices.*

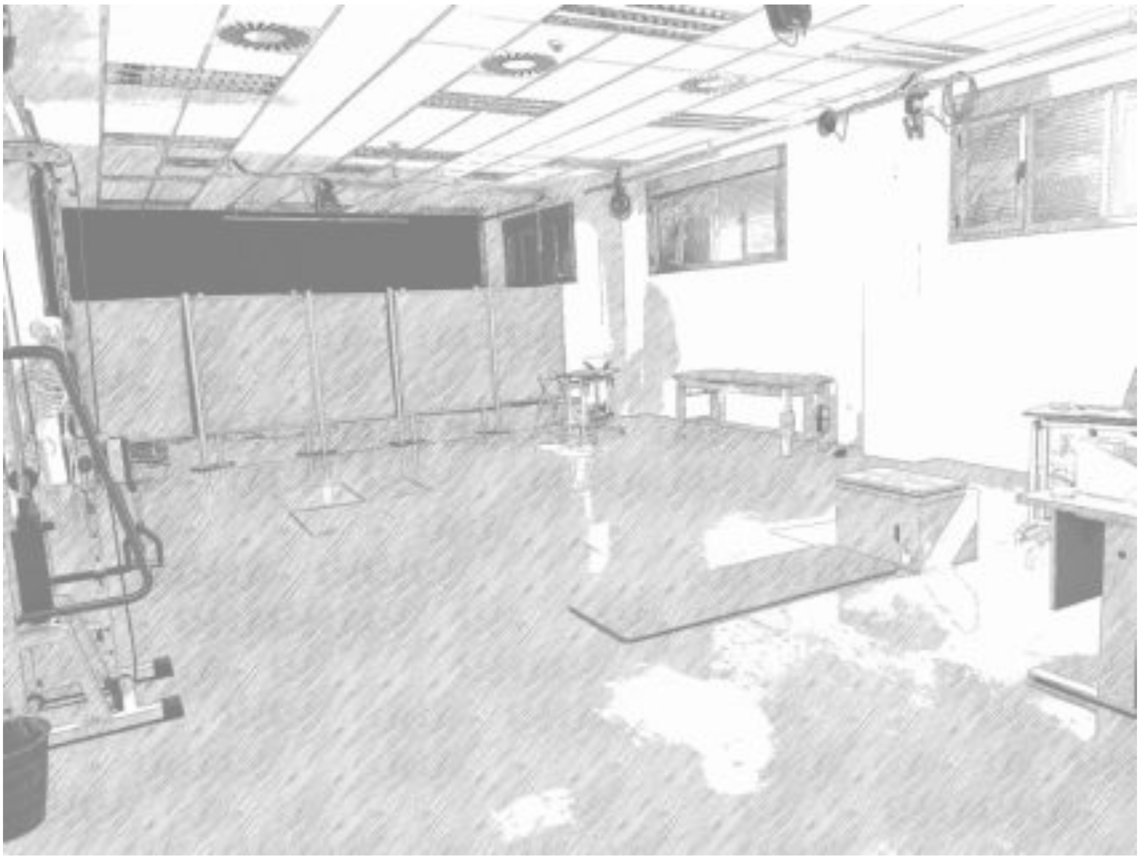
# Resumen

Los programas de ejercicio focalizados en el tronco (PET) son aquellos programas de entrenamiento cuyo foco principal son las estructuras activas y/o pasivas del tronco/core. A pesar de que estos programas han mostrado un efecto positivo tanto en contextos deportivos como de salud a lo largo de los últimos años, se observan varias limitaciones en la literatura que dificultan entender adecuadamente el efecto que tienen estos programas y su relación tanto con las características de los participantes, como con las características de los programas de entrenamiento. En este sentido, los PET son comparados en ocasiones con grupos control y/u otros programas de entrenamiento que incluyen ejercicios focalizados en el tronco. Además, a pesar de que las características de los participantes y de los programas de entrenamiento son aspectos clave para su optimización, los estudios experimentales no siempre aportan esta información. Para abordar estas limitaciones, la presente tesis doctoral incluye dos revisiones sistemáticas y un estudio experimental. Las dos revisiones sistemáticas presentan un análisis detallado de la literatura relacionadas con los PET para, a) mejorar el conocimiento sobre la contribución de los ejercicios focalizados en el tronco sobre el desarrollo de la condición física del tronco y la mejora de los síntomas tanto en personas que han sufrido un ictus, como en pacientes con dolor lumbar, y b) comprender mejor cómo las características de los participantes y de los programas de entrenamiento modulan la efectividad de los PET. En general, a pesar de que la calidad de la evidencia fue baja, los resultados de estas revisiones mostraron la efectividad de los PET para mejorar la condición tanto de las personas que han sufrido un ictus, como de aquellas con dolor lumbar crónico inespecífico, obteniendo efectos positivos sobre todas las variables analizadas. Además, el análisis de los factores moderadores reveló que la efectividad de los PET en personas que han sufrido un ictus parece ser mayor cuando la afectación inicial del tronco es mayor, las personas son mayores o el programa de ejercicio comienza antes. Con respecto a las personas con dolor lumbar, el impacto de los PET sobre la reducción de los síntomas (especialmente la reducción del dolor), parece ser mayor cuando hay un mayor incremento del rango de movimiento del tronco y/o de la cadera y los participantes tienen un menor índice de masa corporal. Estos resultados refuerzan la importancia de prestar atención a las características de los participantes y de los programas de ejercicios cuando se diseñan este tipo de programas. Por otro lado, el estudio experimental que incluye esta tesis doctoral aborda algunos de los problemas observados en las revisiones sistemáticas, especialmente la falta de estudios experimentales que controlen de manera objetiva la carga de entrenamiento de los PET. En este sentido, este estudio tuvo como objetivo comparar los efectos de dos programas de ejercicios de estabilidad del tronco (EET), uno de mayor intensidad y otro de mayor volumen, sobre la estabilidad y resistencia del tronco y el equilibrio dinámico general en hombres jóvenes y físicamente activos, utilizando el acelerómetro integrado en un smartphone para controlar la intensidad de los EET. Los resultados mostraron la especificidad de los efectos de los programas de EET, con mayores mejoras sobre el control lumbo-pélvico durante la ejecución de EET isométricos en el grupo de mayor intensidad y un mayor efecto sobre la resistencia de los músculos tronco en el grupo de mayor volumen. Destacar también que la realización de EET isométricos en posiciones de tumbado y cuadrupedia no tuvo un impacto significativo sobre el test del asiento inestable, sobre un protocolo de perturbaciones súbitas y sobre varios test de equilibrio dinámico general. En resumen, los resultados de los estudios incluidos en esta Tesis Doctoral destacan la importancia de realizar PET para mejorar la condición física del tronco, la capacidad funcional y el estado de salud en diferentes poblaciones. Específicamente, las dos revisiones sistemáticas mostraron cómo factores moderadores relacionados con las características de los participantes y de los programas de entrenamiento pueden jugar un papel importante en la modulación de la efectividad de los PET, lo cual debería tenerse en cuenta para maximizar sus beneficios en personas que han sufrido un ictus y en pacientes con dolor lumbar. Sin embargo, la calidad de la evidencia de los estudios en los parámetros analizados fue baja y, por lo tanto, es necesario que estudios de mayor calidad refuercen y mejoren los resultados obtenidos sobre el impacto de los PET en estas poblaciones. Con respecto al estudio experimental, el control de la carga de entrenamiento a través del acelerómetro integrado en un smartphone permitió describir la especificidad de los efectos de un programa de EET de mayor intensidad y de otro de mayor volumen en hombres jóvenes y físicamente activos. Futuros estudios son necesarios para caracterizar de manera adecuada la relación dosis-respuesta de los programas de EET en diferentes poblaciones.

**Palabras clave:** *ejercicios de tronco, factores moderadores, rehabilitación, carga de entrenamiento, dispositivos portátiles.*

# CHAPTER 1

## GENERAL INTRODUCTION



# Chapter 1. General introduction

There is a wide variety of exercise training programs in the literature that, despite having very different characteristics, share a main focus on the trunk/core structures, as, for example, core stability exercise programs,[1–5] Pilates programs,[6–8] motor control programs,[9,10] or McKenzie exercise programs.[11,12] Based on this common interest, they can be grouped under the concept of *trunk-focused exercise programs* (TEP), defined as *those training programs in which the main target of the exercises resides in the active and/or passive trunk/core structures*. These structures are the central zone of the kinetic chains in many sport and daily life activities, and they play an important role in producing and transferring forces to the distant segments and in providing a stable base for upper and lower limb function.[13] It must be pointed out that trunk and core are not the same. Whereas the trunk includes all the body structures between the upper and lower extremities, the core usually refers to the neuromuscular and osteoarticular structures of the lumbar, abdominal, pelvic, and hip regions.[14] Nevertheless, both terms will be used as synonyms throughout the manuscript to facilitate the reading of this doctoral thesis and its relationship with the scientific literature on trunk/core exercises.

The interest on *trunk-focused exercises* has increased in the last years, becoming popular in sport and health contexts. TEP are commonly employed to enhance athletic performance, in which they have shown positive results improving general (e.g., sprint speed, upper and lower limb power, changes-of-direction speed, muscle strength and endurance…)[15–18] and specific outcomes (e.g., handball throwing speed, race time in rowing/swimming, running economy…)[16,18,19] related to individual and team sports. Similarly, trunk-focused exercises have shown to be useful for lower-limb injury prevention and treatment.[2,20] In the clinical context, these exercises have been used successfully as part of rehabilitation programs for many pathologies, for example: decreasing the pain and disability perceived in people with low back pain (LBP),[1,7,9,10,21] improving the functional capacity of people who have suffered a stroke[22,23] or of patients with neurological disorders (e.g., multiple sclerosis, Parkinson…),[5,24] among others. Nonetheless, there are some drawbacks in the literature that hinder the analysis of the real effect of these programs.

### *What do TEP consist of? Experimental design problems of the intervention studies*

As aforementioned, there is a wide variety of TEP named differently (e.g., core stability training, core balance training, trunk muscle training, Pilates training…);[1,5–12,25] however, they often include similar exercises (e.g., in LBP population: Ferreira et al[26] – Motor control exercises, Da Fonseca et al[27] – Pilates exercises, Hwang et al[28] – Sensorimotor training, You et al[29] – Sling exercise program, Ulger et al[30] – Spinal stabilisation exercises), which makes it difficult to differentiate between them. Likewise, not all authors of the randomised trials (RCT) understand those programs in the same way. Sometimes TEP are compared to control groups that also perform exercises focused on the trunk structures,[31–33] and/or to other exercise programs which include a high number of trunk-focused exercises.[34–36] In addition, trunk-focused exercises are hardly the sole component of an athletic training program (e.g., walking lunge, lateral stance balance…),[3,37] and/or can be part of multidimensional approaches, mainly in the clinical context,[12,38–41] which include other components in the program (e.g., usual care, physiotherapy, educational components…). On the whole, despite the efforts made by the authors of several systematic reviews on the impact of TEP on sports performance[25] or on the health status of patients with different pathologies,[1,10,22,23,42–45] it remains difficult to understand to what extent trunk-focused exercises contribute to the effects that are observed by the studies. Therefore, systematic reviews performing a detailed analysis of the RCT features are needed to ensure that the TEP are specifically composed of trunk-focused exercises and they are compared to no exercise control groups (i.e., no exercise intervention or minimal intervention such as ultrasound, massage, educational approach…), and/or to other exercise programs that do not include trunk-focused exercises.

### *What are the underlying causes of TEP benefits?*

Another major limitation of the RCT on TEP is related to the fact that they usually measure the final health or sport performance outcome of interest to be ameliorated through the training program (e.g., pain, disability, balance, etc.). However, the TEP impact on the main intervention target theoretically responsible for health or athletic performance improvements, this is, the trunk structures [e.g., muscle strength, muscle endurance, spine or core stability, range of motion (ROM), etc.] is not usually reported.[37,44] Therefore, more studies assessing the relationship between trunk physical outcome improvements caused by TEP and the changes in the outcomes of interest for the target populations (such as sport performance outcomes in athletes, or functional recovery outcomes in patients with different pathologies) are needed for a better understanding of the underlying causes of the TEP benefits, and, consequently, to optimize the intervention prescription.

### *Which sample features modulate TEP benefits?*

A detailed description of the sample characteristics is essential to understand the impact of TEP. This is especially relevant in clinical populations such as stroke survivors and people with LBP, in which a proper core/trunk function is crucial for a better health prognosis. However, the scientific evidence showing which potential effect modifiers are more relevant for optimizing TEP effects is scarce. Recent reviews and meta-analyses have observed that lower age, earlier rehabilitation onset and shorter program duration are associated with greater trunk function improvements after TEP in people that have suffered a stroke.[22] However, how other factors [the stroke type (i.e., haemorrhagic or ischemic), the brain areas affected after the stroke and the patient's initial trunk impairment] modulate the intervention effects on the most relevant outcomes for the stroke survivors' quality of life (i.e., functional mobility and balance) has not been addressed. Similarly, in the LBP population, it has been observed that middle-aged people and those with sub-clinical intermediate pain tend to benefit most from motor control stabilization exercises.[10] However, other moderator factors such as the LBP type, duration, and whether the patients present low initial trunk performance level or disability or not have not been considered. Thus, despite the relevance of the individuals' characteristics for understanding TEP impact, the knowledge about this impact is still limited, reinforcing the need to address this issue in order to optimize TEP effects on stroke and LBP prognosis.

### *Which TEP features allow to maximize the intervention benefits? The problem of poor training load characterization*

Another important aspect to optimize TEP has to do with the training program characteristics. In general, TEP found in RCT usually last 6-8 weeks, although shorter (i.e., 4 weeks) and longer (i.e., 12 weeks) durations can also be found. The session duration usually ranges between 20-60 min, and the most usual training frequency is 2-3 times per week, but some programs reach higher frequencies (e.g., 5 sessions per week).[1,25] Although different types of trunk-focused exercises can be found in the RCT, the most common exercises can be grouped according to the trunk physical capabilities:

- *Core strength exercises*, i.e., resistance exercises which produce high levels of muscular activation (e.g., trunk flexion strength exercises in machine, figure 1A).[46,47]
- *Core power exercises*, i.e., exercises in which participants perform the maximum rate of force in the shortest timeframe (e.g., medicine ball throws, figure 1B).[48,49]
- *Core endurance exercises*, i.e., bodyweight/non-resistance exercises which moderately activate the trunk muscles during long efforts while imposing low load penalty on the spine (e.g., crunch exercises, figures 1C).[50]
- *Core stability exercises (CSE)*, i.e., exercises which challenge the participants' ability to maintain or restore a steady position (usually a neutral lumbopelvic posture) against internal and/or external loads normally applied in lying or quadruped positions (e.g., front bridge/plank exercise on a fitball, figure 1D).[51]
- *Core mobility and flexibility exercises*, i.e., exercises in which internal or external forces are applied to the tissues with the aim of increasing muscle elasticity and/or joint ROM (e.g., cat-camel exercise, figure 1D; hip extensor stretching while sitting, figure 1E).[52,53]

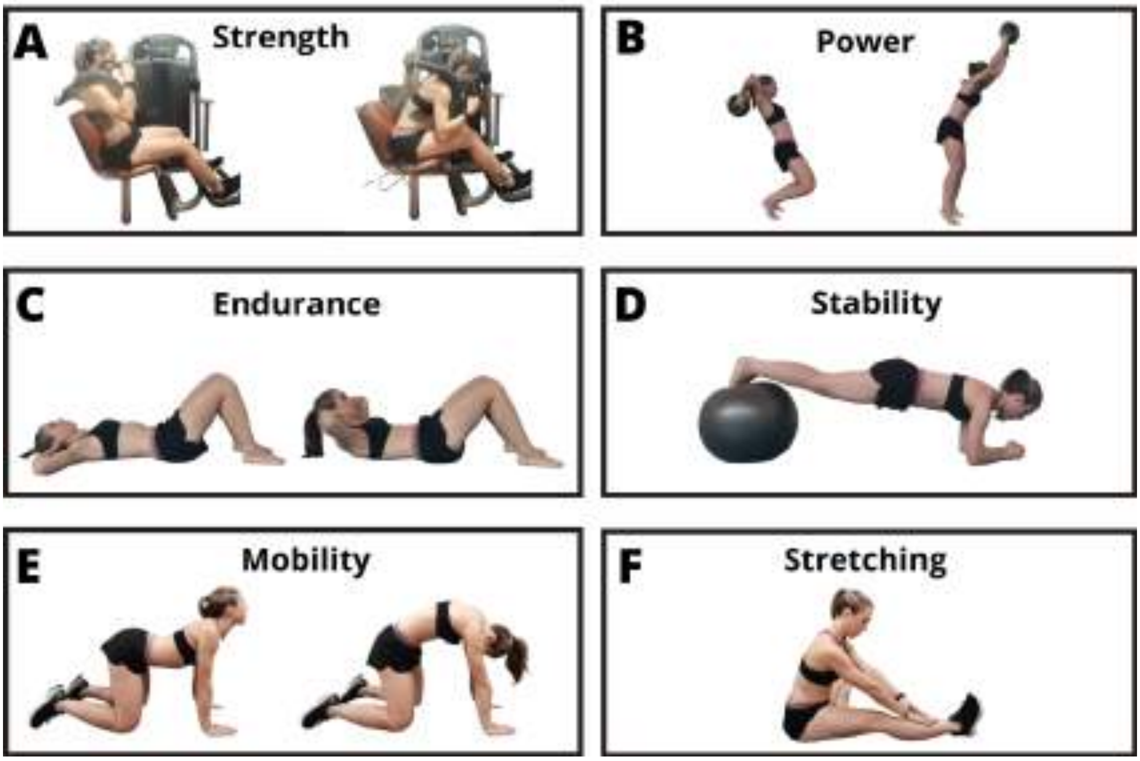


**Figure 1.** Examples of different types of trunk-focused exercises sorted depending on the trunk physical quality trained: A) Trunk flexion strength exercise in machine; B) Medicine ball throws; C) Crunch exercise; D) Front bridge with double-leg support on a fitball; E) Cat-camel exercise focusing on spine and pelvic mobility; F) Single-leg stretch while sitting.

Nowadays, CSE are some of the most popular trunk-focus exercises (figure 2) in both clinical and sport settings. Among them, *bridges* and *bird-dog* exercises stand out because they challenge the lumbopelvic stability while exerting little compressive forces on the spine.[50,54] Due to their great popularity, many electromyography and mechanical studies on CSE have analysed trunk muscle activation and spine loading during different variations of the conventional form of these bridging and bird-dog exercises (e.g., comparing short vs. long bridges,[55] bridging with single-leg vs. double-leg support,[55,56] CSE on unstable vs stable surfaces,[55,57] etc.), which have provided valuable information for CSE selection and prescription.

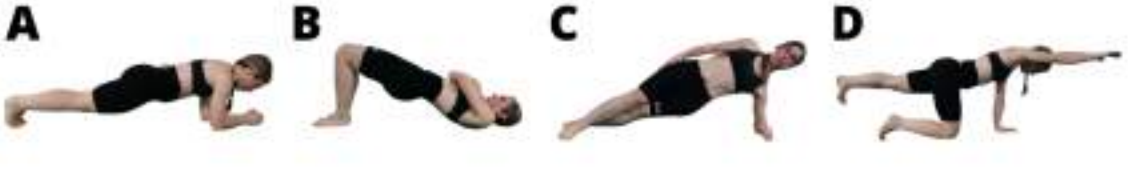


**Figure 2.** Examples of common core stability exercises: A) Front bridge, which mainly activates the trunk and hip flexor muscles;[55,58] B) Back bridge, which mainly activates the trunk and hip extensor muscles;[55,58] C) Side bridge, which mainly activates the trunk lateral flexor and hip abductor muscles;[55,58] D) Bird-dog, which mainly activates the trunk extensor and rotator muscles and the hip extensor muscles.[55,58]

Nonetheless, despite the important information offered by biomechanical studies on these and other trunk-focused exercises, information about how to quantify, control, and modulate the TEP training load is lacking. In this sense, RCT on TEP used to provides scarce information about the training program features, which hinders the dose-response characterization of these programs. This can be seen in several reviews of TEP studies, in which although all of them have analysed the impact of these exercises in the outcomes of interest according to the population studied (e.g., lower limb muscle power and strength, linear sprint speed, and agility in athletes, pain and disability in LBP individuals…), few of them have analysed how the training load characteristics modulate the effects reported.[1,25] As a clear example of this problematic situation, table 1 shows the poor training program description of several TEP found in a systematic review of CSE programs for chronic non-specific LBP patients, in which relevant information on basic training characteristics (i.e., type of exercise, number of sets, repetitions, rest between sets,…) is lacking in the experimental studies.[25] They observed the highest pain and disability reductions when stabilization exercises were applied between 3 and 5 times per week and from 20 to 30 min per session.[1] However, the effects of other types of trunk-focused exercises (rather than stabilization exercises) and their intensity have not been explored.

**Table 1.** Training characteristics of stabilisation exercise programs for patients with chronic non-specific low back pain. Table adapted from Mueller et al.[1]

| First author, year | Type of intervention | Exercises (nº; Description) | Training period (weeks) | Training frequency (sessions per week) | Training duration (min/session) | Sets (nº per exercise) | Repetitions (per set and exercise) | Resting period (between set and exercises) |
|---|---|---|---|---|---|---|---|---|
| Alp, 2014 | Lumbar core stabilisation exercise | N.P | 6 | 3 | 45-60 | N.P | N.P | N.P; N.P |
| Alrwaily, 2019 | Stabilisation exercise | 5; Abdominal bracing, abdominal bracing with heel slide, abdominal bracing with leg lifts, abdominal bracing with bridging, bracing with single leg bridging | 6 | 2 | 20 | N.P | N.P | N.P;N.P |
| Bae, 2018 | Core stability exercises | 6; Abdominal drawing-in in 4-point kneeling and supine position, opposite upper/lower extremity lifted in quadruped position, straight leg raise exercise in prone position, supine lower extremity extender in supine position, straight leg raised exercise in supine position, horizontal side-support exercise in side lying position. | 4 | 3 | 30 | N.P | N.P | N.P;N.P |
| Rabin, 2014 | Lumbar stabilisation exercise | 4; Quadruped, side lying, supine, and standing positions. | 8 | Supervised:<br>2 x first 4 weeks;<br>1 x week 5-8 | N.P | N.P | N.P | N.P;N.P |
| Inani, 2013 | Core stability exercises | 4; Slow curl ups, sit ups, oblique plank/side bridge, bird-dog. | 12 | N.P | N.P | N.P | N.P | N.P;N.P |

N.P: not provided.

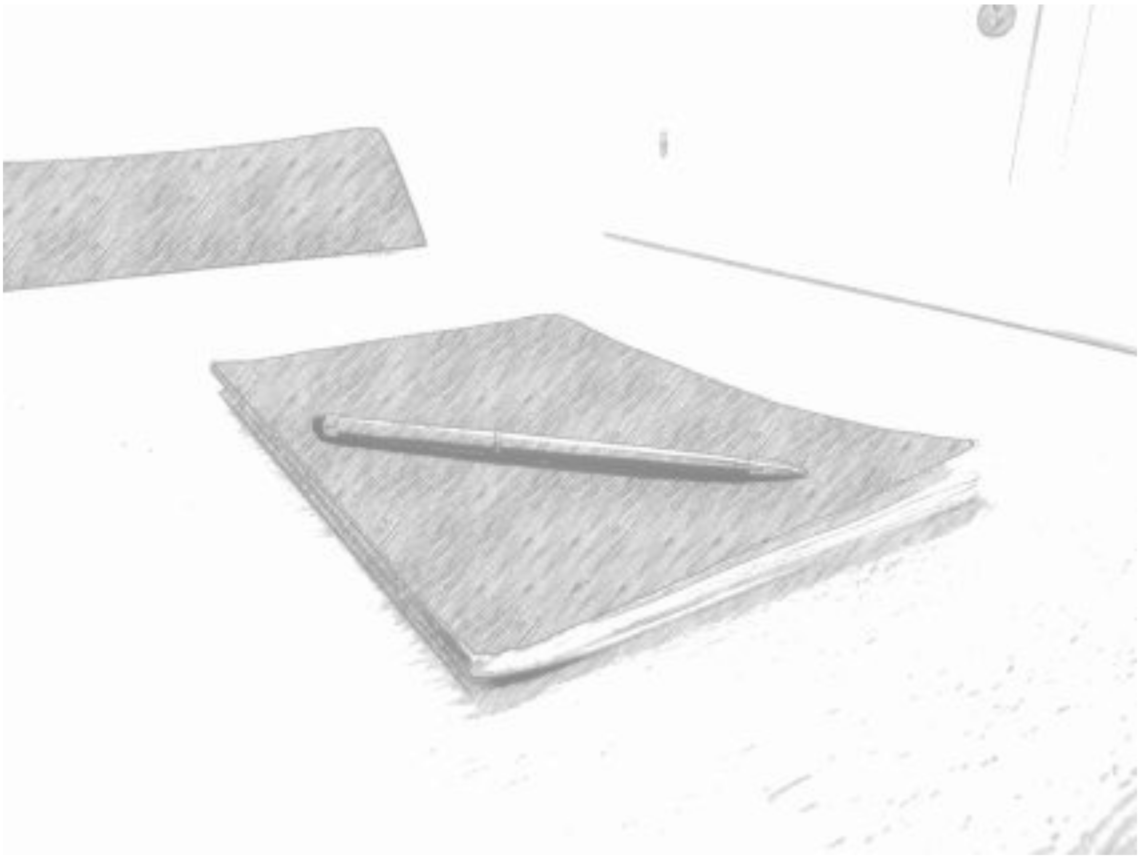
The intensity of the CSE is usually established based on the experience and subjective criteria of the exercise professionals who design and/or conduct the training programs (criteria not normally specified in the experimental studies) through the modulation of exercise mechanical parameters, such as lever arms, base of support, number of support points, stability level of the supporting surface, limb motion, etc.[51,56,59] Thus, the prescription of the CSE intensity and its progression throughout the training program does not rely on objective and quantifiable parameters, which hinders the dose-response characterization and replication of the CSE programs.[60,61] Nonetheless, over the last few years, posturographic techniques have been used in research settings to objectively calculate external indexes of CSE intensity based on the postural control challenge imposed on the participants.[51,60–62] In this sense, the centre of pressure displacement provided by force platforms during bridging and bird-dog exercises has been used to established different CSE intensity progressions.[51] In addition, the lumbopelvic accelerations recorded by smartphone-based accelerometry have been used as low-cost and reliable measures of CSE intensity.[60–62] Recently, Heredia-Elvar et al[61] studied the association between CSE experts' assessments of whether some CSE variations represented adequate intensity levels or not for each of the participants and the lumbopelvic accelerations recorded in these participants during the performance of the CSE variations. Interestingly, they found some relationship between the experts' assessments and different smartphone-based acceleration thresholds, which seems to represent the minimum level of CSE intensity necessary to elicit training adaptations in young physically active males and females. On this wise, two different thresholds were proposed depending on whether a restrictive or a conservative approach is to be used, in which the use of one or the other may vary depending on the participants (e.g., athletes, people with pathological conditions…). However, despite the potential of the smartphone-accelerometry to quantify the CSE intensity in field settings, these acceleration thresholds have not been used yet in experimental studies, and thus, their usefulness to prescribe different CSE intensities has not been verified.

### *Summary of the research problems*

As presented in this chapter, although the number of experimental studies on TEP has grown in the last few years, there are important limitations in the literature that need to be addressed to understand the effects of these programs and their relationship to the training load characteristics better. In this sense, due to the heterogeneity of the training programs and of the control groups found in the experimental studies, further systematic reviews should analyse the studies in detail to assure that the TEP are specifically made up of trunk-focused exercises and compared to real control groups and/or to programs not focusing on the trunk structures. In addition, it is also important that these reviews and the experimental studies consider not only outcomes related to performance in sport or functional recovery or pain in pathologies, but also related to trunk physical fitness (e.g., endurance, strength, stability, ROM…). Likewise, the study of how potential effect modifiers related to the training program and individuals' characteristics modulate the TEP impact would help to optimize the prescription of these programs. On the other hand, the lack of information of the experimental studies on basic training features of the TEP, especially the exercise intensity, hinders the dose-response characterization of these programs, so future studies should pay special attention to the correct training load description and quantification. Although smartphone-accelerometry seems a reliable, low-cost and easy to use technique to quantify the CSE intensity, to the best of our knowledge, it has not been yet tested in experimental studies. Therefore, all these limitations and the need to improve the TEP prescription motivated the development of this doctoral thesis.

# CHAPTER 2

## RESEARCH OBJECTIVES AND HYPOTHESES



# Chapter 2. Research objectives and hypotheses

## 2.1. General objectives

To address the limitations that have been formerly exposed, the main objectives of the present doctoral thesis were: *(i) to analyse the effects of performing trunk-focused exercise programs on trunk performance, functional capacity, and health status in different populations, and (ii) to explore the relationship between these effects and the training load and the participants' characteristics.*

To accomplish this objective, two systematic reviews with meta-analyses (*Study 1* and *2*) and an experimental study (*Study 3*) were performed. *Study 1* consisted of a systematic review with meta-analysis that aimed at studying the TEP effects on rehabilitation outcomes in stroke survivors and how potential effect modifiers modulate their effects. As a result of the learning process and due to the heterogeneity that was observed in the RCT experimental design of the TEP of *Study 1* but also in other populations such as athletes employing TEP,[25] *Study 2* presented similar aims, but an in-depth review was performed to ensure that the TEP included in this second study were specifically made up of trunk-focused exercises and compared to no exercise control groups and/or to programs not focused on the trunk structures. Finally, *Study 3* consisted of an experimental study that intended to overcome some limitations observed in the former reviews, especially the vague training load description and control and, consequently, the poor dose-response characterization of the TEP. This study used smartphone-accelerometry to analyse the effect of different CSE training doses (different intensities and volumes) on core performance and whole-body dynamic balance. The studies titles are as follows:

- Study 1: *Do initial trunk impairment, age, intervention onset, and training volume modulate the effectiveness of additional trunk exercise programs after stroke? A systematic review with meta-analyses.*
- Study 2: *Effect of trunk-focused exercises on pain, disability, quality of life and trunk physical fitness in low back pain and how potential effect modifiers modulate their effects: systematic review with meta-analyses.*
- Study 3: *Effect of two core stability training programs on core performance and whole-body balance based on smartphone-accelerometry monitorization: a double-blind randomised controlled trial.*

## 2.2. Specific objectives

The specific objectives have been structured according to the studies included in this doctoral thesis:

**Study 1:**

I. To analyze the effect that adding trunk-focused exercises to the conventional rehabilitation programs (ATEP) has on trunk function, balance ability, gait performance, and functional mobility in the stroke population.

II. To analyze how potential effect modifiers, related to the participant and the training program characteristics, modulate the impact of additional trunk-focused exercises to the conventional rehabilitation programs on trunk function, balance ability, gait performance, and functional mobility in the stroke population.

**Study 2:**

III. To analyze the effect of trunk-focused exercise programs on pain, disability, quality of life, and trunk physical fitness in people with non-specific chronic low back pain.

IV. To analyze how potential effect modifiers, related to the participant and the training program characteristics, modulate the impact of trunk-focused exercise programs on pain, disability, quality of life and trunk and/or hip ROM ($TH_{ROM}$) in people with non-specific chronic low back pain.

**Study 3:**

V. To explore the feasibility of the smartphone-accelerometry to establish and control different training loads during CSE programs.

VI. To compare the effect of two CSE programs, i.e., one with higher volume and lower intensity and another one with higher intensity and lower volume, on core stability, core endurance and whole-body dynamic balance in young physically active individuals.

## 2.3. Hypotheses

The following hypotheses were established in the studies included in this doctoral thesis according to the previous evidence:

**Study 1:**

1) Previous systematic reviews with meta-analyses observed a positive effect of TEP on trunk function, balance, and functional mobility.[23,42,63,64] Based on these results, our results will confirm the benefits of ATEP after the stroke-onset.
2) The identification of the moderator factors related to the training program and the individuals' characteristics remains a key point to optimize post-stroke rehabilitation programs.[65] In line with this, greater effects on trunk function after carrying out trunk-focused exercises have been observed if the rehabilitation starts earlier (i.e., acute phase after the stroke-onset), or the duration of the training programs is short.[22] Thus, based on these results, ATEP will confirm a greater impact on trunk function when the rehabilitation starts earlier, which will be also observed in the rest of outcomes analysed (i.e., balance, limits of stability, gait, and functional mobility). Regarding the training program characteristics, contrarily to the former evidence in trunk exercises,[22] we expected to observe larger effects on longer training programs, since in general, a greater training dose has been related to higher motor recovery after stroke.[66,67] Although other moderator factors related to patients' characteristics such as the greater initial impairment and older age have been related with a poorer recovery process,[68,69] their relationship with ATEP effect has not yet been analysed, from which we expect that they will modulate for less benefit after ATEP.

**Study 2:**

3) Previous systematic reviews with meta-analyses performed in people with non-specific chronic LBP have observed a positive impact of TEP on pain, disability, trunk strength, and trunk endurance.[1,7,9,10,44,45,70–73] Most of them have focused on one type of TEP (e.g., stabilization, Pilates…), and have analysed their impact on pain and disability, being scarce the number of studies reporting their effects on trunk physical capabilities,[44] which are common impairments in people with LBP.[74–77] Based on these results, this study will confirm the benefits of performing TEP on pain, disability, trunk strength and trunk endurance. Furthermore, since a poor general health and psychological stress have been identified as a LBP risk factor,[78] TEP will also increase the perceived quality of life. Because people with LBP usually have lower lumbar and pelvic ROM,[75] TEP will also increase their $\mathrm{TH}_{\mathrm{ROM}}$.

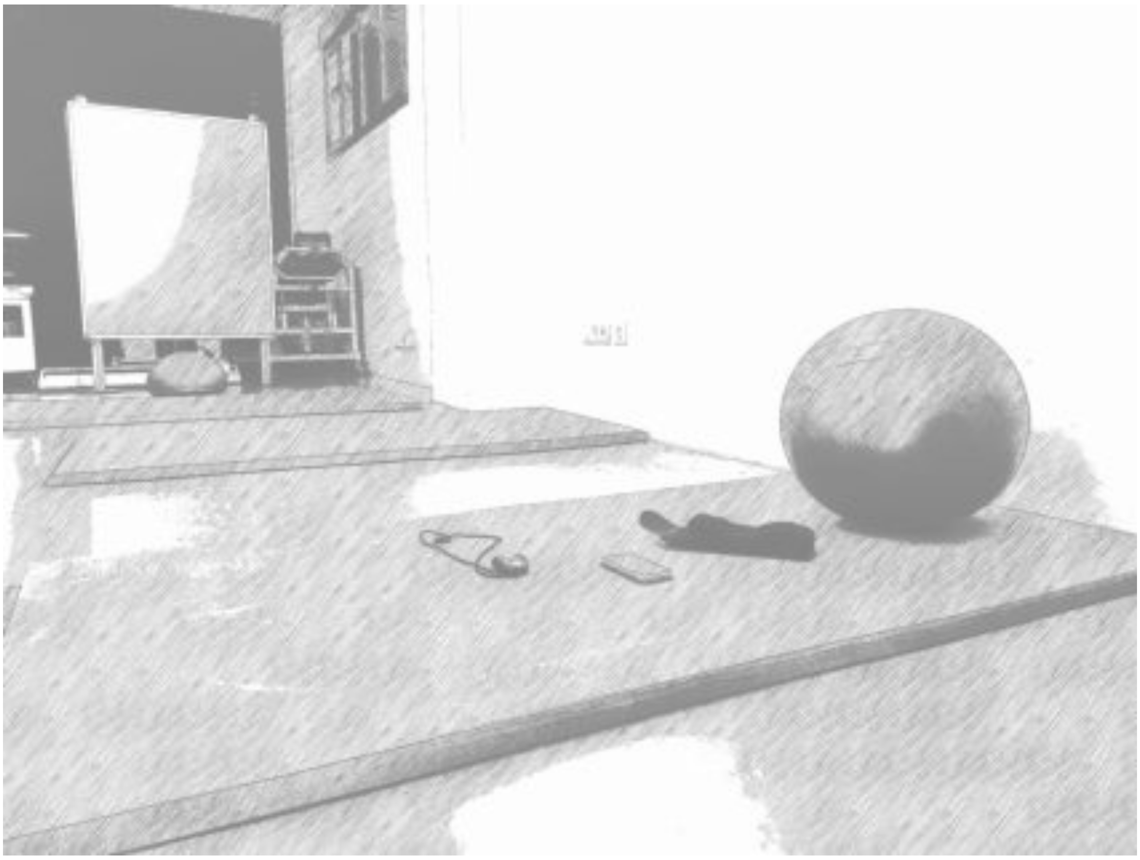
4) Previous studies on LBP patients have shown that motor control stabilization exercises have the highest benefits in middle-aged individuals and those with sub-clinical intermediate pain (i.e., 2-2.5/10 on a 10-point pain scale).[10] Considering these results, we expect that older individuals with lower initial pain and disability levels will benefit the most from TEP on pain, but also in the rest of outcomes analysed (i.e., disability, quality of life and trunk physical fitness). Regarding pain duration, since the population is restricted to chronic LBP, we do not expect an influence of pain duration on the effect evoked by TEP. On the other hand, since the body mass index (BMI) has not been observed to be a predictor of pain and disability changes,[10,79] we do not expect that the BMI will modulate the impact of TEP. Regarding the training program characteristics, a former systematic review with meta-analysis on trunk stabilization programs in LBP population has shown that training frequencies of 3-5 times per week, and session durations of 20-30 min produce the largest effects on pain and disability.[1] Although this review did not report the total training volume, as in *Study 1*, we expect to observe larger effects on longer training programs, since higher doses have shown to be more effective than lower exercise training doses.[43]

**Study 3:**

5) Considering the smartphone-accelerometry reliability to quantify CSE intensity[60] and the lumbopelvic acceleration thresholds established by Heredia-Elvar et al[61] in young physically active individuals, the smartphone-accelerometry will enable the setting and control of two different training intensity levels, one for the higher intensity CSE program and another one for the higher volume CSE program.
6) Based on the core training and testing specificity,[80–82] the higher intensity CSE program and the higher volume CSE program will have a greater impact on core stability and core endurance outcomes, respectively.
7) As previous studies on TEP have shown static and dynamic balance improvements in healthy athletic individuals,[3,4,6] the CSE programs will have a positive effect on whole-body dynamic balance. In addition, considering that the higher intensity CSE program imposes greater postural control demands on the participants, it will have a greater effect on the participants' whole-body dynamic balance than the higher volume CSE program.

# CHAPTER 3

## SUMMARY OF THE METHODS



# Chapter 3. Summary of the methods

The summary of the methods will be presented independently from the systematic reviews with meta-analyses and from the experimental study due to the differences in the methodological procedure.

## 3.1. Systematic reviews with meta-analyses

*Studies 1* and *2* were systematic reviews with meta-analyses carried out following the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines.[83] Based on the limitations found in *Study 1* during the journal peer reviewing process, *Study 2* was registered in the PROSPERO database (registration number: CRD42019122865). The study selection, coding process, risk of bias, and quality of the evidence processes were carried out by two independent researchers. In case of disagreement, a third researcher was consulted to reach a consensus.

### 3.1.1. Data search and sources

Different Boolean searches were employed and adapted to each of the databases for *Study 1* (PubMed, Scopus, Cochrane Library, and EMBASE) and *Study 2* (PubMed, Scopus, EMBASE, SPORTDiscus, and Cochrane Library). In both studies a complementary search was performed to ensure the minimal loss of potential studies.

### 3.1.2. Study selection

The inclusion criteria of studies 1 and 2 were established following the Population Intervention Comparison Outcomes and Study (PICOS) design, which is based on the consideration of the subsequent items: participants, intervention, comparison, outcomes, and study design. These inclusion criteria for each systematic review with meta-analyses are as follows:

*Study 1*

Participants had suffered a stroke (participants); the trunk exercise program was additional to the conventional therapy (intervention); there was a control group that only performed the conventional therapy (comparison); at least one of the outcomes of interest of the study: trunk function, balance ability, limits of stability, gait, or functional mobility was reported (outcomes); the study was a randomised controlled trial (study design); and language was restricted to English, Spanish, French and Italian., The studies were also excluded if: (i) it was a single training session; (ii) studies did not provide pre-post intervention data.

*Study 2*

Participants between 20 and 65 years of age that had non-specific (including recurrent) chronic LBP (participants); there was an experimental group that performed trunk-focused exercises (intervention); there was a second group that was a control group (i.e., they did not receive an intervention, it was a minimal intervention or a hands-on/off treatment), or a group that underwent another type of exercise intervention that was not focused on trunk/core structures (from now on referred to as general exercise program or GEP) (comparison); at least one of the outcomes of interest of the study: pain, disability, quality of life, trunk endurance, trunk strength, or $TH_{ROM}$ (outcomes) was reported; the study was a randomised controlled trial (study design); the exercise program length was 4 weeks or longer; training sessions were supervised at least once per week; and language was restricted to English, Spanish, French and Italian. Also, the studies were excluded if: (i) the sample consisted of athletes; (ii) pain duration was less than 12 weeks; (iii) the training program was additional to what was performed by the control group or the GEP; (iv) they were yoga interventions; (v) the GEP included 25% or more of trunk-focused exercises; (vi) data to perform the analyses could not be extracted.

### 3.1.3. Data extraction

The following information was extracted from the studies and registered in a codebook created specifically for each systematic review with meta-analyses (*Study 1* and *2*): (1) study characteristics (e.g., year of publication); (2) individuals' characteristics (e.g., age, sex, LBP duration…); (3) Training program characteristics: type of trunk exercises, number of weeks of training, training frequency, session duration, and exercise progression; (4) methodological procedures (i.e., test and/or questionnaires) to assess the outcomes; (5) statistical information: pre- and post-intervention mean and standard deviation (SD) (mean change and SD of the changes if they were provided) of the experimental and control groups. In the case that a study reported the same outcome through different scales or tests, the most used scale or test was selected to reduce potential heterogeneity. The outcomes registered in *Study 1* were trunk function, balance ability, limits of stability, gait performance, and functional mobility. The outcomes registered in *Study 2* were pain, disability, quality of life, trunk extension endurance, trunk strength and $TH_{ROM}$.

### 3.1.4. Data synthesis and statistical analyses

The mean change and SD of the changes of the outcomes were used to calculate the pooled effect sizes (ES). If this data was not provided, then this was calculated from the mean and SD pre- and post-assessments. In *Study 1*, the SD of the changes was calculated by using a *r* value of 0.7, as suggested in the literature,[84] although sensitivity analyses with 0.5, 0.6, 0.8 and 0.9 correlation values were also performed to verify that the results did not change substantially. In *Study 2*, the *r* value employed was 0.5,[85,86] and the sensitivity analyses were performed with 0.6, 0.7, 0.8 and 0.9 correlation values. The pooled ES were calculated as the weighted standardised mean difference (SMD) and the weighted mean difference (MD) when the studies employed the same or different tests, respectively.[87,88] A positive SMD or MD indicated the effect in favour of the experimental groups [i.e., ATEP in *Study 1* and TEP in *Study 2*). A random-effects model was employed for the pooled analyses due to the nature of the studies, with the aim of reducing the heterogeneity of both, training programs and sample. In *Study 2*, if a study had two experimental groups that met the inclusion criteria of the systematic review, the sample of the control group was divided, avoiding sample duplication in the pooled ES.[89] In these cases, the groups from the same study were named as group A and group B. All the pooled ES were calculated with the confidence interval (CI) set at 95%, and the heterogeneity was studied through the $I^2$ index.[90] A correction factor $c\,(gl) = 1 - \left(\frac{3}{(4 \times n) - 9}\right)$ was also used to avoid the overestimation of the ES.[91]

Moderator factors were obtained after selecting the studies and thus, they must be considered as *post-hoc* analyses. In *Study 1*, the potential effect modifiers were the following: (1) initial trunk impairment; (2) participants' age; (3) moment of the beginning of the intervention after the stroke-onset; (4) total volume of the ATEP. In *Study 2*, they were as follows: (1) participants' age; (2) body mass index; (3) low back pain duration at the time of starting the study; (4) initial level of pain; (5) initial level of disability; (6) total volume of the trunk-focused exercise programs. For the analyses, in *Study 1* two groups were established using the median score (below and over) from all the studies for each potential effect modifier and the pooled ES for each subgroup was calculated. In *Study 2* multiple weighted meta-regressions with inverse variance were employed to analyse the impact of the moderator factors on the outcomes though a backward elimination procedure. To select the moderator factors of the multiple models, those models showing a significant association ($p$<.05) on single regression analysis were included. Also, the adjusted R-squared ($R^2$) was employed to report the between-study variability caused by moderator factors, whilst the residual heterogeneity ($I^2_{res}$) index was employed to show the variability caused by between-study variation after the inclusion of the moderator factors.

To provide a clinical insight of the results, the percentage of the change regarding the maximal possible score in trunk function and balance ability outcomes in *Study 1* was calculated. In *Study 2*, the pre-post percentage of change was calculated for all the outcomes. Regarding pain and disability outcomes, an improvement superior to the 30% with respect to the baseline score was established as a meaningful clinical change.[92] Likewise, the prediction interval for the outcomes with a number of studies equal or over 10 was calculated in this study.[93] The Review Manager (RevMan) software (version 5.3, the Nordic Cochrane Centre, the Cochrane Collaboration, Copenhagen, Denmark, 2014) and the Stata V.16 software (StataCorp, College Station, Texas, USA) were employed for the statistical analyses for *Study 1* and *2*, respectively.

### 3.1.5. Risk of bias and quality of evidence

In *Study 1* and *2* the Physiotherapy Evidence Database (PEDro)[94] scale was used to analyse the risk of bias of the individual studies. This scale assesses 11 items, from which all but the first contribute to the final score, and it is categorized as follows: excellent: 9-10 points, good: 6-8 points, fair: 4-5 points, and poor: <4 points. In addition, in *Study 2* the Cochrane risk of bias II tool[95] was also employed for the risk of bias assessment. The quality of the evidence of the outcomes was evaluated through the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach in both studies.[96–101] The quality of evidence was classified as very low, low, moderate, or high depending on the items of risk of bias, inconsistency, indirectness, imprecision, and publication bias.

## 3.2. Experimental study

*Study 3* was registered at ClinicalTrials.gov: NCT03459430 and was approved by the University Office for Research Ethics (DPS.FVG.02.14). There were no deviations from the registered protocol.

### 3.2.1. Participants

Sixty-three healthy physically active male aged between 18 and 35 years of age were assessed for eligibility. They were excluded if they had previously participated in a TEP or in sports that required high demands of these structures (e.g., judo, gymnastics…), or if they had back pain, back injuries or any other type of issues (e.g., musculoskeletal injuries, coronary diseases, visual or vestibular problems, etc.) that contraindicated the practice of physical exercise.

### 3.2.2. Study design

*Study 3* was a double-blind randomised controlled trial paired to the initial participants' core stability performance level. Participants were randomised through opaque envelopes to the two CSE experimental groups monitored with smartphone-accelerometry [one performed the higher volume CSE program ($EG_{HV}$), the other performed the higher intensity CSE program ($EG_{HI}$)] or the control group (CG) by an independent researcher. The experimental design comprised 2 weeks of pre-test (separated by one-week), a 6-week period of training for the experimental groups and of no activity for the CG, and one week of post-test. The researchers involved in the testing sessions were not aware of the group to which the participants belonged, nor of the researcher in charge of the statistical analyses.

### 3.2.3. General assessment procedures and data reduction of the main outcomes

Two testing sessions with one-day rest in between were performed in the pre- and post-test weeks. These testing sessions were conducted as follows:

1) First testing day: *Core stability measures*: trunk postural control was assessed through lumbopelvic accelerations recorded with a smartphone-accelerometer in seven variations of front, back and side bridges, and the bird-dog exercise (Figure 3).[61] The triaxial mean vector magnitude was calculated (low pass filter: 4th-order, zero-phase-lag, Butterworth) for a 12-second window of each trial acceleration.[61] An average of the 3 most difficult variations of each CSE was calculated for each participant.

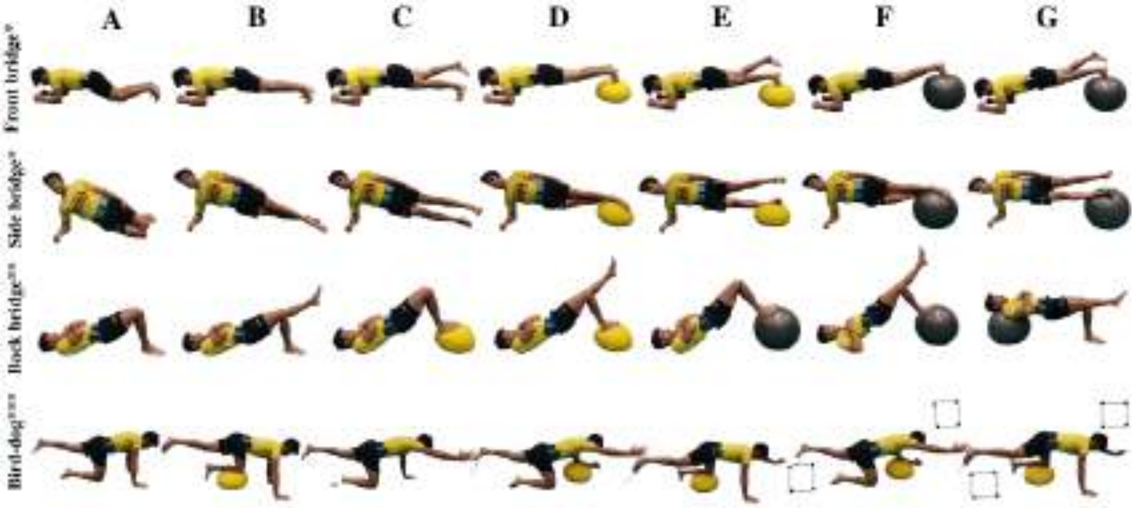


**Figure 3.** Core stability exercises: **Front and side bridge variations*: A) short bridge; B) long bridge; C) bridging with single leg support; D) bridging with double leg support on a hemisphere ball; E) bridging with single leg support on a hemisphere ball; F) bridging with double leg support on a fitball; G) bridging with single leg support on a fitball. ***Back bridge variations*: A) short bridge; B) bridging with single leg support; C) bridging with double leg support on a hemisphere ball; D) bridging with single leg support on a hemisphere ball; E) bridging with double leg support on a fitball; F) bridging with single leg support on a fitball; G) bridging with single leg support and with the upper-back on a fitball. ****Bird-dog variations*: A) three-point position with an elevated leg; B) three-point position with the knee on a hemisphere ball; C) classic two-point bird-dog position with elevated contralateral leg and arm; D) two-point bird-dog position with the forearm on a hemisphere ball; E) two-point bird-dog position with the knee on a hemisphere ball; F) two-point bird-dog position with the forearm on a hemisphere ball while drawing squares in the air with the elevated limbs; G) two-point bird-dog position with the knee on a hemisphere ball while drawing squares in the air with the elevated limbs.

2) Second testing day:

(i) *Core stability measures*: trunk postural control while sitting and trunk passive and reflex response to quick external perturbations to the upper-body centre of mass (in frontal, right-side and posterior directions) were assessed through the unstable sitting test and a sudden loading protocol, respectively.[80] For the loading protocol, the angular displacement at 110 ms was analysed for each of the three directions.[80] In the unstable sitting test, the mean radial error was calculated as the average of the vector distance between a target point and the participants' centre of pressure displacement during a circular tracking task;[102]

(ii) *Core endurance measures*: trunk flexion, trunk lateral bending, and trunk extension endurance were assessed through the prone plank test,[103] the right side bridge test,[104] and the Biering-Sorensen test,[105] respectively;

(iii) *Whole-body dynamic balance measures*: stability limits in single-leg stance, postural control in tandem and single-leg stance, and single-leg power with high balance demands were assessed through the Y-Balance test,[106] two posturographic tests on a force platform,[102] and the triple hop test,[107] respectively. The Y-Balance test was analysed in anterior, posteromedial, and posterolateral directions, noting the largest distance reached. A composite score gathering all directions was also calculated. For the triple hop test, the maximal distance reached was registered. In the posturographic tests, the mean radial error was calculated as the average of the vector distance between a target point and the participants' centre of pressure displacement during a circular tracking task.[102] Three trials were performed in each of the three tests, using an average of the two closest trials for further analysis.

Videos of the testing procedures can be seen in the following quick response code:

*Interventions*

After the pre-test, the participants were divided into two groups (better and lower core stability initial level) depending on their lumbopelvic accelerations registered during the CSE. Considering these two performance groups, participants were randomised to $EG_{HI}$, $EG_{HV}$ and CG, pairing all groups to this outcome. Two training sessions were performed on each of the 6 training weeks, in which participants in the experimental groups performed four repetitions of front bridge, back bridge, right side bridge, left side bridge and the bird-dog exercise at an intensity level corresponding to the group they belonged to ($EG_{HI}$: 0.40-0.50 m/s$^2$; $EG_{HV}$: 0.20-0.30 m/s$^2$) and based on the lumbopelvic accelerations recorded during the performance of these exercises at the pre-test (Figure 3). In this sense, for each of the five CSE, the $EG_{HI}$ participants executed an exercise variation (out of the seven recorded) in which lumbopelvic accelerations between 0.40 and 0.50 m/s$^2$ were found, whilst the $EG_{HV}$ participants executed an exercise variation in which lumbopelvic accelerations between 0.20 and 0.30 m/s$^2$ were obtained. These lumbopelvic acceleration ranges were established based on the acceleration thresholds proposed by Heredia-Elvar et al.[61] As performing CSE below these thresholds could minimize the impact of the CSE program, the exercise duration was adjusted to the intensity of each CSE program, i.e., each repetition lasted 15 s and 30 s for the $EG_{HI}$ and $EG_{HV}$, respectively. The participants of both groups had a 30-second rest between trials and 1 min between exercises, leading to a 21.5 min and 16.5 min of total session duration for the $EG_{HV}$ and the $EG_{HI}$, respectively. Two lumbopelvic acceleration re-assessments were performed in the 4th and 8th training session to readjust the training load. Two examples of the CSE intensity readjustment process are shown in Figure 4. Two researchers that did not participate in the testing sessions conducted the training program. It must be noted that extra training sessions were provided each week to the participants if they missed any of the training sessions.

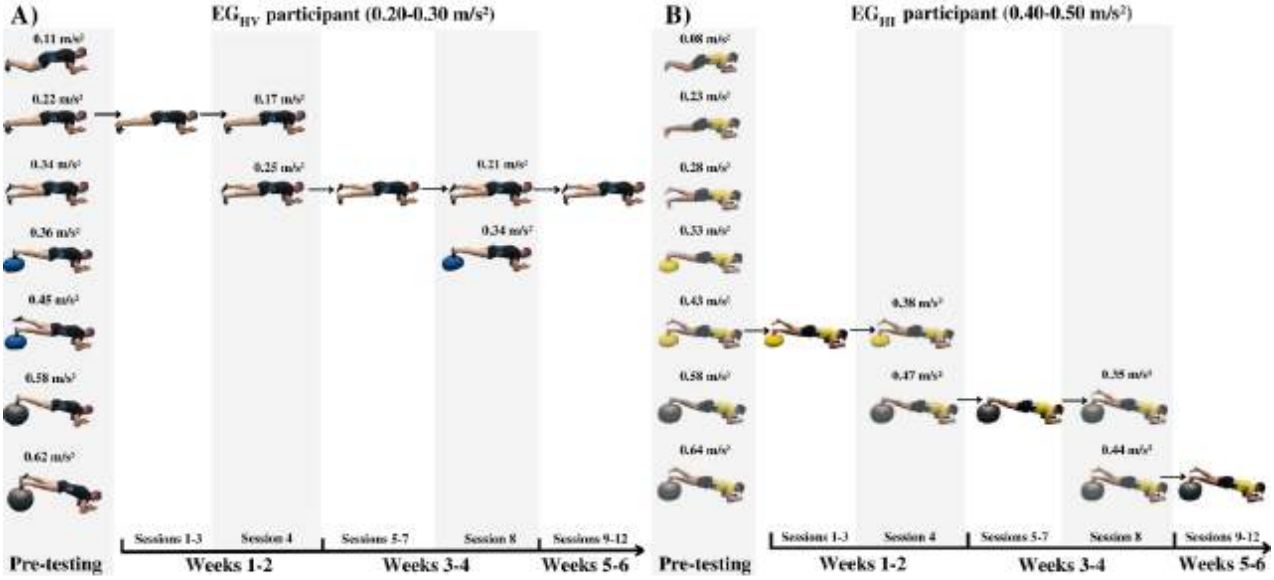


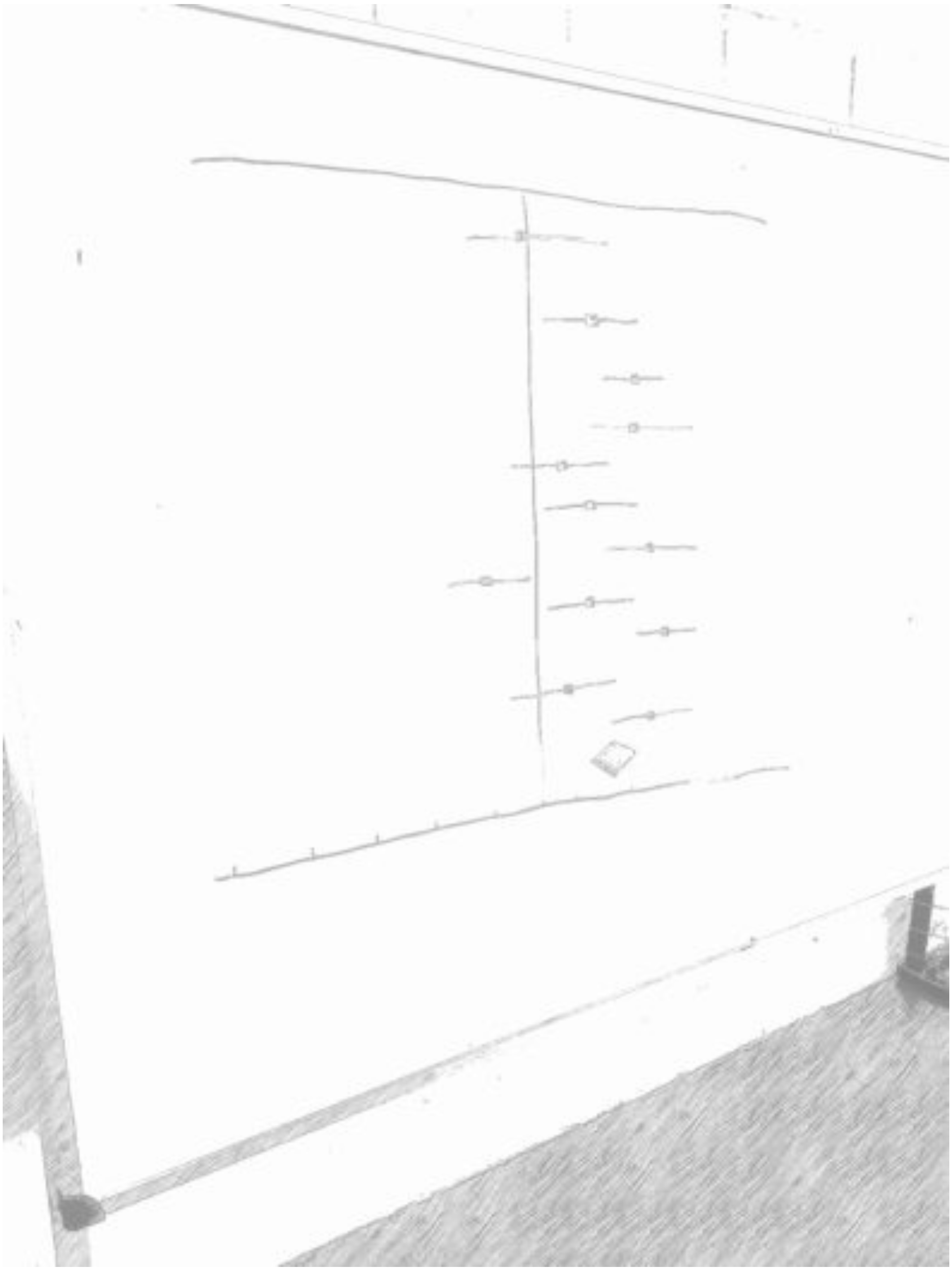
**Figure 4.** Example of the exercise intensity readjustment during the training process for two participants. The grey shaded areas represent the acceleration assessment periods. The pre-test with refers to the 2nd week of baseline assessment in which all the exercise variations were performed by the participants. From all the variations, the one that was within the corresponding acceleration range of each group (i.e., 0.20-0.30 m/s2 for EGHV and 0.40-0.50 m/s2 for EGHI) in the pre-test was selected for weeks 1 and 2 of the training period. In the 4th and 8th session, an exercise intensity readjustment was performed using the smartphone-accelerometer. In these sessions, the participants performed 2 repetitions (out of 4 for each core stability exercise) using the variation that they had been performing in the last three sessions, and 2 repetitions using the variation that obtained the next higher lumbopelvic acceleration during the pre-test. Of both variations, the one that fell within the corresponding acceleration range of each group was selected as the new exercise variation for the following two weeks of training.

### 3.2.4. Statistical analyses

Mean, SD and the delta of changes (Δ) of pre-post differences were calculated for the outcomes assessed. The relative Δ (Δ %) was also calculated to provide a clinically interpretable index of the ES caused by each CSE program.[108,109] The distribution of the data and the equality of variances were verified with the Kolgomorov-Smirnov with the Lillefors' correction and the Levene's test, respectively. Between group differences for pre- and post-test were analysed through a one-way ANOVA in the Δ (between-subject factor group: study group with 3 levels, CG, EG$_{HV}$, EG$_{HI}$). Afterwards, independent and repeated student t-test were used to analyse between-group pairwise comparisons and pre-post changes of each group, respectively. Per-protocol and intention-to-treat analysis were performed for all parameters. The statistical package SPSS (version 22.0, SPSS Inc., Chicago, IL, USA) with a significance level at $p<.05$ was used.

# CHAPTER 4

## SUMMARY OF THE RESULTS



# Chapter 4. Summary of the results

This chapter summarises the main results of this doctoral thesis, which will be presented according to the aims previously established. First, the two systematic reviews with meta-analyses (*Study 1*: in stroke population; *Study 2*: in LBP population). Afterwards, the experimental study (*Study 3*) comparing a higher intensity *vs.* a higher volume CSE program in young physically active males.

## 4.1. Systematic review with meta-analysis on the effects of additional trunk-focused exercise programs in stroke

### 4.1.1. Study selection and characteristics

Twenty studies were included in the systematic review after excluding the studies that did not match the inclusion criteria from a total of 737 studies initially identified. The average age of the participants was 60.1±11.8 years and the main characteristics of the ATEP were: (i) a training program duration between 2 and 8 weeks (the most common was 4 weeks); (ii) session duration between 10 and 60 min (the most common was 30 min); (iii) total training program volume between 240 and 1200 min; (iv) time frame in which the intervention started after the stroke-onset, from 15 days to 34 months. The studies presented poor to good methodological quality, and the quality of the evidence was very low (in trunk function, limits of stability of the unaffected arm in forward and lateral directions, and functional mobility) and low (in balance, limits of stability of the affected arm in lateral direction, and gait performance).

### 4.1.2. Pooled effect sizes for trunk function, balance ability, gait, and functional mobility performance

ATEP produced a positive effect in all the outcomes analysed: trunk function was assessed in 13 studies and ATEP improved by SMD 1.06 (95% CI, 0.74-1.37; $I^2$=53%), balance ability was assessed in 9 studies and ATEP improved by SMD 0.83 (95% CI, 0.52-1.14; $I^2$=42%). Limits of stability were evaluated in different conditions: the forward non-affected-arm reach was assessed in 6 studies and ATEP improved by SMD 0.90 (95% CI, 0.47-1.33; $I^2$=43%), the lateral non-affected-arm reach was assessed in 4 studies and ATEP improved by SMD 1.16 (95% CI, 0.67-1.66; $I^2$=26%), and the lateral affected-arm reach was assessed in 3 studies and improved ATEP by 0.89 (95% CI, 0.26-1.52; $I^2$=39%). Gait performance was assessed in 8 studies and ATEP improved by 0.63 (95% CI, 0.38-0.89; $I^2$=0%), and functional mobility was assessed in 6 studies and ATEP improved the timed and go test by MD 3.40 s (95% CI, -0.32-7.12; $I^2$=67%).

### 4.1.3. Effects of potential effect modifiers

After compilation of the studies that were finally included in the systematic review, the moderator factors regarding the training program and the individuals' characteristics were analysed, from which the subsequent were chosen due to a higher availability among the studies:

initial trunk impairment, participants' age, time gone by since stroke-onset until the start of the intervention, total volume of ATEP.

### *Initial trunk impairment*

Subgroup analyses indicated that those studies with participants with a higher initial trunk impairment improved trunk function, balance ability and the limits of stability ($1.10<\text{SMD}< 1.54$) to a greater extent than those with less initial trunk impairment ($0.51<\text{SMD}< 0.76$).

### *Participants' age*

On the one hand, subgroup analyses indicated that those studies with older participants had a high effect on trunk function (SMD 1.13, 95% CI, 0.79-1.46; $I^2$=37%) and limits of stability (SMD 1.06, 95% CI, 0.11-2.01; $I^2$=75%), and a moderate effect on balance ability (SMD 0.79, 95% CI, 0.53-1.05; $I^2$ = 3%). On the other hand, those studies with younger participants revealed a high effect on trunk function (SMD 0.98, 95% CI, 0.35-1.61; $I^2$=66%) and balance ability (SMD 1.12, 95% CI, 0.06-2.18; $I^2$= 77%), and a moderate effect on limits of stability (SMD 0.80, 95% CI, 0.37-1.24; $I^2$ = 0%). The functional mobility change was greater in the older participants (5.75 *vs.* 1.93 s), although this change was not significant.

### *Time gone by since stroke-onset until the start of the intervention*

Subgroup analyses showed medium to high effects on trunk function, balance ability, and gait for all the participants, although the effect was slightly lower in the studies with participants that started the ATEP later ($0.59<\text{SMD}<0.98$ *vs.* $0.76<\text{SMD}<1.13$).

### *Total volume of additional trunk-focused exercise programs*

For the studies with a lower total volume of ATEP, subgroup analysis showed a high effect on trunk function, limits of stability, and gait performance ($0.87<\text{SMD}<1.09$), and a moderate effect on balance ability (SMD 0.70, 95% CI, 0.21-1.19; $I^2$=55%). For the studies with higher total volume of ATEP, the effect on trunk function and balance ability was high (SMD 1.24, 95% CI, 0.80-1.69; $I^2$=52% and SMD 0.95, 95% CI, 0.50-1.39; $I^2$=44%, respectively), the effect on gait performance was low (SMD 0.39, 95% CI, 0.03-0.75; $I^2$=0%), and the effect on limits of stability was moderate (SMD 0.72, 95% CI, -0.03-1.47; $I^2$=65%). In addition, although functional mobility improved in a higher extent in the ATEP with lower total volume (3.62 *vs.* 2.41 s), the effects were not significant.

## 4.2. Systematic review with meta-analysis on the effects of trunk-focused exercise programs in chronic non-specific low back pain

### 4.2.1. Study selection and characteristics

A total of 40 studies were included in the systematic review after reviewing the 5073 initially identified. All the studies had participants with non-specific chronic low back pain in which the mean age was 41.3±8.6 years. All exercise programs were TEP, although there was a high heterogeneity within the exercises performed in the studies, which hindered the sub-division of the programs into different types of TEP. The TEP characteristics found in the studies were: a) training program lengths between 4 and 22.5 weeks; b) weekly training frequencies between 1 and 5 days per week; c) session durations between 20 and 90 min. The studies presented high or some concerns in the risk of bias analysed with the Cochrane Risk of Bias tool II (specially in *domain 2*: bias due to deviations from the intended intervention, and in *domain 5*: bias in the selection of the reported results), and mostly good and fair quality with the PEDro scale. Regarding the quality of evidence, the GRADE approach showed a very low quality of the evidence.

### 4.2.2. Pooled effect sizes for pain, disability, quality of life and trunk physical fitness

*Pain and disability*

Pain was assessed in 31 studies with a total of 38 groups (total sample, n=1630; TEP, n=904; CG, n=726) compared to a CG, in which TEP showed a high effect (SMD 1.31, 95% CI, 0.99-1.63; $I^2$=87%; prediction interval: -0.54 to 3.16). The percentage of pre-post change was over the 30% in 27 groups (53.4±17.6%) and below (21.7±6.0%) in 11 groups. When comparing GEP to TEP, 6 studies with a total of 7 groups (total sample, n=669; TEP, n=368; CG, n=301) found a low effect for TEP (SMD 0.20, 95% CI, 0.03-0.37; $I^2$=13%). The percentage of pre-post change was over the 30% in 5 TEP groups (47.2±19.1%) and below (27.7±2.1%) in 2 groups, whilst in GEP, 3 groups were over the 30% (35.0±5.0%), and 4 were below (27.8±1.4%).

Disability was assessed in 27 studies with a total of 33 groups (total sample, n=1565; TEP, n=870; CG, n=695) compared to a CG, in which TEP showed a high effect (SMD 0.90, 95% CI, 0.66-1.13; $I^2$=77%). The percentage of pre-post change was over the 30% in 21 groups (48.7±11.9%) and below (20.5±7.4%) in 12 groups. With respect to the comparison TEP *vs.* GEP, 6 studies (total sample, n=482; TEPs, n=238; CG, n=244) showed a low effect in favour of TEP (SMD 0.20, 95% CI, 0.02-0.38; $I^2$=0%). The percentage of pre-post change was over the 30% in 4 TEP groups (50.2±15.0%) and below (11.6±9.2%) in 2 groups, whilst in GEP, 2 groups were over the 30% (37.1±8.3%), and 4 were below (17.8±10.8%).

### Quality of life

Quality of life was assessed in 10 studies with a total of 13 groups (total sample, n=550; TEP, n=315; CG, n= 235) compared to a CG, in which TEP showed a high effect (SMD 0.82, 95% CI, 0.38-1.27; $I^2$=82%). The pre-post change for TEP was 16.9%.

### Trunk physical fitness

Trunk extension endurance was assessed in 4 studies with a total of 5 groups (total sample, n=180; TEP, n=106; CG, n=74) compared to a CG, in which TEP showed a high effect (SMD 2.46, 95% CI, -0.04-4.96; $I^2$=98%). The pre-post change for TEP was 55.0%. Trunk strength was assessed in 7 studies with a total of 10 groups (total sample, n=220; TEP, n=139; CG, n= 81) compared to a CG, in which TEP showed a high effect (SMD 0.91, 95% CI, 0.42-1.41; $I^2$=61.2%). The pre-post change for TEP was 22.51%. $TH_{ROM}$ was assessed in 13 studies with a total of 17 groups (total sample, n=530; TEP, n=301; CG, n=229) compared to a CG, in which TEP showed a high effect (SMD 0.93, 95% CI, 0.58-1.29; $I^2$=71%). The pre-post change for TEP was 26.4%.

## 4.2.3. Effects of potential effect modifiers

From the two moderator factors that were related with pain, i.e., body mass index and $TH_{ROM}$, only the second one was maintained in the final model (n=17, $p<.01$, CI, 0.25-0.87; $R^2$=75.16%, $I^2_{res}$=27%). Similarly, this factor was the only one that displayed a significant impact on disability in the multiple regression model (n=14, $p<.01$, CI, 0.27-1.05; $R^2$=73.20%, $I^2_{res}$=35%).

## 4.2.4. Sensitivity analyses and small-study and/or publication bias

Sensitivity analyses were performed to estimate the pooled SMD with 0.6, 0.7, 0.8, and 0.9 values in *Study 2*, which did not indicate substantial differences in the effects of the outcomes analysed. Furthermore, pain, disability, quality of life and trunk extension endurance showed significant bias on TEP *vs.* CG, and in pain when TEP was compared to GEP.

## 4.3. Double-blind randomised controlled trial on the effect of two core stability training programs monitored with smartphone-accelerometry

### 4.3.1. Study participants

Fifty-six out of the sixty-three initially recruited participants (88.9%) completed the study. Regarding participants' characteristics, there were no differences among EG$_{HI}$, EG$_{HV}$ and CG in the baseline assessment with exception of the posterolateral direction of the Y-Balance test (*p*=.03). There was full training attendance by 82.05% of the participants, and the rest of them attended to at least 10 of the 12 training sessions. No adverse events related to this research were reported by the participants during the experimental period. There were no drawbacks in the use of the smartphone-accelerometer for the pre-post core stability assessment and the CSE training load progression. However, it should be noted that since the accelerations were not provided in real time, it took approximately 2 days after its use to process the data obtained.

### 4.3.2. Effect of the core stability exercise programs on core stability outcomes

Overall between-group differences were observed in the one-way ANOVA for the pelvic acceleration scores of the front bridge (Δ: F=3.684, *p*=.03; Δ%: F=4.101, *p*=.02), the bird-dog (Δ: F=4.193, *p*=.02; Δ%: F=4.498, *p*=.01), and the CSE composite (Δ: F=3.432, *p*=.04; Δ%: F=3.660, *p*=.03). The EG$_{HI}$ showed the largest lumbopelvic acceleration reductions in the CSE (Δ% for the CSE composite: EG$_{HI}$=-15.5; EG$_{HV}$=-10.6; CG=-4.1), which were significant compared to the CG for the front bridge, the bird-dog and the CSE composite (Table 2). On the contrary, the smaller acceleration reductions observed in the EG$_{HV}$ were significantly higher than in the CG only for the front bridge (Δ%: EG$_{HV}$=-13.5; CG=-0.1). Regarding the unstable sitting test, the three groups showed a significant mean radial error reduction in the post-test (Δ%: EG$_{HI}$=-7.8; EG$_{HV}$=-7.6; CG=-5.5), but the one-way ANOVA did not show significant between-group differences (Table 2). Moreover, no significant pre-post changes nor between-group differences were observed in the maximal angular displacement at 110 ms after sudden loading.

**Table 2.** Per-protocol analyses of the core stability outcomes before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| *Core stability exercise accelerometry tests - Lumbopelvic acceleration ($m/s^2$)* | | | | | |
| Front bridge | CG (17) | 0.45 ± 0.10 | 0.44 ± 0.09 | -0.01 ± 0.07 | -0.1 ± 17.7 |
| | $EG_{HV}$ (19) | 0.48 ± 0.09 | 0.41 ± 0.09* | -0.07 ± 0.08$^{A}$ | -13.5 ± 14.7$^{A}$ |
| | $EG_{HI}$ (19) | 0.47 ± 0.11 | 0.40 ± 0.09* | -0.06 ± 0.07$^{A}$ | -11.9 ± 13.2$^{A}$ |
| Back bridge | CG (17) | 0.44 ± 0.12 | 0.40 ± 0.12 | -0.04 ± 0.09 | -9.0 ± 16.9 |
| | $EG_{HV}$ (19) | 0.48 ± 0.10 | 0.42 ± 0.08* | -0.06 ± 0.09 | -11.7 ± 15.7 |
| | $EG_{HI}$ (19) | 0.50 ± 0.10 | 0.40 ± 0.07* | -0.09 ± 0.08 | -17.0 ± 14.0 |
| Dominant side bridge | CG (17) | 0.45 ± 0.10 | 0.43 ± 0.09 | -0.02 ± 0.10 | -0.8 ± 21.3 |
| | $EG_{HV}$ (19) | 0.43 ± 0.08 | 0.42 ± 0.13 | -0.01 ± 0.10 | -1.7 ± 21.8 |
| | $EG_{HI}$ (19) | 0.47 ± 0.09 | 0.41 ± 0.10* | -0.06 ± 0.08 | -11.7 ± 22.2 |
| Bird-dog | CG (17) | 0.40 ± 0.11 | 0.38 ± 0.09 | -0.02 ± 0.07 | -0.6 ± 20.8 |
| | $EG_{HV}$ (19) | 0.44 ± 0.07 | 0.39 ± 0.08* | -0.05 ± 0.06 | -12.1 ± 14.3 |
| | $EG_{HI}$ (19) | 0.43 ± 0.09 | 0.34 ± 0.07* | -0.09 ± 0.09$^{A}$ | -19.1 ± 17.8$^{A}$ |
| CSE composite | CG (17) | 0.44 ± 0.08 | 0.41 ± 0.08 | -0.02 ± 0.06 | -4.1 ± 13.2 |
| | $EG_{HV}$ (19) | 0.46 ± 0.06 | 0.41 ± 0.08* | -0.05 ± 0.06 | -10.6 ± 13.1 |
| | $EG_{HI}$ (19) | 0.47 ± 0.08 | 0.39 ± 0.07* | -0.08 ± 0.06$^{A}$ | -15.5 ± 11.7$^{A}$ |
| *Unstable sitting test - Mean radial error (mm)* | | | | | |
| | CG (17) | 6.91 ± 1.64 | 6.45 ± 1.32* | -0.47 ± 0.76 | -5.5 ± 10.8 |
| | $EG_{HV}$ (20) | 6.84 ± 1.63 | 6.28 ± 1.55* | -0.56 ± 0.89 | -7.6 ± 11.3 |
| | $EG_{HI}$ (19) | 6.86 ± 1.51 | 6.26 ± 1.33* | -0.59 ± 0.80 | -7.8 ± 11.5 |
| *Sudden loading protocol - Maximal angular displacement at 110 ms (º)* | | | | | |
| Frontal direction | CG (17) | 5.36 ± 0.92 | 5.15 ± 0.89 | -0.21 ± 0.77 | -3.2 ± 14.2 |
| | $EG_{HV}$ (20) | 5.04 ± 0.76 | 4.91 ± 0.90 | -0.13 ± 0.84 | -1.8 ± 16.9 |
| | $EG_{HI}$ (18) | 5.00 ± 0.73 | 5.20 ± 1.19 | 0.20 ± 1.20 | 5.1 ± 23.3 |
| Lateral direction | CG (17) | 4.59 ± 0.94 | 4.50 ± 1.26 | -0.09 ± 1.14 | -0.7 ± 23.3 |
| | $EG_{HV}$ (20) | 4.40 ± 0.94 | 4.29 ± 1.06 | -0.11 ± 1.06 | -0.6 ± 27.4 |
| | $EG_{HI}$ (18) | 4.55 ± 1.22 | 4.81 ± 1.07 | 0.26 ± 1.00 | 9.8 ± 27.4 |
| Posterior direction | CG (16) | 9.86 ± 1.13 | 9.41 ± 1.43 | -0.46 ± 1.41 | -4.1 ± 13.6 |
| | $EG_{HV}$ (20) | 9.29 ± 1.20 | 8.79 ± 1.58 | -0.50 ± 1.84 | -4.3 ± 18.0 |
| | $EG_{HI}$ (17) | 9.67 ± 1.46 | 9.28 ± 1.34 | -0.39 ± 1.37 | -2.9 ± 14.5 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group;* $EG_{HV}$*: experimental group which performed the higher volume program;* $EG_{HI}$*: experimental group which performed the higher intensity program;* CSE: core stability exercise. *For pelvic accelerations during the CSE, an average of the three most difficult variations of each exercise (i.e., the three highest accelerations) were calculated for each participant. *Significant pre-post differences p<.05.* $^{A}$*Significantly different with respect to the CG.*

### 4.3.3. Effect of the core stability exercise programs on core endurance outcomes

Overall, between-group differences were observed in the one-way ANOVA for the core endurance composite score (Δ: F=4.848, *p*=.01). The $EG_{HV}$ showed significant pre-post holding time improvements in all endurance outcomes and significant differences with respect to the CG in the core endurance composite (Δ%: $EG_{HV}$=15.9; CG=2.5) and the prone plank test (Δ%: $EG_{HV}$=20.5; CG=8.2) (Table 3). Although the $EG_{HI}$ also showed significant pre-post improvements in the Biering-Sorensen test and the core endurance composite, the change magnitude was lower (Δ% for the core endurance composite=9.4) and not significantly higher than the CG in any endurance outcome.

**Table 3.** Per-protocol analyses of the maximal holding time (s) observed in the core endurance tests before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| Prone plank test | CG (17) | 161.5 ± 65.9 | 161.2 ± 54.2 | -0.3 ± 50.6 | 8.2 ± 43.6 |
| | $EG_{HV}$ (20) | 156.8 ± 48.5 | 186.3 ± 62.6* | 29.5 ± 38.6$^{A}$ | 20.5 ± 25.6 |
| | $EG_{HI}$ (19) | 164.2 ± 52.1 | 177.9 ± 63.4 | 13.7 ± 38.7 | 10.6 ± 26.0 |
| Dominant side bridge test | CG (17) | 93.6 ± 24.5 | 91.4 ± 22.0 | -2.3 ± 18.3 | 1.1 ± 23.6 |
| | $EG_{HV}$ (20) | 93.3 ± 22.3 | 102.1 ± 23.7* | 8.8 ± 16.2 | 11.5 ± 19.4 |
| | $EG_{HI}$ (19) | 94.3 ± 33.2 | 95.2 ± 27.8 | 1.4 ± 23.1 | 7.1 ± 25.0 |
| Biering-Sorensen test | CG (17) | 118.0 ± 43.0 | 115.4 ± 35.1 | -2.6 ± 34.4 | 5.3 ± 32.7 |
| | $EG_{HV}$ (20) | 120.1 ± 37.4 | 135.3 ± 37.0* | 15.2 ± 18.5 | 15.8 ± 22.6 |
| | $EG_{HI}$ (19) | 117.3 ± 31.1 | 132.7 ± 36.6* | 15.4 ± 27.2 | 15.5 ± 26.4 |
| Core endurance composite | CG (17) | 124.4 ± 35.0 | 122.7 ± 25.4 | -1.7 ± 21.2 | 2.5 ± 23.0 |
| | $EG_{HV}$ (20) | 123.4 ± 28.5 | 141.2 ± 29.8* | 17.8 ± 14.6$^{A}$ | 15.9 ± 14.0$^{A}$ |
| | $EG_{HI}$ (19) | 125.8 ± 30.2 | 135.9 ± 35.6* | 10.2 ± 21.1 | 9.4 ± 17.8 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group;* $EG_{HV}$*: experimental group which performed the higher volume program;* $EG_{HI}$*: experimental group which performed the higher intensity program. *Significant pre-post differences p<.05.* $^{A}$*Significantly different with respect to the CG.*

### 4.3.4. Effect of the core stability exercise programs on whole-body dynamic balance outcomes

The one-way ANOVA did not show overall between-group differences in any of the whole-body dynamic balance outcomes, nor significant differences were revealed in the pairwise comparisons. With respect to pre-post changes, $EG_{HI}$ and CG showed significant mean radial error reductions in the single-leg balance test (Δ%: $EG_{HI}$=-6.0; CG=-6.4) and all groups showed an increase in the distance reached in the Y-Balance test (Δ% for the Y-Balance composite: $EG_{HI}$=1.3; $EG_{HV}$=2.1; CG=2.1), except for the anterior direction in the $EG_{HI}$ and for the posterolateral direction in the $EG_{HI}$ and the CG.

# CHAPTER 5

## SUMMARY OF THE DISCUSSIONS

# Chapter 5. Summary of the discussions

The systematic reviews included in the present doctoral thesis carried out an in-depth analysis of the literature on TEP both, to improve knowledge about the trunk-focused exercise contribution to increase trunk physical fitness and ameliorate stroke and LBP symptoms, and to understand how the individuals and exercise programs characteristics modulate the TEP effectiveness better. Especially, in *Study* 2 a detailed analysis of the experimental studies was performed to ensure that the TEP included in the systematic review were specifically composed of trunk-focused exercises and compared to no exercise control groups and/or to programs non-focusing on the trunk structures. Overall, although the quality of evidence was low, the systematic reviews showed that TEP were effective to ameliorate stroke and non-specific chronic LBP patients' condition, with positive effects in all the outcomes analysed. Furthermore, the analysis of the moderator factors revealed that the TEP effectiveness in stroke patients seems to be higher when the initial trunk impairment is greater, the patients are older, and the intervention starts earlier. Importantly, the TEP impact on LBP symptoms (mainly pain reduction) seems higher when a greater improvement in $TH_{ROM}$ is recorded after the training program and participants have a lower body mass index. These results reinforce the importance of paying close attention to the individuals and to the exercise program characteristics when designing this type of interventions.

Some of the main problems found in the literature to perform the systematic reviews were the heterogeneity of the training programs and the ambiguity in the use of concepts (e.g., core stability, core strengthening, trunk exercise…),[26–30] the lack of studies analysing the TEP effects on trunk physical fitness,[25,44] and the poor description and control of the training load characteristics.[1,25] These limitations, especially the lack of experimental studies that objectively controlled the training load intensity, motivated the development of the experimental study of this doctoral thesis (*Study* 3). To the best of our knowledge, this is the first RCT that has established and controlled the CSE intensity based on smartphone-accelerometry, comparing the effects of a higher intensity and a higher volume CSE program on core stability, core endurance and whole-body dynamic balance in young physically active males. These study results showed the specificity of the effects caused by the CSE programs, with a larger increase in the lumbopelvic postural control during the execution of the CSE for the higher intensity CSE program and a larger increase in the core endurance tests for the higher volume CSE program. Interestingly, the performance of conventional isometric CSE in lying and quadruped positions during the CSE programs did not have a significant impact on the unstable sitting test, the sudden loading protocol or the whole-body dynamic balance tests.

The discussions of the main results of this doctoral thesis are presented below structured according to the three studies:

## 5.1. Systematic review with meta-analysis on the effects of additional trunk-focused exercise programs in stroke

Results from the systematic review on stroke patients confirmed the former evidence[23,42,63,64] of the positive impact of ATEP on trunk function SMD 1.06, (95% CI, 0.74-1.37) and balance ability SMD 0.83, (95% CI, 0.52-1.14). Similarly, a high ATEP effect on other balance dimensions such as limits of stability in frontal and lateral directions for both the affected and non-affected arm was observed. Therefore, although lateral balance is usually more affected in stroke population,[110] ATEP seem to be effective to improve limits of stability independently of the direction.

This study results also confirmed the positive impact of ATEP on gait performance SMD 0.63, (95% CI, 0.38-0.89), which highlights the importance of the trunk control to maintain balance during dynamic actions.[111] However, contrary to our hypotheses, ATEP did not have a significant impact on functional mobility MD 3.40 s, (95% CI, -0.32-7.12), probably influenced by the low number of studies (i.e., 6) and/or some patients' physical, cognitive and/or sensory deficits that may hinder the performance of the timed up and go test.[112,113]

Regarding the moderator factors of the ATEP impact, older participants and participants with a higher initial trunk impairment had greater improvements in the motor recovery parameters. Although these results could be related with the larger room for improvement that older or more impaired patients might have,[68] they do not agree with previous findings indicating that older age and more severe motor impairment after stroke-onset are determinant factors for a poorer recovery process.[68,69] The interpretation of these findings can be biased by the facts that (i) in those studies with the more affected and older participants, the patients started the stroke-rehabilitation sooner, and (ii) non-statistical comparison between subgroups was performed.

In regard to the total volume of training, it is interesting to note that while longer ATEP obtained higher benefits in trunk function and balance ability, shorter ATEP showed better results on limits of stability, gait performance and functional mobility. These controversial results can be caused by the low number of studies analysed and may indicate that even short ATEP can have important motor recovery improvements.

Finally, as subgroup analyses for moderator factors were not compared statistically and the quality of the evidence was low, the information provided by this systematic review should not be considered as categorical facts but as future questions to investigate in higher quality studies on stroke rehabilitation.

## 5.2. Systematic review with meta-analysis on the effects of trunk-focused exercise programs in chronic non-specific low back pain

Results from the systematic review on LBP individuals confirmed the TEP efficacy to ameliorate LBP symptoms,[1,7,9,10,44,45,70–73] with a high impact on pain SMD 1.31, (95% CI, 0.99-1.63), disability SMD 0.90, (95% CI, 0.66-1.13) and quality of life SMD 0.82, (95% CI, 0.38-1.27) compared to no intervention, minimal intervention or *hands-on/off* treatments (CG). In addition, TEP showed low effects on pain SMD 0.20, (95% CI, 0.03-0.37) and disability (SMD 0.20, 95% CI, 0.02-0.38) when TEP were compared to other type of exercise programs (GEP). The number of studies analysing TEP *vs.* GEP is scarce, so further evidence is required to clarify whether TEP are more effective than other type of exercise programs.[7,73,114,115]

Although the number of studies was lower than those analysing pain and disability, TEP obtained high effects on trunk extension endurance SMD 2.46, (95% CI, -0.04-4.96), trunk strength SMD 0.91, (95% CI, 0.42-1.41) and $TH_{ROM}$ SMD 0.93, (95% CI, 0.58-1.29) compared to the CG. This is in line with a recent systematic review by Owen et al[44] which also observed that different types of exercise programs (including TEP) had a positive impact on trunk endurance and strength. Since poor trunk physical fitness is an important predictor for future LBP,[116–118] future experimental studies should develop and evaluate the physical capabilities of the trunk in the LBP rehabilitation programs.

Regarding the moderator factors, the multiple meta-regression analysis found an association between larger improvements in $TH_{ROM}$ and greater reductions in pain and disability. Although these findings do not establish a cause-effect relationship, they highlight the importance of considering trunk, pelvic and hip flexibility when designing and assessing TEP for LBP treatment. It must be noted that although no other moderator factors were significant in the multiple models, the body mass index showed a significant association with pain in a single meta-regression (i.e., the lower body mass index, the greater pain reduction). This may suggest that TEP impact on LBP symptoms might be increased by adding weight-loss interventions. However, meta-regression results about trunk or $TH_{ROM}$ and body mass index could be susceptible of ecological bias, so they should be analysed carefully.

Although the exercise training effects depend to a great extent on the training program characteristics,[1] no association was found between the total volume of training and changes in pain and disability after the TEP. Although these results are in line with the systematic review by Niederer et al,[10] the recent review by Mueller et al[1] found that 3-5 days of core stability training per week and 20-30 min of session duration induced the greatest effects on pain and disability. No other moderator factors related to the training program characteristics could be analysed in our study, as many RCT did not provide a detailed description of the basic training characteristics.

## 5.3. Double-blind randomised controlled trial on the effect of two core stability exercise programs monitored with smartphone-accelerometry

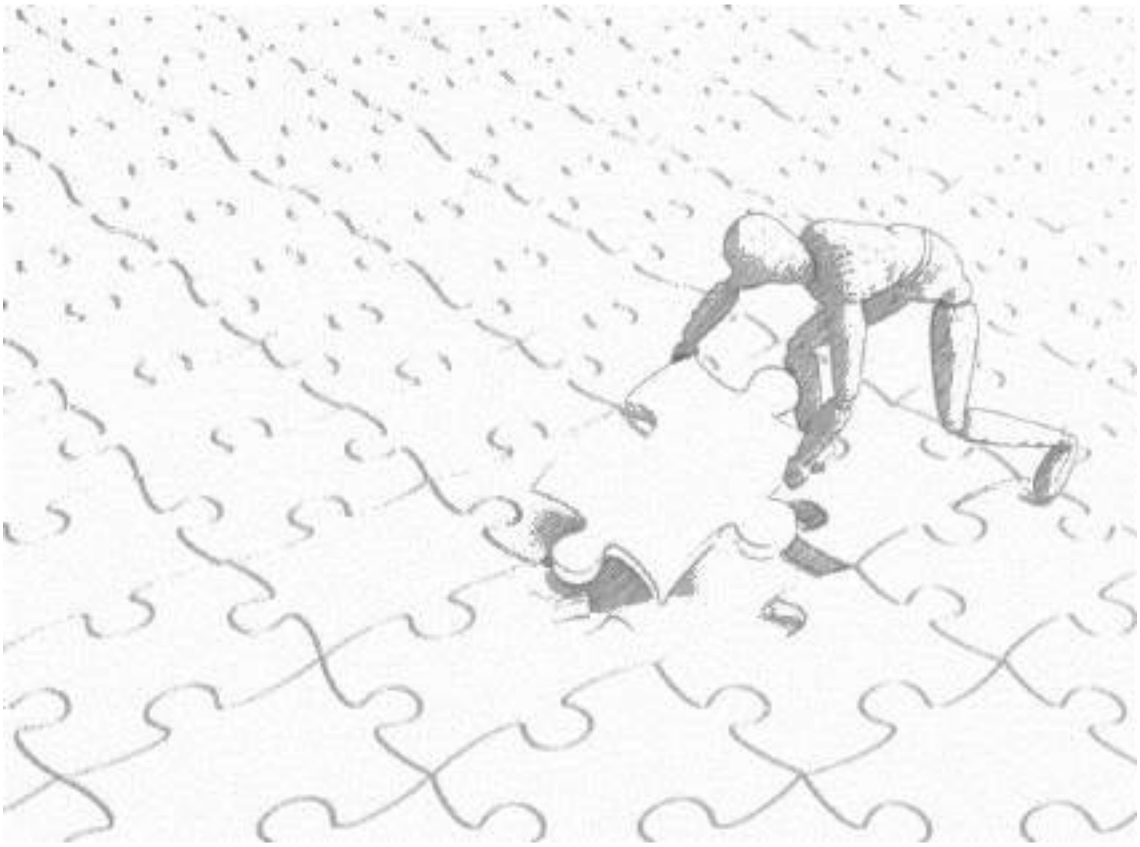
The lack of significant differences in the training effects between the higher intensity and the higher volume CSE programs suggests that the characteristics of these programs were not distinct enough to induce different short-term adaptations in young physically active males. However, only $EG_{HI}$ showed significant lumbopelvic acceleration reductions in the CSE (Δ% for composite score: $EG_{HI}$=-15.5; $EG_{HV}$=-10.6; CG=-4.1) compared to the CG, and only $EG_{HV}$ showed significant endurance increases (Δ% for composite score: $EG_{HV}$=15.9; $EG_{HI}$=9.4; CG=2.5) with respect to the CG, which reveals specific adaptations depending on the stimulus provided for each CSE program through the smartphone-accelerometry. Future studies with larger samples and longer training durations should explore which CSE intensities and volumes are most suitable to produce differential core stability and endurance adaptations.

Despite the specific adaptations found in the CSE and the core endurance tests, none of the CSE programs had a significant impact on trunk postural control during unstable sitting, on trunk response to sudden perturbations or on whole-body dynamic balance. Therefore, the trunk postural control demands imposed on young active males while holding lying and quadruped positions during the CSE induced core adaptations only revealed through specific measurements (i.e., CSE and core endurance tests performed in lying or quadruped positions). Although, some previous studies on CSE programs have observed a positive effect on different balance outcomes in similar populations,[3,4,6] the training program were longer[4,6] or they combined CSE executed in lying positions with other more general exercises (i.e., non-trunk-focused exercises, such as walking lunge, frontal and lateral stance balance, etc.).[3] Therefore, further research is needed to determine to what extent the impact of performing conventional lying CSE can be generalizable to core stability and whole-body balance measures obtained in more functional conditions.

Although the results of this experimental study seem to contribute to the characterization of the dose-response relationship of CSE programs, their interpretation is limited because the participants were physically fit (without balance or core stability deficits) and the training program lasted only 6 weeks (i.e., 12 training sessions).

# CHAPTER 6

## CONCLUSIONS OF THE THESIS



# Chapter 6. Conclusions of the thesis

## 6.1. General conclusions

This doctoral thesis comprises two systematic reviews with meta-analyses and an experimental study which: a) analysed the impact of performing trunk-focused exercises on trunk performance, functional capacity, and health status in both, pathological populations (stroke in *Study 1* and non-specific chronic LBP in *Study 2*) and young physically active individuals (*Study 3*), and b) explored the relationship of the TEP effects with the training load (*Studies 1, 2* and *3*) and the participants' characteristics (*Studies 1* and *2*).

The main conclusions of this doctoral thesis are as follows:

*Study 1*

1) Adding trunk-focused exercises to the conventional rehabilitation programs produced a positive impact on trunk function, balance ability, gait performance, and functional mobility recovery in stroke population.
2) Moderator factors related to individuals and training programs characteristics modulated the impact of adding trunk-focused exercises to the conventional rehabilitation therapy:
    a. Studies with individuals that had a greater initial trunk impairment obtained higher improvements in trunk function and balance ability.
    b. Studies with older participants had a greater impact on trunk function, limits of stability and functional mobility but not on balance ability.
    c. Studies in which the intervention started earlier had a greater impact on trunk function, balance, and gait performance. However, it should be noted that these studies were also those with older and more affected participants.
    d. Studies with longer training programs obtained higher improvements in trunk function and balance ability, but those with shorter training programs showed better results on limits of stability, gait performance, and functional mobility.

*Study 2*

3) TEP were effective to ameliorate non-specific chronic LBP patients' condition, with positive effects on pain, disability, quality of life, and trunk physical fitness (i.e., trunk extension endurance, trunk strength, and $TH_{ROM}$) when they were compared to no intervention, minimal intervention, or *hands-on/off* treatments (CG).
4) TEP had a low impact on pain and disability when they were compared to other physical exercise programs (GEP) in non-specific chronic LBP population.
5) Moderator factors related to the individuals' characteristics (rather than training program characteristics) modulated the TEP impact:

   a. Multiple meta-regressions showed that a greater improvement in $TH_{ROM}$ was associated with a higher reduction in pain and disability.
   b. Single meta-regressions showed that a lower body mass index was associated with a higher reduction of pain.

*Study 3*

6) The CSE intensity quantification through smartphone-accelerometry allowed to control and modulate the training load of the CSE programs and helped to describe their effects in young physically active males.
7) While the higher intensity CSE program had a greater impact on lumbopelvic postural control during the execution of the CSE, the higher CSE program volume produced larger effects on the core endurance tests.
8) Contrarily to our hypotheses, performing conventional isometric CSE in lying and quadruped positions did not have a significant short-term effect on trunk postural control while sitting on an unstable seat, on trunk response to sudden perturbations, or on whole-body dynamic balance.

Overall, the results of the studies included in this doctoral thesis highlight the importance of performing TEP to improve trunk performance, functional capacity, and health status in different populations. Specifically, the two systematic reviews showed how moderator factors related to both the training program and the individuals' characteristics can play an important role in modulating TEP effectiveness, which should be considered to maximize and tailor the TEP benefits in stroke and LBP patients. However, the quality of the evidence for all the outcomes analysed in these systematic reviews was low, and thus, higher quality studies are required in order to strengthen the evidence of the impact of performing trunk-focused exercises in stroke and LBP rehabilitation programs. Regarding the experimental study, the training load control performed through the smartphone-accelerometry allowed to describe the specificity of the effects caused by a higher intensity and a higher CSE program volume in young physically active males. Further research is needed to characterize the dose-response relationship of CSE programs in different populations properly.

## 6.2. Conclusiones generales

Esta tesis doctoral comprende dos revisiones sistemáticas con meta-análisis y un estudio experimental que: a) han analizado el impacto de la realización de ejercicios focalizados en el tronco sobre la condición física del tronco, la capacidad funcional y el estado de salud de personas que han sufrido un ictus (*Estudio 1*), pacientes con dolor lumbar crónico inespecífico (*Estudio 2*) y jóvenes sanos y físicamente activos (*Estudio 3*); y b) han explorado la relación de los efectos provocados por los programas de ejercicios focalizados en el tronco con la carga de entrenamiento (*Estudios 1, 2* y *3*) y las características de los participantes (*Estudios 1* y *2*).

Las conclusiones principales de esta tesis doctoral son las siguientes:

*Estudio 1*

1) Añadir ejercicios focalizados en el tronco a programas de rehabilitación convencional tiene un impacto positivo en la función del tronco, el equilibrio, la marcha y la movilidad funcional en personas que han sufrido un ictus.
2) Factores moderadores relacionados con las características de las personas y de los programas de entrenamiento han modulado el efecto de los programas que combinan ejercicios focalizados en el tronco con las terapias de rehabilitación convencional:
    a. Aquellos estudios con participantes que presentaban una mayor afectación inicial del tronco obtuvieron mayores beneficios en la función del tronco y el equilibrio.
    b. Aquellos estudios con participantes de mayor edad obtuvieron mayores beneficios en la función del tronco, los límites de estabilidad y la movilidad funcional, pero no en el equilibrio.
    c. Aquellos estudios con participantes que empezaron antes la intervención obtuvieron mayores beneficios en la función del tronco, el equilibrio y la marcha. Sin embargo, estos estudios también eran los que tenían participantes de mayor edad y con una mayor afectación inicial del tronco.
    d. Aquellos estudios con programas de entrenamiento de mayor duración obtuvieron mayores mejoras en la función del tronco y el equilibrio, pero aquellos con programas de menor duración mostraron mejores resultados en los límites de estabilidad, la marcha y la movilidad funcional.

*Estudio 2*

3) Los programas de entrenamiento focalizados en el tronco mostraron un impacto positivo sobre el dolor, la discapacidad, la calidad de vida y la condición física del tronco (i.e., resistencia de los extensores del tronco, fuerza de los músculos del tronco y rango de

movimiento del tronco y/o de la cadera) cuando fueron comparados con personas con dolor lumbar crónico inespecífico que no habían realizado ejercicio físico (grupo control).

4) Los programas de entrenamiento focalizados en el tronco tuvieron un impacto positivo sobre el dolor y la discapacidad cuando fueron comparados con otro tipo de programas de ejercicio físico en población con dolor lumbar inespecífico.
5) Factores moderadores relacionados con las características de los pacientes modularon el impacto de los programas:
    a. Las meta-regresiones múltiples mostraron que a mayor incremento en el rango de movimiento del tronco y/o de la cadera, mayor reducción del dolor y de la discapacidad.
    b. Las meta-regresiones simples mostraron que un menor índice de masa corporal estaba relacionado con una mayor reducción del dolor.

*Estudio 3*

6) La cuantificación de la intensidad de los ejercicios de estabilidad del tronco a través de acelerometría integrada en smartphone permitió el control y la modulación de la carga de entrenamiento de los programas de ejercicio de estabilidad del tronco, ayudando a describir sus efectos en hombres jóvenes y físicamente activos.
7) El grupo que entrenó a mayor intensidad y menor volumen mostró un mayor efecto sobre el control lumbo-pélvico durante la ejecución de los ejercicios de estabilidad del tronco. Por otro lado, el grupo que entrenó con mayor volumen y menor intensidad mostró un mayor efecto sobre los test de resistencia del tronco.
8) Contrariamente a nuestras hipótesis, realizar ejercicios isométricos de estabilidad del tronco en posición de tumbado y cuadrupedia no tuvo un efecto significativo en el control del tronco en sedestación sobre un asiento inestable, en la respuesta del tronco ante perturbaciones súbitas o en el equilibrio dinámico corporal.

En general, los resultados de los estudios incluidos en esta tesis doctoral resaltan la importancia de realizar programas de ejercicios focalizados en el tronco para mejorar la condición física del tronco, la capacidad funcional y el estado de salud en diferentes poblaciones. Concretamente, las dos revisiones sistemáticas mostraron cómo factores moderadores relacionados tanto con las características de las personas, como con las características del entrenamiento, pueden jugar un papel importante en la modulación de la efectividad de estos programas, lo cual debería ser tenido en cuenta para maximizar los beneficios en personas que han sufrido un ictus o en pacientes con dolor lumbar crónico inespecífico. Sin embargo, la calidad de la evidencia en todos los parámetros evaluados de estas revisiones fue baja y, por lo tanto, se necesitan estudios experimentales con una mayor calidad para mejorar la evidencia sobre los beneficios de realizar programas de rehabilitación con ejercicios focalizados en el tronco en personas que han sufrido un ictus o que tienen dolor lumbar. Con respecto al estudio experimental, el control de la carga de entrenamiento a través de acelerometría integrada en smartphone permitió describir la especificidad de los efectos provocados por programas de ejercicios focalizados en el tronco realizados a diferentes niveles de intensidad y volumen. Futuros estudios son necesarios para mejorar la caracterización de la relación dosis-respuesta de los programas de ejercicios focalizados en el tronco en distintas poblaciones.

## 6.3. Limitations and future directions

The studies included in this doctoral thesis showed several drawbacks that could limit the result interpretation. Some of them have motivated the development of new research directions. The main study limitations and future research purposes are as follows:

1) There was a poor training description of TEP in the studies included in both systematic reviews. This hindered the understanding of the training program dose-response characterization. Only the total volume of training was analysed, but other important features such as training intensity could not be studied. In this sense, future experimental studies should describe the training program features more in detail to characterize the dose-response relationship better.
2) There was a high TEP heterogeneity, especially in *Study 2*, in which a subdivision of different training programs was not possible. As explained before, many TEP with different names (Ferreira et al[26] – Motor control exercises, Da Fonseca et al[27] – Pilates exercises, Hwang et al[28] – Sensorimotor training, You et al[29] – Sling exercise program, Ulger et al[30] – Spinal stabilisation exercises) included similar trunk-focused exercises, which made it difficult to differentiate between them.
3) The quality of evidence of the outcomes analysed in both systematic reviews was poor. There is a need of clinical trials with higher quality to certify the results found in these reviews.
4) The number of studies analyzing the impact of TEP in all the outcomes was not the same, and therefore not all of the studies present an equal degree of precision. In *Study 1*, the least reported outcomes were limits of stability and functional mobility, whereas in *Study 2* they were trunk extension endurance and trunk strength. In this sense, it is important that these and other relevant outcomes be analysed in experimental studies, increasing their level of evidence in both populations.
5) Some of the moderator factors could not be further meta-analysed because of the low number of studies reporting them. Because the number of studies was lower in *Study 1*, the moderator factors were compared by subgroup analysis, but not statistically. In *Study 2*, multiple meta-regressions could only be performed on pain and disability and should be interpreted with caution since they do not imply a cause-effect relationship and the individuals' features could be under ecological bias.
6) In *Study 1*, ATEP were compared to a CG that performed a conventional rehabilitation program. It would be interesting that future studies compare different types of ATEP to observe which is better for stroke rehabilitation. In *Study 2*, the number of studies comparing TEP *vs.* GEP was low, and therefore high quality RCT are necessary to increase the evidence.

7) Although the *Study* 3 aimed to compare the effects of performing higher intensity *vs.* longer duration CSE, it would be interesting to match the training volume of both programs to compare the effects of performing CSE at intensities above and below the acceleration thresholds established by Heredia-Elvar et al.[61]
8) The CSE programs performed in *Study 3* did not have a significant impact on trunk postural control while sitting in unstable position, on trunk response to sudden perturbations, or on whole-body dynamic balance. As explained above, these results could be influenced by: i) the sample characteristics (i.e., young physically active males without postural control or balance deficits); ii) the short program duration (i.e., 6 weeks); iii) the non-functional positions performed during the CSE (i.e., lying or quadruped positions). Therefore, further research should assess the impact of performing longer training programs, based on the execution of the most functional CSE, on individuals with and without postural control deficits. In this sense, our research group is currently performing an experimental study to explore the effect of executing CSE at different intensities (monitored with smartphone-accelerometry) on trunk performance, whole-body balance, gait, and functional mobility in older people. In addition, we have recently initiated a research line to develop new CSE and CSE progressions performed in more functional positions (e.g., standing, sitting, kneeling, etc.) and applied to different populations (athletes from different sport disciplines, recreationally trained individuals, older people, multiple sclerosis patients, etc.).
9) In *Study 3*, the pelvic acceleration measurements during the execution of the CSE at the pre-test and post-test lasted 15 s for each trial, while each exercise repetition in the training programs lasted 15 s for the $EG_{HI}$ and 30 s for the $EG_{HV}$. Although these differences may have had some impact on the pelvic acceleration results, acceleration measurement times of 30 s were not used to avoid fatigue during the 56 trials performed in each acceleration testing session.[61]
10) In *Study 3*, the smartphone-accelerometry was successfully used by CSE experts (members of our research group) to establish and control the CSE program intensity. However, it should be noted that since the accelerations were not provided in real time, it took approximately 2 days after its use to process the data obtained. To address this, we are currently developing a mobile application to provide the information in real time. On the other hand, no study has explored the feasibility of using this technique by non-CSE experts yet, which could perhaps benefit more from controlling the CSE intensity objectively. Future studies are needed to compare the smartphone-accelerometry utility in different contexts and used by different professionals (CSE experts or non-experts).

# CHAPTER 7

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# Chapter 7. References

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# CHAPTER 8

## APPENDIX

# APPENDIX 1

## STUDY 1

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### Do Initial Trunk Impairment, Age, Intervention Onset, and Training Volume Modulate the Effectiveness of Additional Trunk Exercise Programs after Stroke? A Systematic Review with Meta-Analyses.

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Note. This study was published

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# Chapter 8. Appendices

## 8.1. Appendix 1

### 8.1.1. Study 1. Do Initial Trunk Impairment, Age, Intervention Onset, and Training Volume Modulate the Effectiveness of Additional Trunk Exercise Programs after Stroke? A Systematic Review with Meta-Analyses.

### Abstract

The aim of this systematic review was to analyze how, after additional trunk-focused training programs (ATEP), motor recovery after a stroke is modulated by potential effect modifiers. 20 randomized controlled studies that carried out ATEP were included. Results showed moderate to high effects in favor of ATEP for trunk function, balance ability, gait performance and functional mobility. Studies with a higher initial trunk impairment obtained a higher effect on trunk function and balance; studies with older participants had a higher effect on trunk function, limits of stability, functional mobility but not on balance ability. Older and more affected patients were, as well, those who started the intervention earlier, which was also linked with larger higher effects on trunk function, balance and gait performance. Longer ATEP found a high effect on trunk function and balance ability. The potential effect modifiers seem to be important in the modulation of the effectiveness of ATEP and should be considered in the design of rehabilitation programs. Thus, since potential effect modifiers seem to modulate ATEP effectiveness, future studies should consider them in their experimental design to better understand their impact on stroke rehabilitation.

**Keywords:** *core stability, rehabilitation, moderator*

## INTRODUCTION

Commonly, trunk muscles are bilaterally affected after a stroke-onset, leading to an impairment of trunk function [1,2]. Since trunk structures are important to maintain the body in a stable state [3], the decreased trunk control experienced by this population (stroke patients) affects their ability to maintain balance [1,4]. The relevance of trunk control in this population is also supported by severallongitudinal studies showing that the degree of trunk impairment seems to determine, to what extent, patients recover their motor function months after stroke-onset [5-7]. Based on these findings, the need to introduce trunk-focused exercises in stroke rehabilitation programs has increased [8–11].

Because of evidence leading towards an association between trunk function and motor performance in stroke patients, meta-analyses have been performed in order to obtain more in-depth knowledge about the effectiveness of additional trunk-focused exercise programs (ATEP) in conventional strokerehabilitation programs to restore motor function [8–11]. In general, their results showed a positive impact of trunk-focused exercises on variables, such as trunk function, balance, and functional mobility.

In this sense, a key point to optimize rehabilitation programs resides in the identification of potential effect modifiers, such as initial trunk impairment, age, and intervention onset or training volume that might modulate motor recovery [12]. However, little is known about which of these factors might induce a higher motor restoration after ATEP. To the authors' knowledge, only Alhwoaimel et al., (2018) [9] performed sub-group analyses to observe the effects of the moment in which the rehabilitation program starts after stroke-onset, and the effects of total training volume on trunk function. Overall, they observed a higher effect on trunk function when rehabilitation started earlier, mainly when the program was applied in the acute phase after the stroke. Unexpectedly, they found that the shorter the rehabilitation programs were, the greater the recovery of the trunk function. In addition, it must be noted that these factors were only analysed on trunk function, and the impact that they have on other relevant outcomes, such as balance or functional mobility, remains unknown [9]. Furthermore, although participants' features, such as initial motor impairment or age, have been shown as relevant factors in the recovery process after a stroke, their potential relevance on modulating the effectivenessof ATEP has not been explored yet [12]. In this sense, analyzing how the initial trunk impairment (or the age at when people suffer the stroke) influence the improvement degree induced by ATEP could help to optimize this rehabilitation program, according to the stroke patients' features [13]. Overall, although trunk exercises have shown to be effective in motor recovery, there is lack of evidence regarding what factors can influence ATEP in stroke rehabilitation.

Thus, the aim of this systematic review was to analyze the influence of potential effect modifiers as the initial trunk impairment, and participants' age, the start of the intervention after stroke-onset, and the total volume of the ATEP on trunk function, balance ability, gait performance, and functionalmobility in the stroke population. The analysis of these potential effect modifiers on ATEP could help in the optimization of stroke rehabilitation programs, maximizing their effectiveness.

## METHOD

The current study was a systematic review carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Table S1) [14].

### *Data sources and Searches*

Different Boolean search strategies were employed for each of the databases (PubMed, Scopus, Cochrane Library, and EMBASE). Due to the broad amount of terms used to refer to the training of trunk structures (e.g., “core stability”, “core strength”, etc.) [15,16], a wide search combination was required as a strategy to avoid the loss of relevant articles (Table S2 of the Supplementary Materials).Furthermore, a manual search of the references was carried out to select any other potential study thatcould be included in the systematic review.

For the literature revision, two independent reviewers checked the titles and abstracts of the references to select any potentially relevant study. Afterwards, a full-text read was carried out on the selected documents. A third reviewer was consulted in case of disagreement.

### *Study Selection*

The studies included had to meet the ensuing inclusion criteria: (1) the patients were in the stroke population; (2) they were peer-reviewed randomized controlled trials; (3) they included a control group receiving conventional rehabilitation; (4) they reported at least one outcome related to trunk function, balance, gait or functional mobility; (5) the experimental group performed a training program targeting the trunk structures as the main area, in addition to the conventional rehabilitation performed by the control group; (6) they had to be written in English, French, Italian, or Spanish. The following exclusion criteria were applied: (1) studies in which the experimental group targeted other body structures as the main area (e.g., upper or lower limbs); (2) studies analyzing a single session; (3) studies that did not provide pre- and post-intervention data. The search publication date was limited up to June 2020.

### *Data Extraction and Quality Assessment*

The information extracted from the studies was registered in a codebook, including general data (e.g., the authors, year of publication, sample number, study-design, etc.), data from the intervention characteristics (e.g., number of training weeks, sessions per week, total training volume, type of exercises, and exercise progression), and pre- and post-intervention data (mean, standard deviation,and sample size) from the experimental and control groups.

The outcomes registered were trunk function, balance ability, gait performance, and functional mobility. To reduce within-outcome heterogeneity, when a study used more than one test/scale to analyze a specific outcome, the most frequent test/scale among the studies included was selected. Based on these criteria, the test/scales employed by the studies were:

- Trunk function was mainly assessed by the Trunk Impairment Scale and the Trunk ImpairmentScale 2.0, which have been stated as valid and reliable tools to assess trunk motor impairment after a stroke [17,18]. The Trunk Control Test [19] was also employed.
- The Berg Balance Scale [20], the 3-level Berg Balance Scale [21], the Standing Equilibrium Index [22], and the Brief-BESTest [23] were employed for balance ability assessment. The limits of stability were evaluated through the Functional Reach Test [24], the modified Functional Reach Test [25],and the Lateral reach Test [26]. For limits of stability, three analyses were performed to observe the effects on the forward reach of the unaffected arm, and on the lateral reach of the unaffectedarm and the affected arm respectively;
- Regarding gait performance, this outcome was assessed through the Functional Ambulation Categories test [27], the gait subscale of the Tinetti Scale [28], the 3-m walking test (m/s) [29], and the 10-m walking test (m/s) [30];
- Lastly, functional mobility was assessed with the Timed Up and Go Test (TUG) [31].

All assessment methods, with exception of the TUG and gait performance, implied a better motor function if the score was higher, but all were expressed in positive values if there was an improvement, and in negative values if there was a deterioration.

### *Risk of Bias and Quality of Evidence*

The methodological quality of the studies was assessed with the Physiotherapy Evidence Database (PEDro) scale to evaluate the risk of bias, which establishes a maximum score of 10 points. Based on this scale, studies were categorized as follows: excellent (9–10 points), good (6–8 points), fair (4–5 points),and poor (<4 points) [32].

The quality of the evidence for each outcome was analyzed through the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach [33]. A.P. and P.M. analyzed and ranked the quality of evidence as very low, low, moderate, or high based on the score of the five GRADE items addressed: (1) risk of bias (PEDro scale), (2) inconsistency, (3) indirectness, (4) imprecision, (5) publication bias.

### *Data Synthesis and Analysis*

The mean change and the standard deviation (SD) of the changes were taken from each study. Nonetheless, when this information was not provided, data from the pre- and post-test of the experimental and control groups were used to calculate the mean change and the standard deviation (SD) of the changes of each group. In these cases, as proposed by Rosenthal (1991) [34], an R-value equal to 0.7 was employed to estimate the SD of the changes. A correction factor was applied ($c(gl) = 1 - (3/(4\times(n - 1) - 1))$ to avoid the bias of an overestimated pooled effect size [35].

The Review Manager (RevMan) software, (version 5.3, the Nordic Cochrane Centre, the Cochrane Collaboration, Copenhagen, Denmark, 2014), was used for the meta-analyses. The mean and SD of the changes for both the experimental and the control groups of each study were used to obtain the pooled effect sizes and their confidence intervals at 95%. A random-effect model was used in all cases because of the heterogeneity in the interventions and the inter-studies sample heterogeneity. The pooled effect size of each outcome was calculated using the weighted mean difference (MD) or the weighted standardized mean differences (SMD), depending on if the studies employed the same or different test, respectively. The standardized pooled effect sizes were categorized as follows: trivial: <0.20, low effect: 0.20–0.50, medium effect: 0.51–0.80, and high effect: >0.80 [36]. Finally, between-studies, heterogeneity was checked via the $I^2$ statistic, categorized as none, low, moderate, and high for 0%, 25%, 50%, and 75%, respectively [37]. Additionally, in order to provide more clinically meaningful information that can be used by healthcare professionals, the pooled effect size was also calculated as the percentage of the pre-post change relative to each maximum scale score as showed by the intervention group compared to the control group. This index was calculated for those outcomes that used scales, which were trunk control and balance ability.

The potential effect modifiers (i.e., initial trunk impairment, participants' age, the start of the intervention after stroke-onset, and total volume of training of additional trunk exercises) were analyzed through subgroup analyses. The initial trunk impairment was calculated as the average pre-test score of the trunk function outcome and transformed to relative score (%) in order to homogenize all the scales employed. Participants' age was obtained from descriptive data. The start of the intervention after stroke-onset was obtained from the descriptive data and, when it was necessary, transformed into days. Lastly, the total volume of ATEP was calculated from the session duration, the frequency of the training and the duration (in weeks) of the program. All potential effect modifiers data, except the total volume of training (which only included the total ATEP duration), were averaged from the experimental and control groups. Afterwards, two groups were created based on the median score obtained from the data of all the studies (group A: articles below the median; group B: articles over the median).

## RESULTS

A total of 737 studies were initially identified (Figure 1) through both database searching (n = 717) and additional search of studies (n = 20), out of which 102 were duplicated records. From the 635-screened studies, 561 studies were removed after title/abstract reading. After a more detailed reading, 54 of them were excluded for different reasons (5 were systematic reviews; 14 did not have a control group; 12 did not match the characteristics of the training program (e.g., they included cardiovascular exercises, lower or upper limb strengthening, etc.); 5 only evaluated immediate effects; 1 did not provide post-intervention results; 7 did not measure the desired outcomes, and in 10, the experimental group did not perform an additional training). Twenty studies were finally included in the systematic review [26,29,30,38–54]. One of the articles [47] had the same sample as a previously published article that was also included in the present work [43]. In order to avoid duplicated samples, it was only counted once.

The most recent article [47] was only included in the gait performance outcome, which was the new outcome that was added, with respect to the prior article. Furthermore,it is important to note that five of the studies included [29,42,51–53] were published in predatory journals. Nevertheless, characteristics of these studies matched the inclusion criteria of this systematic review and, thus, they were kept for the subsequent analyses. The participants' mean age was 60 ± 11 years. The training program duration ranged between 2 and 8 weeks, in which 4 weeks was the most common (12 studies). The duration of each session ranged between 10 and 60 min, with 30 min being the most common duration. The total volume ranged between 240 and 1200 min, with an average of 511 min. Regarding the period of time in which the intervention started after stroke-onset, it rangedfrom 15 days to 34 months. The characteristics of the studies can be seen more in detail in Table 1.

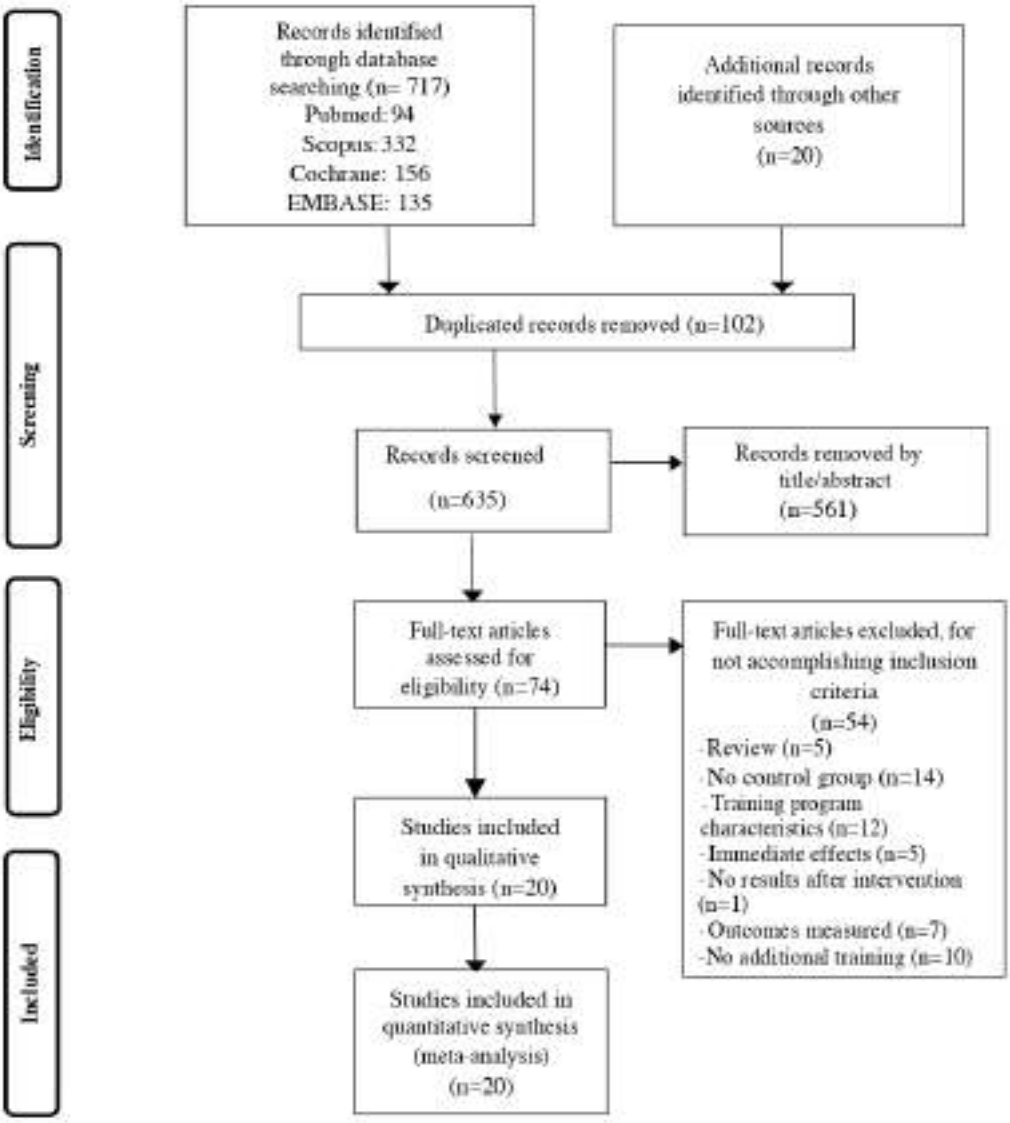

**Figure 1.** Flow chart diagram.

**Table 1.** Characteristics of the studies included in the meta-analysis.

| *General characteristics* | | | | | *Training programs characteristics* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Study** | **N total (EG, CG)** | **Age (mean±SD)** | **Time after stroke (days)** | **Outcomes** | **Intervention** | **Total weeks** | **Sessions per week** | **Duration (min)*** | **Total duration (min)** | **PEDro scale** | |
| DeSèze et al., 2001 | 20 (10, 10) | EG(63.5±17.0)<br>CG(67.7±15.0) | 32.3 | Trunk, control test, Equilibrium Index, FAC | **EG:** CRP + trunk control training pointing targets (through a device located above the head) with auditive and visual feedback when the target is reached. They performed weight-shifting of the trunk in many directions. | 4 | 5 | 60 | 1200 | 8 | Good Quality |
| | | | | | **CG**: CRP (Bobath-inspired approach + functional therapy). | 8 | 5 | 120 | 4800 | | |
| Howe et al., 2005 | 33 (15, 18) | EG(71.5±10.9)<br>CG(70.7±7.9) | 24.8 | LRT (standing) | **EG:** CRP + trunk weight transference in sitting and standing position. Movements involved trunk flexion and extension, lateral flexion, moving objects from the unaffected to the affected arm beyond the base of support. They also performed exercises changing from sitting to standing position. | 4 | 3 | 30 | 360 | 6 | Good Quality |
| | | | | | **CG:** CRP (Usual care and physiotherapy). | 4 | - | - | 8643 | | |
| Dean et al., 2007 | 12 (6, 6) | EG(60.0±7.0)<br>CG(74.0±12.0) | 29.0 | 10 m walk test | **EG:** CRP + lateral trunk weight transference in sitting position. Movements included trunk frontal and lateral flexion and extension, reaching for objects of different weight placed at different points on a table. | 2 | 5 | 30 | 300 | 8 | Good Quality |
| | | | | | **CG:** CRP + sham sitting training | 2 | 5 | 30 | 300 | | |
| Verheyden et al., 2009 | 33 (17, 16) | EG(55.0±11.0)<br>CG(62.0±14.0) | 51.0 | TIS | **EG:** CRP + trunk exercises in supine position: legs bent and feet on the table they performed antero-posterior pelvic movements, back bridge, and upper and lower trunk rotation; and in sitting position: weight transference involving trunk and hip flexion and extension movements. | 5 | 4 | 30 | 600 | 8 | Good Quality |
| | | | | | **CG:** CRP (physiotherapy, occupational therapy, nursing care). | 5 | - | - | 600 | | |
| Yoo et al., 2010 | 59 (28, 31) | EG(59.6±18.1)<br>CG(61.7±12.5) | 45.5 | TIS, BBS | **EG:** CRP + trunk exercises divided in 3 levels based on the difficulty level (1: trunk bracing, bridge exercise, segmental rotation; 2: dead | 4 | 3 | 30 | 360 | 3 | Poor Quality |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | bug, hamstring curls, crossed extension; 3: side bridge, belly blasterm and the bird-dog exercise). | | | | | | |
| | | | | | **CG:** CRP (Neuro-development treatment, walking, occupational therapy). | 4 | 3 | - | - | | |
| Kim et al., 2011 | 40 (20, 20) | EG(51.4±5.7)<br>CG(53.5±7.1) | 755.9 | FRT (standing) | **EG:** CRP + trunk exercises with propioceptive neuromuscular facilitation (stabilizing reversal and rhythmic stabilization techniques) in sitting and standing positions. | 6 | 5 | 10 | 300 | 5 | Fair Quality |
| | | | | | **CG:** CRP (Stretching and Range of Movement exercises). | 6 | 5 | 30 | 900 | | |
| Vijayakumar et al., 2011 | 20 (10,10) | EG(59.5±12.9)<br>CG(57.8±13.4) | 15.4 | TIS, BBA | **EG:** CRP + trunk exercises in supine position: back bridge, unilateral pelvic bridge, upper and lower trunk rotation; and sitting position: static sitting balance, trunk flexion and extensions, trunk lateral flexion. | 3 | 6 | 45 | 810 | 5 | Fair Quality |
| | | | | | **CG:** CRP (Usual care including physiotherapy). | 3 | - | - | - | | |
| Lee et al., 2011 | 28 (14, 14) | EG(59.0±11.0)<br>CG(62.3±14.2) | 1034.2 | TIS, mFRT (sitting forward and both sides lateral reach) | **EG:** CRP + dual motor task in sitting position (trunk weight transference). Patients sat on an unstable seat with hips and knees 90º flexed performing movements on the frontal plane. They also threw a ball to targets and afterwards did fishing and played badminton while sitting on the unstable surface. | 6 | 3 | 30 | 540 | 6 | Good Quality |
| | | | | | **CG:** CRP (Brunnstrom motion therapy, Bobath neurological development and PNF). | 6 | 5 | 60 | 1800 | | |
| Saeys et al., 2012 | 33 (18, 15) | EG(61.9±13.8)<br>CG(61.0±9.0) | 35.4 | TIS, BBS, FAC | **EG:** CRP + trunk muscle exercises in supine position: back bridges, shoulder girdle lifts (symmetrical and asymmetrical); and sitting position: antero-posterior pelvic tilt, upper and lower trunk rotation, reaching tasks beyond arm's length, shuffling forward and backwards, sitting on unstable seat. | 8 | 4 | 30 | 960 | 8 | Good Quality |

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| | | | | | **CG:** CRP (physical and occupational therapy) + passive mobilization of upper limb and transcutaneous electrical nerve stimulation of the hemiplegic shoulder. | 8 | 4 | 30 | 960 | | |
| Chung et al., 2013 | 16 (8, 8) | EG(44.3±9.9)<br>CG(48.3±9.7) | 342.3 | TUG, 3 m walk test | **EG:** CRP + core stability exercises consisting in three parts: 1) bed exercises (bridge, bridge with legs crossed, unipedal back bridge), 2) wedge exercises (forward and lateral curl-ups, bird-dog exercise and side bridge); 3) ball exercises (bridge, bridge to side, bridge-up, curl-ups, bird-dog exercise and push-ups). | 4 | 3 | 30 | 360 | 6 | Good Quality |
| | | | | | **CG:** CRP (stretching, strengthening and stationary bicycle). | 4 | 5 | 60 | 1200 | | |
| Jung et al., 2014 | 17 (9, 8) | EG(51.9±10.3)<br>CG(57.9±8.5) | 437.2 | TIS, TUG | **EG:** CRP + weight-shifting training in two sitting positions (knees extended on a mat, and knees flexed on the edge of a table). Exercises involved static sitting balance (unstable seat) and trunk movements forward, backwards and in lateral directions. | 4 | 5 | 30 | 600 | 6 | Good Quality |
| | | | | | **CG:** CRP (physiotherapy, stretching, strengthening, stationary bike). | 4 | 5 | 30 | 600 | | |
| Cabanas-Valdés et al., 2015 | 79 (40, 39) | EG(74.9±10.7)<br>CG(75.6±9.4) | 23.6 | TIS 2.0, BBS, Tinetti scale (gait subscale) | **EG:** CRP + core stability exercises in supine position: pelvis anteversion and retroversion, back bridge, unilateral back bridge with the unaffected leg, upper and lower trunk rotation, back bridge (bilateral and unilateral) with swiss ball; and sitting position (on stable and unstable surfaces): trunk flexion and extension, lateral trunk flexion starting from the shoulders, upper and lower trunk rotation, and forward reach in three directions. | 5 | 5 | 15 | 375 | 7 | Good Quality |
| | | | | | **CG:** CRP (physiotherapy, walking, occupational therapy, nursing care) | 5 | 5 | 60 | 1500 | | |
| Jung et al., 2015 | 22 (11, 11) | EG(53.1±16.6)<br>CG(54.1±9.1) | 490.8 | TIS, FRT (sitting forward and | **EG:** CRP + core stability training with visual feedback of the center of pressure while sitting on an unstable seat (trunk and pelvis movements). | 4 | 3 | 20 | 240 | 6 | Good Quality |

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| | | | | both sides lateral reach) | **CG:** CRP (Brunnstrom approach exercise, neuro-development treatment with Bobath concepts, neuromuscular facilitation). | 4 | 5 | 60 | 1200 | | |
| Haruyama et al., 2016 | 32 (16, 16) | EG(67.5±10.1)<br>CG(65.6±11.9) | 69.0 | TIS, Brief BESTest, FRT (standing), FAC, TUG | **EG:** CRP + core stability training with abdominal hollowing: pelvic control exercises in supine and sitting positions. They performed antero-posterior tilt, lateral lift and transverse rotation. | 4 | 5 | 20 | 400 | 7 | Good Quality |
| | | | | | **CG:** CRP (physical therapy, occupational therapy, speech therapy, nursing care, bridges, pelvic movements and reaching exercises). | 4 | 5 | 60 | 1200 | | |
| Shin et al., 2016 | 24 (12, 12) | EG(57.7±14.0)<br>CG(59.2±9.7) | 498.4 | TIS, FRT (sitting forward and both sides lateral reach), TUG, **10 m walk test* (Data from Shin 2020)** | **EG:** CRP + core stability training in sitting position with an unstable seat that tilts in any direction and provides visual feedback. Patients moved their center of pressure to point at the target through pelvic and trunk movements. | 4 | 3 | 20 | 240 | 8 | Good Quality |
| | | | | | **CG:** CRP (physical and occupational therapy and electrical stimulation therapy). | 4 | 5 | 80 | 1600 | | |
| Rose et al., 2016 | 24 (12, 12) | EG(57.0±2.8)<br>GC(56.7±3.1) | 194.7 | TIS | **EG:** CRP + core stability training in prone position: trunk extension; and sitting position: trunk flexion from sitting reclined position (120º), leaning back and forward, from sitting position with trunk rotated to the hemiplegic side the patient lies down, and lateral flexion of the trunk. | 4 | 3 | - | - | 7 | Good Quality |
| | | | | | **CG:** CRP (Usual care including physiotherapy). | 4 | - | - | - | | |
| An et al., 2017 | 29 (15, 14) | EG(59.7±8.9)<br>CG(57.1±17.1) | 277.9 | BBS, TUG | **EG:** CRP + trunk exercises in supine position: back bridge, unilateral back bridge, upper and lower trunk rotation; and sitting position: flexion and extension of the lower trunk, upper and lower trunk lateral flexion, upper and lower trunk rotation, forward and lateral reach. | 4 | 3 | 30 | 360 | 6 | Good Quality |
| | | | | | **CG:** CRP (Neurodevelopment therapy). | 4 | 5 | 30 | 600 | | |
| Park et al. 2019 | 28 (14,14) | EG(56.2±13.7)<br>CG(57.1±11.7) | 336.7 | TIS, BBS-3L, FRT (standing) | **EG:** CRP + trunk exercises land-based: supine position (back bridge, upper and lower trunk rotation) sitting position (lower trunk flexion | 4 | 5 | 30 | 600 | 6 | Good Quality |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | and extension, lateral trunk flexion and rotation, and arm reach exercises); and aquatic-based: trunk movements (trunk flexion, extension, lateral flexion and rotation) in sitting and standing positions. | | | | | | |
| | | | | | **CG:** CRP (Neuro-development treatment Bobath approach). | 4 | 5 | 60 | 1200 | | |
| Min et al., 2020 | 38 (19, 19) | EG(61.4±11.1)<br>CG(56.3±9.1) | 855.1 | BBS, 10 m walk test, TUG | **EG:** CRP + trunk stability training with a robot system (standing balance, sitting balance and move from sitting to standing). | 4 | 5 | 30 | 600 | 8 | Good Quality |
| | | | | | **CG:** CRP (symmetrical static and dynamic standing balance during walking). | 4 | 5 | 30 | 600 | | |

SD: Standard Deviation; EG: Experimental Group; CG: Control Group; TIS: Trunk Impairment Scale; BBS: Berg Balance Scale; BBS-3L: 3-level Berg Balance Scale; BBA: Brunel Balance Assessment; TUG: Timed Up and Go; FR Functional Reach Test; LRT: Lateral Reach Test; FAC: Functional Ambulation Categories; CRP: Conventional Rehabilitation Program. **For the EG of the different studies, in the following table, duration only involves the time of the addition trunk exercises program it does not include the time of the CRP.*

### *Risk of Bias and Quality of Evidence*

The studies presented poor to good methodological quality (poor: 5.3%, fair: 10.5%, good: 84.2%); (scores are presented in Table 1 and in higher detail in Table S3). The quality of the evidence was verylow and low for the outcomes registered (Table S4).

### *General Effects*

The effect of ATEP was assessed on trunk function, balance ability, gait performance, and functional ability. Pooled effect sizes of each outcome are shown in Tables 2 and 3. Forest plots are also availablein Figures S1–S5.

- Trunk function was evaluated in thirteen studies [38–43,45,48–50,52–54], ATEP improved trunk function by SMD 1.06 (95% CI, 0.74–1.37; $I^2$ = 53%), representing a 13% of pre-post change respect to the control group.
- Balance ability was evaluated in nine studies [39,41,44–46,48,50,52,54], ATEP improved balance ability by SMD 0.83 (95% CI, 0.52–1.14; $I^2$ 42%), which was a 17% of pre-post change respect to the control group. Balance was also assessed through the limits of stability. The forward non-affected-arm reach was analyzed in six studies [40,41,43,45,51,53], and showed that ATEP improved by SMD 0.90 (95% CI 0.47–1.33; $I^2$ 43%). The lateral non-affected-arm reach was analyzed in four studies [26,40,43,53] and improved by SMD 1.16 (95% CI, 0.67–1.66; $I^2$ 26%). Lastly, the lateral affected-arm reach was analyzed in three studies [40,43,53] and improved by SMD 0.89 (95% CI 0.26–1.52; $I^2$ 39%).
- Gait performance was evaluated in eight studies [29,30,39,41,46–48,54], ATEP improved gait performance by SMD 0.63 (95% CI 0.38–0.89; $I^2$ 0%).
- Functional mobility was evaluated in six studies through the TUG [29,38,41,43,44,46], ATEP improved the TUG by MD 3.40 s (95% CI, −0.32–7.12; $I^2$ 67%).

**Table 2.** Pooled effect size in trunk function of additional trunk exercises vs conventional rehabilitation and potential effect modifiers characteristics depending on the initial trunk impairment.

| | N (studies) | N (sample) | SMD | LCL | UCL | $I^2$ | *p* |
|---|---|---|---|---|---|---|---|
| **Trunk function** | 13 | 419 | 1.06 | 0.74 | 1.37 | 53 | <0.01 |

| | *Studies with higher initial trunk impairment* | | *Studies with lower initial trunk impairment* | |
|---|---|---|---|---|
| | *Mean* | *(SD)* | *Mean* | *(SD)* |
| **Initial trunk impairment (%)** | 43.6 | (11.1) | 66.5 | (7.0) |
| **Stroke-onset (days)** | 240.7 | (391.1) | 263.2 | (187.0) |
| **Total volume of additional trunk exercises (min)** | 582.9 | (319.7) | 440.0* | (157.5)* |
| **Participants' age** | 62.3 | (5.9) | 56.8 | (5.6) |

**Rose et al. (2016) was not included because it did not provide the total volume of training.* SMD: Standardized mean difference; LCL: lower confidence limit; UCL: upper confidence limit; $I^2$ (%): heterogeneity statistic. The effect was in favor of additional trunk exercises when the SMD is positive.

**Table 3.** Pooled effect sizes in balance, limits of stability, gait performance, and functional mobility of additional trunk exercises vs. conventional rehabilitation.

| | N (studies) | N (sample) | SMD | LCL | UCL | $I^2$ | *p* |
|---|---|---|---|---|---|---|---|
| **Balance ability** | 9 | 338 | 0.83 | 0.52 | 1.14 | 42 | <0.01 |
| **LOS forward unaffected arm** | 6 | 174 | 0.90 | 0.47 | 1.33 | 43 | <0.01 |
| **LOS lateral unaffected arm** | 4 | 107 | 1.16 | 0.67 | 1.66 | 26 | <0.01 |
| **LOS lateral affected arm** | 3 | 74 | 0.89 | 0.26 | 1.52 | 39 | <0.01 |
| **Gait performance** | 8 | 254 | 0.63 | 0.38 | 0.89 | 0 | <0.01 |
| **Functional mobility** | 6 | 156 | 3.40* | -0.32 | 7.12 | 67 | 0.07 |

**Pooled effect size was obtained through the weighted mean difference since all the studies employed the same test/scale.* SMD: Standardized mean difference; LCL: lower confidence limit; UCL: upper confidence limit; $I^2$ (%): heterogeneity statistic. The effect was in favor of additional trunk exercises when the SMD is positive.

### *Potential Effect Modifiers*

The potential effect of the initial trunk impairment, participants' age, the start of rehabilitation after stroke-onset, and total volume of training after ATEP was explored on trunk function, balance ability, gait performance, and functional ability. Pooled effect sizes of each potential effect modifier are shown in Table 4. Forest plots are also available in Figures S6–S9.

#### Initial Trunk Impairment

The median score was 55.15% of the total score on the trunk function scale, with seven studies below the median and six studies over the median. Subgroup analyses showed high pooled effect sizes on trunk function, balance ability, and limits of stability (forward reach of the unaffected arm) for those studies with higher initial trunk impairment (1.10 < SMD < 1.54). In case of the studies with lower trunk impairment, they showed medium pooled effect sizes on the same outcomes

(0.51 < SMD < 0.76). It must be noted that those participants who had a higher initial trunk impairment were older and they also started the rehabilitation programs earlier (Table 2).

### Participants Age

The median score was 58.65 years, with nine studies below and 10 studies over the median.The subgroup analyses showed high pooled effect sizes on trunk function and on limits of stability (SMD 1.13 and 1.06 respectively), and a medium effect on balance ability for the studies with older participants (SMD 0.79). In the case of the studies with younger participants, high pooled effect sizeswere observed on trunk function and balance ability (SMD 0.98 and 1.12, respectively), and a mediumeffect on limits of stability (SMD 0.80). The change on functional mobility was higher in the older participant's group (5.72 s vs. 1.93 s), although the change in the older group was not significant.

### Time since Stroke-Onset until Rehabilitation

The median score was 194.67 days from stroke-onset until the rehabilitation started, with nine studies below and 10 studies over the median. Subgroup analyses showed medium-to-high pooled effect sizes on trunk function, balance ability, and gait performance for those studies that started the ATEP sooner after the stroke onset (0.76 < SMD < 1.13). In the case of the studies that started the ATEP later, they also showed medium-to-high effect sizes, although the score was lower (0.59 < SMD < 0.98).

### Total Volume of Additional Trunk Exercises Program

The median score was 387.5 min, with nine studies below and nine studies over the median. The subgroup analyses showed high pooled effect sizes on trunk function, limits of stability, and gait performance for those studies with a shorter duration of ATEP (0.87 < SMD < 1.09), and a medium effect on balance ability (SMD 0.70). In the case of the studies with longer duration of ATEP, they showed high pooled effect sizes on trunk function and balance ability (SMD 1.24 and 0.95, respectively), and a low-to-medium effect on gait performance and limits of stability (SMD 0.39 and 0.72, respectively). Functional mobility improved slightly more in the shorter ATEP group (3.62 vs. 2.41 s), although, in neither of the groups was the effect significant.

**Table 4.** Pooled effect sizes on the outcomes sub-grouped by the potential effect modifiers.

**Initial impairment (median of the studies 55.15% of the trunk function pre-test score)**

| | *Studies with higher trunk impairment* | | | | | | | *Studies with lower trunk impairment* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Outcomes** | **Initial trunk impairment (%)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** | **Initial trunk impairment (%)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** |
| | Mean | (SD) | | | | | | Mean | (SD) | | | | | |
| **Trunk function** | 43.6 | 11.1 | 252 | 1.32 | 0.87 | 1.78 | 56 | 66.5 | 7.0 | 156 | 0.76 | 0.40 | 1.12 | 15 |
| **Balance ability** | 43.0 | 12.2 | 211 | 1.10 | 0.51 | 1.70 | 71 | 67.4 | 0.1 | 60 | 0.65 | 0.13 | 1.17 | 0 |
| **LOS-forward reach** | 45.3 | 11.5 | 52 | 1.54 | 0.91 | 2.18 | 0 | 70.8 | 5.8 | 82 | 0.51 | 0.06 | 0.95 | 0 |

**Participants' age (median of the studies 58.65 years)**

| | *Younger participants* | | | | | | | *Older participants* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Outcomes** | **Participants' age (years)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** | **Participants' age (years)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** |
| | Mean | (SD) | | | | | | Mean | (SD) | | | | | |
| **Trunk function** | 56.5 | 2.0 | 144 | 0.98 | 0.35 | 1.61 | 66 | 64.1 | 5.7 | 275 | 1.13 | 0.79 | 1.46 | 37 |
| **Balance ability** | 57.9 | 1.1 | 77 | 1.12 | 0.06 | 2.18 | 77 | 64.8 | 5.9 | 261 | 0.79 | 0.53 | 1.05 | 3 |
| **LOS-forward reach** | 54.2 | 2.2 | 90 | 0.80 | 0.37 | 1.24 | 0 | 61.9 | 4.2 | 84 | 1.06 | 0.11 | 2.01 | 75 |
| **Functional mobility** | 53.2 | 6.2 | 62 | 1.93* | 0.10 | 3.76 | 0 | 61.3 | 4.6 | 94 | 5.72* | -2.27 | 13.72 | 40 |

**Time from the stroke-onset until the start of the rehabilitation program (median of the studies 194.67 days)**

| | *Studies starting the rehabilitation program earlier* | | | | | | | *Studies starting the rehabilitation program later* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Outcomes** | **Time after stroke-onset (days)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** | **Time after stroke-onset (days)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** |
| | Mean | (SD) | | | | | | Mean | (SD) | | | | | |
| **Trunk function** | 38.8 | 18.0 | 276 | 1.13 | 0.65 | 1.61 | 67 | 498.7 | 286.1 | 143 | 0.98 | 0.55 | 1.41 | 31 |
| **Balance ability** | 36.8 | 18.8 | 243 | 0.98 | 0.52 | 1.44 | 60 | 499.9 | 310.8 | 95 | 0.62 | 0.21 | 1.03 | 0 |
| **Gait performance** | 38.4 | 20.8 | 143 | 0.76 | 0.41 | 1.10 | 0 | 565.3 | 262.9 | 78 | 0.59 | -0.08 | 1.26 | 48 |

**Total volume of additional trunk exercises program (median of the studies 387.5 min)**

| | *Studies with lower volume of additional trunk exercises* | | | | | | | *Studies with higher volume of additional trunk exercises* | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Outcomes** | **ATEP (min)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** | **ATEP (min)** | | **Total N** | **SMD** | **LCL** | **UCL** | **$I^2$** |
| | Mean | (SD) | | | | | | Mean | (SD) | | | | | |
| **Trunk function** | 303.8 | 73.9 | 184 | 0.97 | 0.58 | 1.35 | 29 | 696.9 | 257.4 | 211 | 1.24 | 0.80 | 1.69 | 52 |
| **Balance ability** | 365.0 | 8.7 | 167 | 0.70 | 0.21 | 1.19 | 55 | 739.2 | 289.5 | 171 | 0.95 | 0.50 | 1.39 | 44 |
| **LOS-forward reach** | 260.0 | 34.6 | 86 | 1.09 | 0.63 | 1.55 | 0 | 513.3 | 102.6 | 88 | 0.72 | -0.03 | 1.47 | 65 |
| **Gait performance** | 318.8 | 61.7 | 131 | 0.87 | 0.51 | 1.23 | 0 | 790.0 | 358.3 | 123 | 0.39 | 0.03 | 0.75 | 0 |
| **Functional mobility** | 320.0 | 69.3 | 69 | 3.62* | -0.78 | 8.01 | 84 | 533.3 | 115.5 | 87 | 2.41* | -6.29 | 11.11 | 23 |

**Pooled effect size was obtained through the weighted mean difference since all the studies employed the same test/scale.* SMD: Standardized mean difference; LCL: lower confidence limit; UCL: upper confidence limit; $I^2$ (%): heterogeneity statistic; ATEP: Additional trunk exercises program. The effect was in favor of additional trunk exercises when the SMD is positive.

## DISCUSSION

The aim of the following systematic review was to analyze how different potential effect modifiers modulate the effectiveness of trunk exercises added to conventional stroke rehabilitation programs. Firstly, the results of the present review confirmed the positive effect that ATEP have on the recovery of trunk function, balance ability, gait performance, and functional mobility. Additionally, the potential effect modifiers analyzed seemed to modulate the effectiveness of ATEP in stroke motor recovery, and should be considered when designing this type of rehabilitation programs.

### *General Effects of ATEP*

Our results confirmed prior evidence [8–11] regarding the positive effect of ATEP on trunk function recovery by SMD 1.06 (CI 0.74–1.37) and balance ability (SMD 0.83; CI 0.52–1.14). The improvement on trunk function caused by ATEP represented a 13% higher than the improvement showed by the conventional therapy alone, which is equal to 3 points on the Trunk Impairment Scale (TIS). On the other hand, balance ability increased by 17%, which corresponds to a change of 9.52 points in the Berg Balance Scale. This information can be useful for practitioners as an improvement score reference when applying ATEP for trunk function and balance restoration in stroke patients. Regarding balance assessed through tests compromising the limits of stability, results also showed high effect in both the lateral reach of the affected (SMD 0.89; CI 0.26–1.52) and the non-affected arm (SMD 1.16; CI 0.67–1.66), and in the forward reach of the unaffected arm (SMD 0.90; CI 0.47–1.33). Thus, although it has been formerly said that lateral balance is more affected after a stroke [55], ATEP seem to provide the same improvement independently of the direction and of the arm involved.

In the same way, our results confirmed that ATEP improved gait performance by SMD 0.63 (CI 0.38–0.89), which supports the fact that a proper control of the trunk is a key factor to maintain balance during dynamic actions, such as gait [56]. However, contrary to what was expected, ATEP did not show a significant effect on the TUG (MD = 3.40 s; 95% CI −0.32–7.12), in spite of being a task in which the trunk control seems to play an important role because of its high balance demands [57]. The non-significant effect of ATEP on functional mobility could be caused by the fact that TUG performance depends on several parameters that could have also been impaired after a stroke, such asmuscle strength in the lower limbs [58] or even cognitive or sensory deficits, hindering the ability to perform, for example, a 180° turn [59]. Nevertheless, from the authors' point of view, observing the magnitude of the pooled effect size (3.40 s), we think that the lack of significant effect is caused by thelimited number of studies analyzing this parameter. Therefore, more experimental studies are neededto confirm if ATEP have a real impact on functional mobility.

### *Effect of the Potential Effect Modifiers on Trunk Function, Balance Ability, Gait Performance, and Functional Mobility*

Motor recovery after a stroke is a multifactorial process in which the interaction between different factors determines the success of a rehabilitation program [12]; however, the way in which different factors modulate the effects of ATEP has been little studied. Our results seem to indicate that a higher initial trunk impairment is related with a greater motor recovery, which can be observed not only in trunk function, but also in balance and limits of stability. These results are not in line with previous findings indicating that the more severe the motor impairment after stroke-onset, the more severe the chronic deficits [12]. A similar controversy regarding patients' age was found, in which older age has been identified as a determinant factor for a poorer recovery process. Thirteen subgroup analyses hint that older participants would have greater improvements after ATEP for all the motor recovery parameters, except for balance. Interestingly, as Table 2 shows, those studies with older participants also displayed higher initial trunk impairment. Although, the rationale behind these findings is not clear, as mentioned elsewhere [60], the influence of initial trunk impairment and age on motor recovery after ATEP could be related with the larger room for improvement that these older or more affected patients may have. However, from the authors' point of view, the interpretation of these findings canbe biased by the fact that, in those studies with more impaired and older participants, these patients were also the ones who started the intervention after the stroke earlier. In this sense, subgroup analyses showed that the pooled effect size was slightly higher in trunk function, balance, and gait performance when stroke patients started the ATEP earlier. In spite of it being plausible that the most suitable timeto start rehabilitation will also depend on the type of therapy performed, the findings of the present systematic review support the idea that ATEP would be advisable in the first stages after stroke-onset.Finally, regarding the total volume of training, it is interesting to note that longer training programs were more effective on trunk function and balance. However, shorter training programs showed better results on limits of stability, gait performance, and functional mobility. Although the controversy in these results can be caused by the low number of studies included, the results obtained seem to indicate that even short trunk training programs (<387.5 min) could be enough to induce meaningful improvements on motor recovery. Nonetheless, future research is required in order to understand the dose-response relationship of ATEP in stroke patients better.

### *Limitations*

The conclusions of this systematic review should be taken with caution, as some limitations are present. First, the main limitation regards the non-statistical comparison between subgroups for the potential effect modifiers analyzed. Although interesting information has been advertised from the subgroups results, they have to be interpreted with caution since they have not compared statistically.Likewise, the quality of evidence obtained with the GRADE approach was low and very low for all outcomes analyzed (Table S4, Supplementary Material). Therefore, higher quality of evidence is needed to reinforce or reject the findings of the present work. In addition, not all of the studies assessed all of the outcomes and, thus, there was a lower sample in some of the variables registered, especially,when subgroup analyses were carried out to assess the impact of the potential effect modifiers. In the same way, as not all of the characteristics were provided in all of the articles, it was not possible to perform the same subgroup analyses of all potential effect modifiers for all the studies included. Regarding the training volume, it must be noted that the experimental group performed a higher total intervention volume, which is an intrinsic feature of any supplementary program added to the conventional therapy. However, it would be interesting that future studies compare the effectiveness of trunk exercise programs versus conventional rehabilitation, equaling the intervention volume in both groups to obtain a clearer view about time cost–benefit of each program. Furthermore, it would also be interesting to analyze different types of additional exercise programs to compare which of them are more effective in stroke rehabilitation. Finally, although ratio-scales allow a quick and easy-to-use evaluation of several parameters, future studies would need to implement tests that employ more quantifiable and objective parameters to assess the different capabilities. For example, following Veerbeek et al.'s proposal [61], the implementation of wearable devices, such as accelerometers, would be helpful to objectively quantify motor recovery parameters.

## CONCLUSIONS

The results of the present systematic review confirmed the positive effects on trunk function, balance ability, gait performance, and functional mobility recovery when trunk exercises were added to the conventional rehabilitation therapy. Regarding the potential effect modifiers analyzed (i.e., initial trunk impairment, age, intervention onset, and ATEP training volume), it seems that these might play an important role in the modulation of ATEP. Older patients, and those with higher initial trunk impairment, obtained, in general, greater improvements on the outcomes assessed. Moreover, it is important to note that these patients were also those who started the rehabilitation program earlier, which was also linked with a larger motor recovery. Regarding the volume of the ATEP, it seems that short durations could be enough to cause positive effects on motor recovery. Thus, since potential effect modifiers seem to modulate ATEP effectiveness, future studies should consider them to better understand their impact in stroke rehabilitation. Finally, the quality of the evidence was low, and thus, higher quality studies are required in order to strengthen evidence towards ATEP in rehabilitation programs after stroke.

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## SUPPLEMENTARY MATERIAL

**Table S1**. Boolean search strategy for each database.

| | |
|---|---|
| **PubMed** | (("core strength"[Title/Abstract] OR "trunk strength"[Title/Abstract] OR “trunk stability”[Title/Abstract] OR “trunk stabilization”[Title/Abstract] OR “trunk control”[Title/Abstract] OR “core stability”[Title/Abstract] OR “core stabilization”[Title/Abstract] OR “core control”[Title/Abstract] OR “lumbar stability”[Title/Abstract] OR “lumbar stabilization”[Title/Abstract] OR “lumbar control”[Title/Abstract] OR “spine stability”[Title/Abstract] OR “spine stabilization”[Title/Abstract] OR “spine control”[Title/Abstract] OR “lumbopelvic stability”[Title/Abstract] OR “lumbopelvic control”[Title/Abstract] OR “lumbopelvic stabilization”[Title/Abstract] OR “lumbo-pelvic stability”[Title/Abstract] OR “lumbo-pelvic control”[Title/Abstract] OR “lumbo-pelvic stabilization”[Title/Abstract]) AND (“training”[Title/Abstract] OR “exercises”[Title/Abstract] OR “program”[Title/Abstract] OR “programme”) AND (“stroke”[Title/Abstract]) NOT “cell”[Title/Abstract]) |
| **Scopus** | TITLE-ABS ( "core strength" OR "trunk strength" OR "trunk stability" OR " trunk stabilization" OR "trunk control" OR "core stability" OR "core stabilization" OR "core control" OR "lumbar stability" OR "lumbar stabilization" OR "lumbar control" OR "spine stability" OR "spine stabilization" OR "spine control" OR "lumbopelvic stability" OR "lumbopelvic control" OR "lumbopelvic stabilization" OR "lumbo-pelvic stability" OR "lumbo-pelvic control" OR "lumbo-pelvic stabilization" ) AND ( "training" OR "exercises" OR "program" OR "programme" ) AND (“stroke”) AND NOT ( "cell" ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) |
| **Cochrane and EMBASE** | ("core strength" OR "trunk strength" OR "trunk stability" OR "trunk stabilization" OR "trunk control" OR "core stability" OR "core stabilization" OR "core control" OR "lumbar stability" OR "lumbar stabilization" OR "lumbar control" OR "spine stability" OR "spine stabilization" OR "spine control" OR "lumbopelvic stability" OR "lumbopelvic control" OR "lumbopelvic stabilization" OR "lumbo-pelvic stability" OR "lumbo-pelvic control" OR "lumbo-pelvic stabilization" ) AND ("training" OR "exercises" OR "program" OR "programme") AND (“stroke”) AND NOT ("cell") |

## Forest plot of the main outcomes analyzed

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 33.7 | 11.5 | 10 | 20 | 18.3 | 10 | 6.7% | 0.86 [−0.07, 1.78] | 2001 |
| Verheyden 2009 | 4.82 | 2.69 | 17 | 3.31 | 3.59 | 16 | 8.9% | 0.47 [−0.23, 1.16] | 2009 |
| Yoo 2010 | 4.78 | 4.55 | 28 | 2.45 | 4.31 | 31 | 10.9% | 0.52 [−0.00, 1.04] | 2010 |
| Vijayakumar 2011 | 6.96 | 1.28 | 10 | 3.13 | 1.24 | 10 | 4.1% | 2.91 [1.58, 4.25] | 2011 |
| Lee 2011 | 3.7 | 2.3 | 14 | 0.9 | 1.4 | 14 | 7.4% | 1.43 [0.58, 2.27] | 2011 |
| Saeys 2012 | 8.72 | 2.8 | 18 | 2.87 | 3.23 | 15 | 7.4% | 1.90 [1.06, 2.74] | 2012 |
| Jung 2014 | 2.4 | 1.5 | 9 | 0.1 | 2.38 | 8 | 5.8% | 1.11 [0.07, 2.16] | 2014 |
| Jung 2015 | 2.36 | 2.94 | 11 | −0.27 | 1.27 | 11 | 6.8% | 1.12 [0.21, 2.03] | 2015 |
| Cabanas-Valdés 2015 | 5.88 | 3.48 | 40 | 2.5 | 2.2 | 39 | 11.4% | 1.15 [0.67, 1.62] | 2015 |
| Rose 2016 | 1.83 | 1.28 | 12 | 1.75 | 2.19 | 12 | 7.8% | 0.04 [−0.76, 0.84] | 2016 |
| Haruyama 2016 | 4.13 | 2.38 | 16 | 1.19 | 2.79 | 16 | 8.3% | 1.11 [0.35, 1.86] | 2016 |
| Shin 2016 | 3.08 | 2.71 | 12 | 0.09 | 1.24 | 12 | 6.8% | 1.37 [0.46, 2.28] | 2016 |
| Park 2019 | 3.07 | 2.04 | 14 | 0.93 | 2.23 | 14 | 7.9% | 0.97 [0.18, 1.76] | 2018 |
| **Total (95% CI)** | | | **211** | | | **208** | **100.0%** | **1.06 [0.74, 1.37]** | |

Heterogeneity: Tau$^2$ = 0.17; Chi$^2$ = 25.59, df = 12 (P = 0.01); I$^2$ = 53%
Test for overall effect: Z = 6.51 (P < 0.00001)

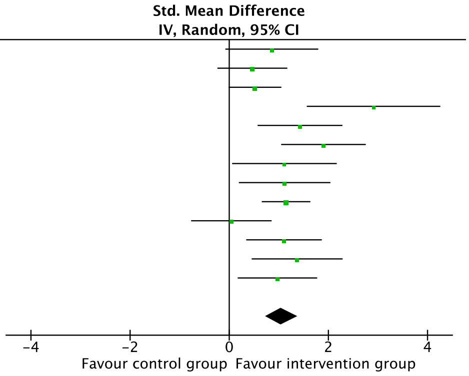


**Figure S1.** Pooled effect sizes on trunk function.

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 1.6 | 0.5 | 10 | 0.8 | 0.7 | 10 | 7.3% | 1.26 [0.28, 2.24] | 2001 |
| Yoo 2010 | 11.29 | 13.25 | 28 | 6.32 | 11.99 | 31 | 15.6% | 0.39 [−0.13, 0.91] | 2010 |
| Vijayakumar 2011 | 7.1 | 0.88 | 10 | 4.4 | 1.1 | 10 | 5.0% | 2.60 [1.34, 3.85] | 2011 |
| Saeys 2012 | 19.39 | 12.61 | 18 | 9.2 | 13.52 | 15 | 11.2% | 0.76 [0.05, 1.48] | 2012 |
| Cabanas-Valdés 2015 | 23.03 | 15.95 | 40 | 8.49 | 8.74 | 39 | 16.7% | 1.12 [0.64, 1.59] | 2015 |
| Haruyama 2016 | 2.79 | 3.34 | 16 | 0.06 | 4.32 | 16 | 11.1% | 0.69 [−0.03, 1.41] | 2016 |
| An 2017 | 2.93 | 2.96 | 15 | 1.36 | 2.84 | 14 | 10.6% | 0.53 [−0.22, 1.27] | 2017 |
| Park 2019 | 4.79 | 3.06 | 14 | 2.86 | 3.19 | 14 | 10.3% | 0.60 [−0.16, 1.36] | 2018 |
| Min 2020 | 7.36 | 3.63 | 19 | 4.42 | 4.49 | 19 | 12.3% | 0.71 [0.05, 1.36] | 2020 |
| **Total (95% CI)** | | | **170** | | | **168** | **100.0%** | **0.83 [0.52, 1.14]** | |

Heterogeneity: Tau$^2$ = 0.09; Chi$^2$ = 13.81, df = 8 (P = 0.09); I$^2$ = 42%
Test for overall effect: Z = 5.29 (P < 0.00001)

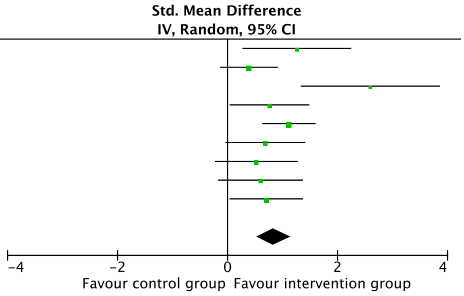
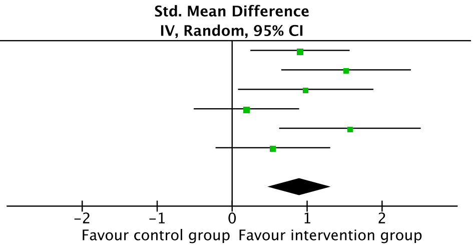


**Figure S2.** Pooled effect sizes on balance ability.

**A)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year |
| Kim 2011 | 4.6 | 5.54 | 20 | 0.1 | 4.1 | 20 | 20.3% | 0.91 [0.25, 1.56] | 2011 |
| Lee 2011 | 16.5 | 9.7 | 14 | 4.1 | 5.6 | 14 | 15.2% | 1.52 [0.66, 2.38] | 2011 |
| Jung 2015 | 8.28 | 5.42 | 11 | 2.37 | 6.15 | 11 | 14.4% | 0.98 [0.09, 1.88] | 2015 |
| Haruyama 2016 | 3.37 | 4.47 | 16 | 2.28 | 6.49 | 16 | 19.1% | 0.19 [−0.50, 0.89] | 2016 |
| Shin 2016 | 7.36 | 5.5 | 12 | 0.99 | 0.63 | 12 | 13.5% | 1.57 [0.63, 2.51] | 2016 |
| Park 2019 | 5.69 | 6.24 | 14 | 2.71 | 4.21 | 14 | 17.5% | 0.54 [−0.21, 1.30] | 2018 |
| **Total (95% CI)** | | | **87** | | | **87** | **100.0%** | **0.90 [0.47, 1.33]** | |

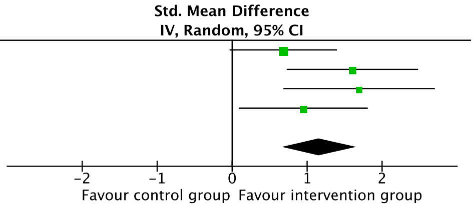
Heterogeneity: Tau$^2$ = 0.12; Chi$^2$ = 8.82, df = 5 (P = 0.12); I$^2$ = 43%
Test for overall effect: Z = 4.13 (P < 0.0001)



**B)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year |
| Howe 2005 | 1 | 1.1 | 15 | 0.4 | 0.59 | 18 | 32.1% | 0.68 [−0.03, 1.39] | 2005 |
| Lee 2011 | 8.7 | 5.2 | 14 | 1.8 | 2.8 | 14 | 24.0% | 1.60 [0.74, 2.47] | 2011 |
| Jung 2015 | 7.91 | 5.01 | 11 | 0.95 | 2.48 | 11 | 19.3% | 1.69 [0.69, 2.70] | 2015 |
| Shin 2016 | 8.36 | 4.5 | 12 | 3.44 | 5.46 | 12 | 24.7% | 0.95 [0.10, 1.80] | 2016 |
| **Total (95% CI)** | | | **52** | | | **55** | **100.0%** | **1.16 [0.67, 1.66]** | |

Heterogeneity: Tau$^2$ = 0.07; Chi$^2$ = 4.08, df = 3 (P = 0.25); I$^2$ = 26%
Test for overall effect: Z = 4.63 (P < 0.00001)



**C)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year |
| Lee 2011 | 5.3 | 4.4 | 14 | 3.5 | 2.1 | 14 | 38.2% | 0.51 [−0.25, 1.26] | 2011 |
| Jung 2015 | 5.66 | 6.35 | 11 | 1.65 | 4.2 | 11 | 32.5% | 0.72 [−0.15, 1.58] | 2015 |
| Shin 2016 | 6.32 | 3.79 | 12 | 1.7 | 1.13 | 12 | 29.3% | 1.60 [0.65, 2.54] | 2016 |
| **Total (95% CI)** | | | **37** | | | **37** | **100.0%** | **0.89 [0.26, 1.52]** | |

Heterogeneity: Tau$^2$ = 0.12; Chi$^2$ = 3.29, df = 2 (P = 0.19); I$^2$ = 39%
Test for overall effect: Z = 2.78 (P = 0.005)

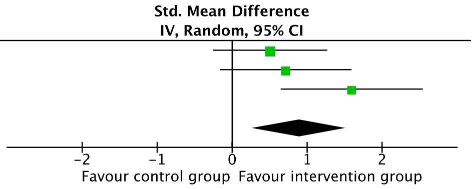


**Figure S3.** (A) Pooled effect sizes on limits of stability forward reach of the unaffected arm; (B) Pooled effect sizes on limits of stability lateral reach of the unaffected arm; (C) Pooled effect sizes on limits of stability lateral reach of the affected arm.

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year |
| De Sèze 2001 | 2.2 | 1 | 10 | 1.1 | 1.1 | 10 | 7.3% | 1.00 [0.06, 1.94] | 2001 |
| Dean 2007 | 0.41 | 0.35 | 6 | 0.21 | 0.16 | 6 | 4.7% | 0.68 [−0.50, 1.86] | 2007 |
| Saeys 2012 | 2.45 | 1.31 | 18 | 1.86 | 1.38 | 15 | 13.5% | 0.43 [−0.27, 1.12] | 2012 |
| Chung 2013 | 14.08 | 13.9 | 8 | −0.3 | 11.24 | 8 | 5.7% | 1.08 [0.01, 2.15] | 2013 |
| Cabanas-Valdés 2015 | 5.57 | 3.97 | 40 | 2.62 | 2.78 | 39 | 30.5% | 0.85 [0.39, 1.31] | 2015 |
| Haruyama 2016 | 0.5 | 0.81 | 16 | 0.12 | 0.93 | 16 | 13.2% | 0.42 [−0.28, 1.13] | 2016 |
| Shin 2020 | 0.17 | 0.15 | 12 | 0.05 | 0.1 | 12 | 9.0% | 0.91 [0.06, 1.76] | 2019 |
| Min 2020 | 0.36 | 0.58 | 19 | 0.32 | 0.71 | 19 | 16.1% | 0.06 [−0.58, 0.70] | 2020 |
| **Total (95% CI)** | | | **129** | | | **125** | **100.0%** | **0.63 [0.38, 0.89]** | |

Heterogeneity: Tau$^2$ = 0.00; Chi$^2$ = 6.30, df = 7 (P = 0.51); I$^2$ = 0%
Test for overall effect: Z = 4.85 (P < 0.00001)

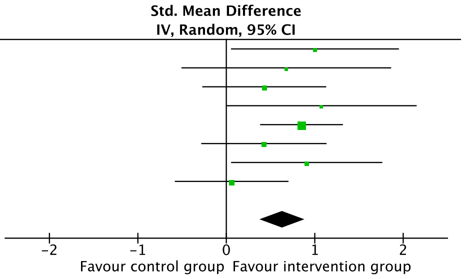


**Figure S4.** Pooled effect sizes on gait performance.

| | Experimental | | | Control | | | | Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| Study or Subgroup | Mean | SD | Total | Mean | SD | Total | Weight | IV, Random, 95% CI | Year |
| Chung 2013 | 5.42 | 5.61 | 8 | 5.48 | 6.8 | 8 | 18.0% | −0.06 [−6.17, 6.05] | 2013 |
| Jung 2014 | 5 | 11.77 | 9 | 2.6 | 7.52 | 8 | 11.0% | 2.40 [−6.89, 11.69] | 2014 |
| Haruyama 2016 | 13.67 | 23.05 | 16 | 1.33 | 25.19 | 16 | 4.3% | 12.34 [−4.39, 29.07] | 2016 |
| Shin 2016 | 9.71 | 4.46 | 12 | 2.18 | 1.13 | 12 | 29.9% | 7.53 [4.93, 10.13] | 2016 |
| An 2017 | 4.11 | 2.24 | 15 | 2 | 3.05 | 14 | 32.0% | 2.11 [0.15, 4.07] | 2017 |
| Min 2020 | 11.69 | 21.27 | 19 | 18.32 | 28.07 | 19 | 4.8% | −6.63 [−22.47, 9.21] | 2020 |
| **Total (95% CI)** | | | **79** | | | **77** | **100.0%** | **3.40 [−0.32, 7.12]** | |

Heterogeneity: Tau$^2$ = 10.25; Chi$^2$ = 15.03, df = 5 (P = 0.01); I$^2$ = 67%
Test for overall effect: Z = 1.79 (P = 0.07)

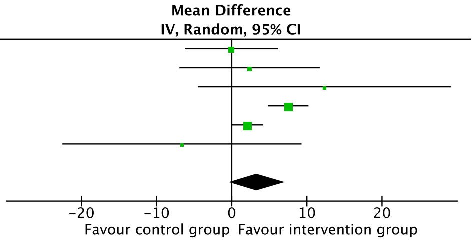
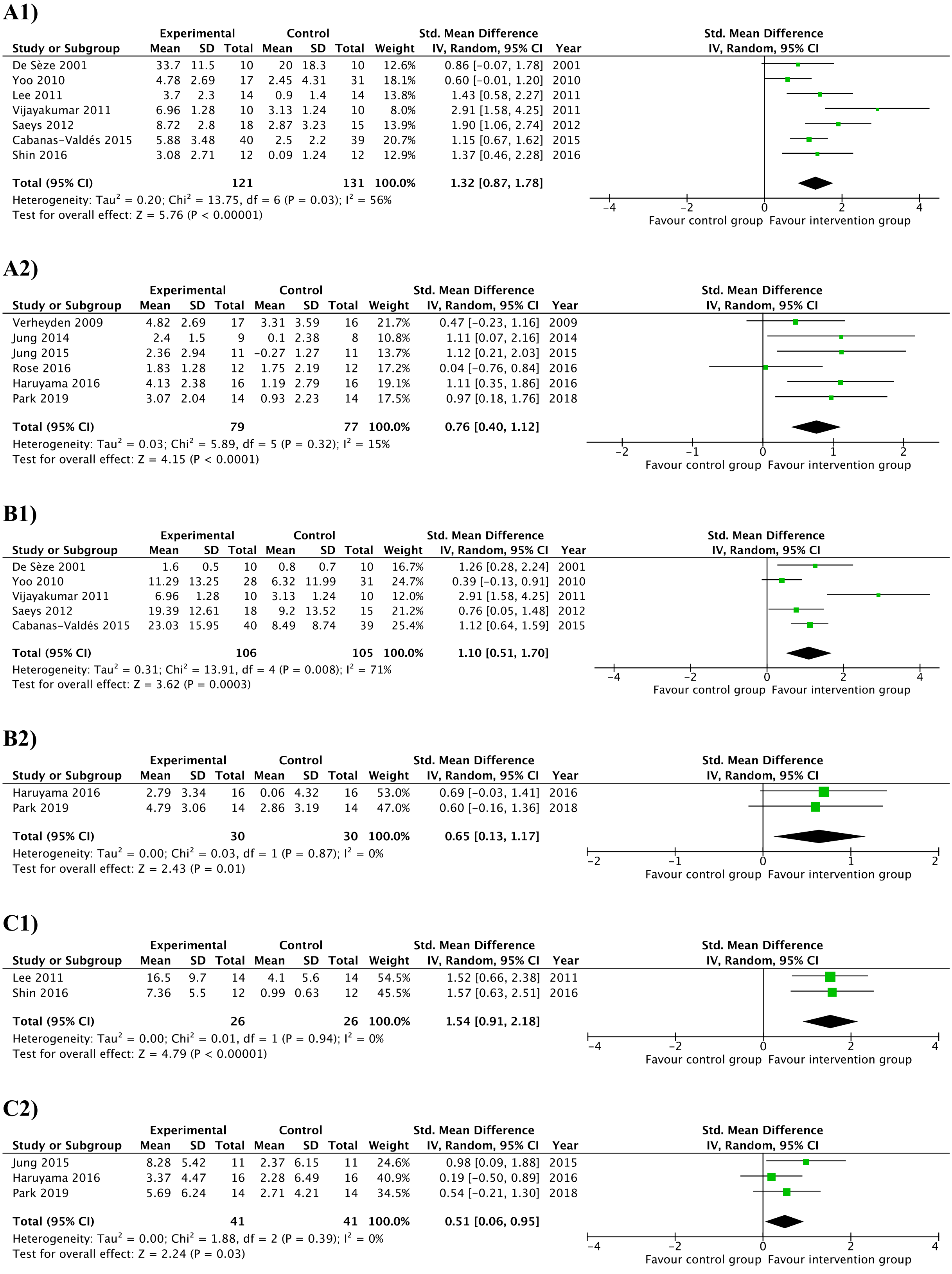


**Figure S5.** Pooled effect sizes on functional mobility.

## Subgroup analyses for the moderator variables analyzed



**A1)**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| De Sèze 2001 | 33.7 | 11.5 | 10 | 20 | 18.3 | 10 | 12.6% | 0.86 [−0.07, 1.78] | 2001 |
| Yoo 2010 | 4.78 | 2.69 | 17 | 2.45 | 4.31 | 31 | 18.1% | 0.60 [−0.01, 1.20] | 2010 |
| Lee 2011 | 3.7 | 2.3 | 14 | 0.9 | 1.4 | 14 | 13.8% | 1.43 [0.58, 2.27] | 2011 |
| Vijayakumar 2011 | 6.96 | 1.28 | 10 | 3.13 | 1.24 | 10 | 8.0% | 2.91 [1.58, 4.25] | 2011 |
| Saeys 2012 | 8.72 | 2.8 | 18 | 2.87 | 3.23 | 15 | 13.9% | 1.90 [1.06, 2.74] | 2012 |
| Cabanas-Valdés 2015 | 5.88 | 3.48 | 40 | 2.5 | 2.2 | 39 | 20.7% | 1.15 [0.67, 1.62] | 2015 |
| Shin 2016 | 3.08 | 2.71 | 12 | 0.09 | 1.24 | 12 | 12.9% | 1.37 [0.46, 2.28] | 2016 |
| **Total (95% CI)** | | | **121** | | | **131** | **100.0%** | **1.32 [0.87, 1.78]** | |

Heterogeneity: $Tau^2 = 0.20$; $Chi^2 = 13.75$, df = 6 (P = 0.03); $I^2 = 56\%$
Test for overall effect: Z = 5.76 (P < 0.00001)

**A2)**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| Verheyden 2009 | 4.82 | 2.69 | 17 | 3.31 | 3.59 | 16 | 21.7% | 0.47 [−0.23, 1.16] | 2009 |
| Jung 2014 | 2.4 | 1.5 | 9 | 0.1 | 2.38 | 8 | 10.8% | 1.11 [0.07, 2.16] | 2014 |
| Jung 2015 | 2.36 | 2.94 | 11 | −0.27 | 1.27 | 11 | 13.7% | 1.12 [0.21, 2.03] | 2015 |
| Rose 2016 | 1.83 | 1.28 | 12 | 1.75 | 2.19 | 12 | 17.2% | 0.04 [−0.76, 0.84] | 2016 |
| Haruyama 2016 | 4.13 | 2.38 | 16 | 1.19 | 2.79 | 16 | 19.1% | 1.11 [0.35, 1.86] | 2016 |
| Park 2019 | 3.07 | 2.04 | 14 | 0.93 | 2.23 | 14 | 17.5% | 0.97 [0.18, 1.76] | 2018 |
| **Total (95% CI)** | | | **79** | | | **77** | **100.0%** | **0.76 [0.40, 1.12]** | |

Heterogeneity: $Tau^2 = 0.03$; $Chi^2 = 5.89$, df = 5 (P = 0.32); $I^2 = 15\%$
Test for overall effect: Z = 4.15 (P < 0.0001)

**B1)**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| De Sèze 2001 | 1.6 | 0.5 | 10 | 0.8 | 0.7 | 10 | 16.7% | 1.26 [0.28, 2.24] | 2001 |
| Yoo 2010 | 11.29 | 13.25 | 28 | 6.32 | 11.99 | 31 | 24.7% | 0.39 [−0.13, 0.91] | 2010 |
| Vijayakumar 2011 | 6.96 | 1.28 | 10 | 3.13 | 1.24 | 10 | 12.0% | 2.91 [1.58, 4.25] | 2011 |
| Saeys 2012 | 19.39 | 12.61 | 18 | 9.2 | 13.52 | 15 | 21.2% | 0.76 [0.05, 1.48] | 2012 |
| Cabanas-Valdés 2015 | 23.03 | 15.95 | 40 | 8.49 | 8.74 | 39 | 25.4% | 1.12 [0.64, 1.59] | 2015 |
| **Total (95% CI)** | | | **106** | | | **105** | **100.0%** | **1.10 [0.51, 1.70]** | |

Heterogeneity: $Tau^2 = 0.31$; $Chi^2 = 13.91$, df = 4 (P = 0.008); $I^2 = 71\%$
Test for overall effect: Z = 3.62 (P = 0.0003)

**B2)**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| Haruyama 2016 | 2.79 | 3.34 | 16 | 0.06 | 4.32 | 16 | 53.0% | 0.69 [−0.03, 1.41] | 2016 |
| Park 2019 | 4.79 | 3.06 | 14 | 2.86 | 3.19 | 14 | 47.0% | 0.60 [−0.16, 1.36] | 2018 |
| **Total (95% CI)** | | | **30** | | | **30** | **100.0%** | **0.65 [0.13, 1.17]** | |

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.03$, df = 1 (P = 0.87); $I^2 = 0\%$
Test for overall effect: Z = 2.43 (P = 0.01)

**C1)**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| Lee 2011 | 16.5 | 9.7 | 14 | 4.1 | 5.6 | 14 | 54.5% | 1.52 [0.66, 2.38] | 2011 |
| Shin 2016 | 7.36 | 5.5 | 12 | 0.99 | 0.63 | 12 | 45.5% | 1.57 [0.63, 2.51] | 2016 |
| **Total (95% CI)** | | | **26** | | | **26** | **100.0%** | **1.54 [0.91, 2.18]** | |

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.01$, df = 1 (P = 0.94); $I^2 = 0\%$
Test for overall effect: Z = 4.79 (P < 0.00001)

**C2)**

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| Jung 2015 | 8.28 | 5.42 | 11 | 2.37 | 6.15 | 11 | 24.6% | 0.98 [0.09, 1.88] | 2015 |
| Haruyama 2016 | 3.37 | 4.47 | 16 | 2.28 | 6.49 | 16 | 40.9% | 0.19 [−0.50, 0.89] | 2016 |
| Park 2019 | 5.69 | 6.24 | 14 | 2.71 | 4.21 | 14 | 34.5% | 0.54 [−0.21, 1.30] | 2018 |
| **Total (95% CI)** | | | **41** | | | **41** | **100.0%** | **0.51 [0.06, 0.95]** | |

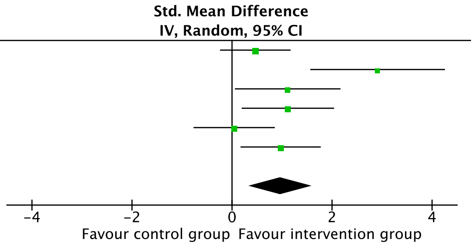
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 1.88$, df = 2 (P = 0.39); $I^2 = 0\%$
Test for overall effect: Z = 2.24 (P = 0.03)

**Figure S6.** Subgroup analyses by initial trunk impairment. (A1) Effect on trunk function for studies below the median; (A2) Effect on trunk function for studies over the median; (B1) Effect on balance ability for studies below the median; (B2) Effect on balance ability for studies over the median; (C1) Effect on limits of stability forward reach of the unaffected arm for studies below the median; (C2) Effect on limits of stability forward reach of the unaffected arm for studies over the median.

## A1)

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Verheyden 2009 | 4.82 | 2.69 | 17 | 3.31 | 3.59 | 16 | 19.6% | 0.47 [−0.23, 1.16] | 2009 |
| Vijayakumar 2011 | 6.96 | 1.28 | 10 | 3.13 | 1.24 | 10 | 12.0% | 2.91 [1.58, 4.25] | 2011 |
| Jung 2014 | 2.4 | 1.5 | 9 | 0.1 | 2.38 | 8 | 15.1% | 1.11 [0.07, 2.16] | 2014 |
| Jung 2015 | 2.36 | 2.94 | 11 | −0.27 | 1.27 | 11 | 16.7% | 1.12 [0.21, 2.03] | 2015 |
| Rose 2016 | 1.83 | 1.28 | 12 | 1.75 | 2.19 | 12 | 18.2% | 0.04 [−0.76, 0.84] | 2016 |
| Park 2019 | 3.07 | 2.04 | 14 | 0.93 | 2.23 | 14 | 18.3% | 0.97 [0.18, 1.76] | 2018 |
| **Total (95% CI)** | | | **73** | | | **71** | **100.0%** | **0.98 [0.35, 1.61]** | |

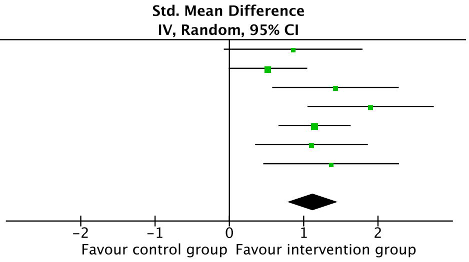
Heterogeneity: Tau$^2$ = 0.40; Chi$^2$ = 14.90, df = 5 (P = 0.01); I$^2$ = 66%
Test for overall effect: Z = 3.05 (P = 0.002)



## A2)

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 33.7 | 11.5 | 10 | 20 | 18.3 | 10 | 10.0% | 0.86 [−0.07, 1.78] | 2001 |
| Yoo 2010 | 4.78 | 4.55 | 28 | 2.45 | 4.31 | 31 | 20.7% | 0.52 [−0.00, 1.04] | 2010 |
| Lee 2011 | 3.7 | 2.3 | 14 | 0.9 | 1.4 | 14 | 11.5% | 1.43 [0.58, 2.27] | 2011 |
| Saeys 2012 | 8.72 | 2.8 | 18 | 2.87 | 3.23 | 15 | 11.5% | 1.90 [1.06, 2.74] | 2012 |
| Cabanas-Valdés 2015 | 5.88 | 3.48 | 40 | 2.5 | 2.2 | 39 | 22.4% | 1.15 [0.67, 1.62] | 2015 |
| Haruyama 2016 | 4.13 | 2.38 | 16 | 1.19 | 2.79 | 16 | 13.5% | 1.11 [0.35, 1.86] | 2016 |
| Shin 2016 | 3.08 | 2.71 | 12 | 0.09 | 1.24 | 12 | 10.4% | 1.37 [0.46, 2.28] | 2016 |
| **Total (95% CI)** | | | **138** | | | **137** | **100.0%** | **1.13 [0.79, 1.46]** | |

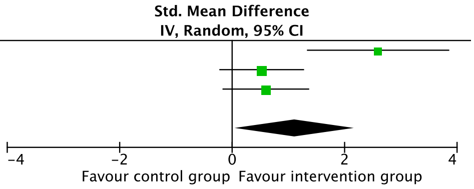
Heterogeneity: Tau$^2$ = 0.07; Chi$^2$ = 9.46, df = 6 (P = 0.15); I$^2$ = 37%
Test for overall effect: Z = 6.52 (P < 0.00001)



## B1)

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Vijayakumar 2011 | 7.1 | 0.88 | 10 | 4.4 | 1.1 | 10 | 27.4% | 2.60 [1.34, 3.85] | 2011 |
| An 2017 | 2.93 | 2.96 | 15 | 1.36 | 2.84 | 14 | 36.4% | 0.53 [−0.22, 1.27] | 2017 |
| Park 2019 | 4.79 | 3.06 | 14 | 2.86 | 3.19 | 14 | 36.1% | 0.60 [−0.16, 1.36] | 2018 |
| **Total (95% CI)** | | | **39** | | | **38** | **100.0%** | **1.12 [0.06, 2.18]** | |

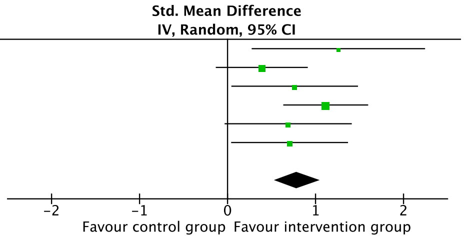
Heterogeneity: Tau$^2$ = 0.66; Chi$^2$ = 8.58, df = 2 (P = 0.01); I$^2$ = 77%
Test for overall effect: Z = 2.06 (P = 0.04)



## B2)

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 1.6 | 0.5 | 10 | 0.8 | 0.7 | 10 | 6.9% | 1.26 [0.28, 2.24] | 2001 |
| Yoo 2010 | 11.29 | 13.25 | 28 | 6.32 | 11.99 | 31 | 24.1% | 0.39 [−0.13, 0.91] | 2010 |
| Saeys 2012 | 19.39 | 12.61 | 18 | 9.2 | 13.52 | 15 | 12.9% | 0.76 [0.05, 1.48] | 2012 |
| Cabanas-Valdés 2015 | 23.03 | 15.95 | 40 | 8.49 | 8.74 | 39 | 28.2% | 1.12 [0.64, 1.59] | 2015 |
| Haruyama 2016 | 2.79 | 3.34 | 16 | 0.06 | 4.32 | 16 | 12.8% | 0.69 [−0.03, 1.41] | 2016 |
| Min 2020 | 7.36 | 3.63 | 19 | 4.42 | 4.49 | 19 | 15.1% | 0.71 [0.05, 1.36] | 2020 |
| **Total (95% CI)** | | | **131** | | | **130** | **100.0%** | **0.79 [0.53, 1.05]** | |

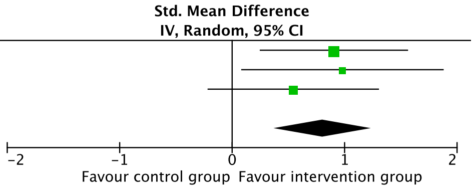
Heterogeneity: Tau$^2$ = 0.00; Chi$^2$ = 5.15, df = 5 (P = 0.40); I$^2$ = 3%
Test for overall effect: Z = 5.96 (P < 0.00001)



## C1)

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Kim 2011 | 4.6 | 5.54 | 20 | 0.1 | 4.1 | 20 | 43.8% | 0.91 [0.25, 1.56] | 2011 |
| Jung 2015 | 8.28 | 5.42 | 11 | 2.37 | 6.15 | 11 | 23.4% | 0.98 [0.09, 1.88] | 2015 |
| Park 2019 | 5.69 | 6.24 | 14 | 2.71 | 4.21 | 14 | 32.8% | 0.54 [−0.21, 1.30] | 2018 |
| **Total (95% CI)** | | | **45** | | | **45** | **100.0%** | **0.80 [0.37, 1.24]** | |

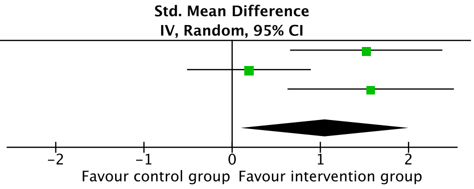
Heterogeneity: Tau$^2$ = 0.00; Chi$^2$ = 0.70, df = 2 (P = 0.71); I$^2$ = 0%
Test for overall effect: Z = 3.64 (P = 0.0003)



## C2)

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Lee 2011 | 16.5 | 9.7 | 14 | 4.1 | 5.6 | 14 | 32.8% | 1.52 [0.66, 2.38] | 2011 |
| Haruyama 2016 | 3.37 | 4.47 | 16 | 2.28 | 6.49 | 16 | 36.1% | 0.19 [−0.50, 0.89] | 2016 |
| Shin 2016 | 7.36 | 5.5 | 12 | 0.99 | 0.63 | 12 | 31.2% | 1.57 [0.63, 2.51] | 2016 |
| **Total (95% CI)** | | | **42** | | | **42** | **100.0%** | **1.06 [0.11, 2.01]** | |

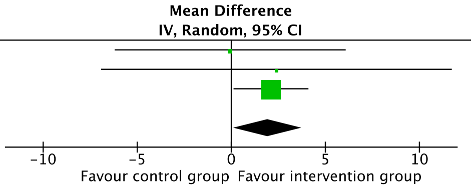
Heterogeneity: Tau$^2$ = 0.53; Chi$^2$ = 7.98, df = 2 (P = 0.02); I$^2$ = 75%
Test for overall effect: Z = 2.18 (P = 0.03)



**D1)**

| | Experimental | | | Control | | | | Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Chung 2013 | 5.42 | 5.61 | 8 | 5.48 | 6.8 | 8 | 9.0% | −0.06 [−6.17, 6.05] | 2013 |
| Jung 2014 | 5 | 11.77 | 9 | 2.6 | 7.52 | 8 | 3.9% | 2.40 [−6.89, 11.69] | 2014 |
| An 2017 | 4.11 | 2.24 | 15 | 2 | 3.05 | 14 | 87.2% | 2.11 [0.15, 4.07] | 2017 |
| **Total (95% CI)** | | | **32** | | | **30** | **100.0%** | **1.93 [0.10, 3.76]** | |

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.45$, df = 2 (P = 0.80); $I^2 = 0\%$
Test for overall effect: Z = 2.06 (P = 0.04)



**D2)**

| | Experimental | | | Control | | | | Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Haruyama 2016 | 13.67 | 23.05 | 16 | 1.33 | 25.19 | 16 | 17.2% | 12.34 [−4.39, 29.07] | 2016 |
| Shin 2016 | 9.71 | 4.46 | 12 | 2.18 | 1.13 | 12 | 64.2% | 7.53 [4.93, 10.13] | 2016 |
| Min 2020 | 11.69 | 21.27 | 19 | 18.32 | 28.07 | 19 | 18.6% | −6.63 [−22.47, 9.21] | 2020 |
| **Total (95% CI)** | | | **47** | | | **47** | **100.0%** | **5.72 [−2.27, 13.72]** | |

Heterogeneity: $Tau^2 = 24.14$; $Chi^2 = 3.35$, df = 2 (P = 0.19); $I^2 = 40\%$
Test for overall effect: Z = 1.40 (P = 0.16)

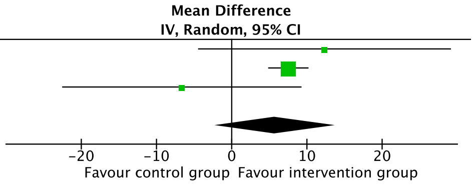


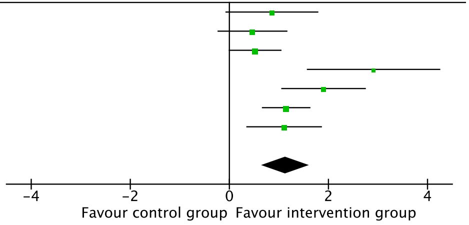
**Figure S7.** Subgroup analyses by participants' age. (A1) Effect on trunk function for studies below the median; (A2) Effect on trunk function for studies over the median; (B1) Effect on balance ability for studies below the median; (B2) Effect on balance ability for studies over the median (C1) Effect on limits of stability forward reach of the unaffected arm for studies below the median; (C2) Effect on limits of stability forward reach of the unaffected arm for studies over the median; (D1) Effects on functional mobility for studies below the median; (D2) Effects on functional mobility for studies over the median.

**A1)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 33.7 | 11.5 | 10 | 20 | 18.3 | 10 | 12.3% | 0.86 [−0.07, 1.78] | 2001 |
| Verheyden 2009 | 4.82 | 2.69 | 17 | 3.31 | 3.59 | 16 | 15.3% | 0.47 [−0.23, 1.16] | 2009 |
| Yoo 2010 | 4.78 | 4.55 | 28 | 2.45 | 4.31 | 31 | 17.9% | 0.52 [−0.00, 1.04] | 2010 |
| Vijayakumar 2011 | 6.96 | 1.28 | 10 | 3.13 | 1.24 | 10 | 8.2% | 2.91 [1.58, 4.25] | 2011 |
| Saeys 2012 | 8.72 | 2.8 | 18 | 2.87 | 3.23 | 15 | 13.3% | 1.90 [1.06, 2.74] | 2012 |
| Cabanas-Valdés 2015 | 5.88 | 3.48 | 40 | 2.5 | 2.2 | 39 | 18.5% | 1.15 [0.67, 1.62] | 2015 |
| Haruyama 2016 | 4.13 | 2.38 | 16 | 1.19 | 2.79 | 16 | 14.5% | 1.11 [0.35, 1.86] | 2016 |
| **Total (95% CI)** | | | **139** | | | **137** | **100.0%** | **1.13 [0.65, 1.61]** | |

Heterogeneity: Tau$^2$ = 0.26; Chi$^2$ = 18.35, df = 6 (P = 0.005); I$^2$ = 67%
Test for overall effect: Z = 4.64 (P < 0.00001)

**Std. Mean Difference**
**IV, Random, 95% CI**

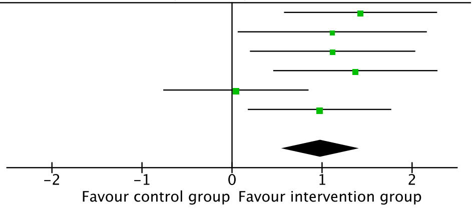


**A2)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Lee 2011 | 3.7 | 2.3 | 14 | 0.9 | 1.4 | 14 | 17.5% | 1.43 [0.58, 2.27] | 2011 |
| Jung 2014 | 2.4 | 1.5 | 9 | 0.1 | 2.38 | 8 | 12.9% | 1.11 [0.07, 2.16] | 2014 |
| Jung 2015 | 2.36 | 2.94 | 11 | −0.27 | 1.27 | 11 | 15.7% | 1.12 [0.21, 2.03] | 2015 |
| Shin 2016 | 3.08 | 2.71 | 12 | 0.09 | 1.24 | 12 | 15.9% | 1.37 [0.46, 2.28] | 2016 |
| Rose 2016 | 1.83 | 1.28 | 12 | 1.75 | 2.19 | 12 | 18.8% | 0.04 [−0.76, 0.84] | 2016 |
| Park 2019 | 3.07 | 2.04 | 14 | 0.93 | 2.23 | 14 | 19.1% | 0.97 [0.18, 1.76] | 2018 |
| **Total (95% CI)** | | | **72** | | | **71** | **100.0%** | **0.98 [0.55, 1.41]** | |

Heterogeneity: Tau$^2$ = 0.09; Chi$^2$ = 7.21, df = 5 (P = 0.21); I$^2$ = 31%
Test for overall effect: Z = 4.49 (P < 0.00001)

**Std. Mean Difference**
**IV, Random, 95% CI**

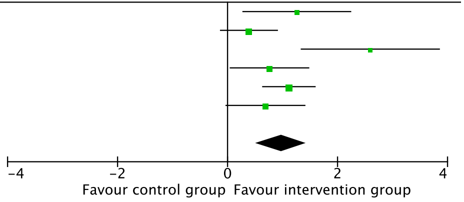


**B1)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 1.6 | 0.5 | 10 | 0.8 | 0.7 | 10 | 12.6% | 1.26 [0.28, 2.24] | 2001 |
| Yoo 2010 | 11.29 | 13.25 | 28 | 6.32 | 11.99 | 31 | 21.5% | 0.39 [−0.13, 0.91] | 2010 |
| Vijayakumar 2011 | 7.1 | 0.88 | 10 | 4.4 | 1.1 | 10 | 9.2% | 2.60 [1.34, 3.85] | 2011 |
| Saeys 2012 | 19.39 | 12.61 | 18 | 9.2 | 13.52 | 15 | 17.2% | 0.76 [0.05, 1.48] | 2012 |
| Cabanas-Valdés 2015 | 23.03 | 15.95 | 40 | 8.49 | 8.74 | 39 | 22.4% | 1.12 [0.64, 1.59] | 2015 |
| Haruyama 2016 | 2.79 | 3.34 | 16 | 0.06 | 4.32 | 16 | 17.2% | 0.69 [−0.03, 1.41] | 2016 |
| **Total (95% CI)** | | | **122** | | | **121** | **100.0%** | **0.98 [0.52, 1.44]** | |

Heterogeneity: Tau$^2$ = 0.18; Chi$^2$ = 12.55, df = 5 (P = 0.03); I$^2$ = 60%
Test for overall effect: Z = 4.20 (P < 0.0001)

**Std. Mean Difference**
**IV, Random, 95% CI**

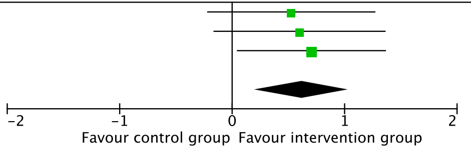


**B2)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| An 2017 | 2.93 | 2.96 | 15 | 1.36 | 2.84 | 14 | 30.9% | 0.53 [−0.22, 1.27] | 2017 |
| Park 2019 | 4.79 | 3.06 | 14 | 2.86 | 3.19 | 14 | 29.6% | 0.60 [−0.16, 1.36] | 2018 |
| Min 2020 | 7.36 | 3.63 | 19 | 4.42 | 4.49 | 19 | 39.5% | 0.71 [0.05, 1.36] | 2020 |
| **Total (95% CI)** | | | **48** | | | **47** | **100.0%** | **0.62 [0.21, 1.03]** | |

Heterogeneity: Tau$^2$ = 0.00; Chi$^2$ = 0.13, df = 2 (P = 0.94); I$^2$ = 0%
Test for overall effect: Z = 2.93 (P = 0.003)

**Std. Mean Difference**
**IV, Random, 95% CI**

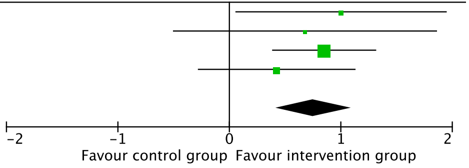


**C1)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 2.2 | 1 | 10 | 1.1 | 1.1 | 10 | 13.1% | 1.00 [0.06, 1.94] | 2001 |
| Dean 2007 | 0.41 | 0.35 | 6 | 0.21 | 0.16 | 6 | 8.4% | 0.68 [−0.50, 1.86] | 2007 |
| Cabanas-Valdés 2015 | 5.57 | 3.97 | 40 | 2.62 | 2.78 | 39 | 54.8% | 0.85 [0.39, 1.31] | 2015 |
| Haruyama 2016 | 0.5 | 0.81 | 16 | 0.12 | 0.93 | 16 | 23.7% | 0.42 [−0.28, 1.13] | 2016 |
| **Total (95% CI)** | | | **72** | | | **71** | **100.0%** | **0.76 [0.41, 1.10]** | |

Heterogeneity: Tau$^2$ = 0.00; Chi$^2$ = 1.30, df = 3 (P = 0.73); I$^2$ = 0%
Test for overall effect: Z = 4.33 (P < 0.0001)

**Std. Mean Difference**
**IV, Random, 95% CI**



**C2)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Chung 2013 | 14.08 | 13.9 | 8 | −0.3 | 11.24 | 8 | 24.9% | 1.08 [0.01, 2.15] | 2013 |
| Shin 2020 | 0.17 | 0.15 | 12 | 0.05 | 0.1 | 12 | 32.6% | 0.91 [0.06, 1.76] | 2019 |
| Min 2020 | 0.36 | 0.58 | 19 | 0.32 | 0.71 | 19 | 42.5% | 0.06 [−0.58, 0.70] | 2020 |
| **Total (95% CI)** | | | **39** | | | **39** | **100.0%** | **0.59 [−0.08, 1.26]** | |

Heterogeneity: Tau$^2$ = 0.17; Chi$^2$ = 3.84, df = 2 (P = 0.15); I$^2$ = 48%
Test for overall effect: Z = 1.74 (P = 0.08)

**Std. Mean Difference**
**IV, Random, 95% CI**

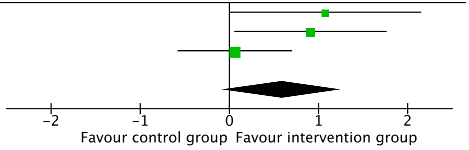
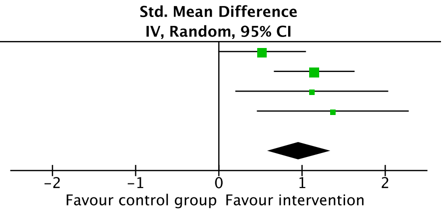


**Figure S8.** Subgroup analyses by the start of the intervention after the stroke-onset. (A1) Effect on trunk function for studies below the median; (A2) Effect on trunk function for studies over the median; (B1) Effect on balance ability for studies below the median; (B2) Effect on balance ability for studies over the median; (C1) Effect on gait performance for studies below the median; (C2) Effect on gait performance for studies over the median.

**A1)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Yoo 2010 | 4.78 | 4.55 | 28 | 2.45 | 4.31 | 31 | 33.4% | 0.52 [−0.00, 1.04] | 2010 |
| Cabanas-Valdés 2015 | 5.88 | 3.48 | 40 | 2.5 | 2.2 | 39 | 36.9% | 1.15 [0.67, 1.62] | 2015 |
| Jung 2015 | 2.36 | 2.94 | 11 | −0.27 | 1.27 | 11 | 14.8% | 1.12 [0.21, 2.03] | 2015 |
| Shin 2016 | 3.08 | 2.71 | 12 | 0.09 | 1.24 | 12 | 14.9% | 1.37 [0.46, 2.28] | 2016 |
| **Total (95% CI)** | | | **91** | | | **93** | **100.0%** | **0.97 [0.58, 1.35]** | |

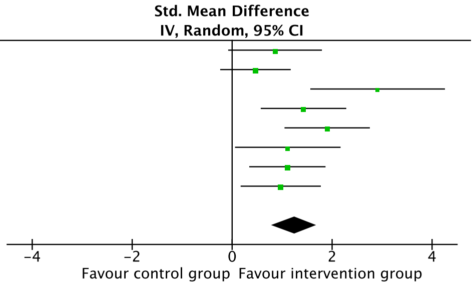
Heterogeneity: Tau$^2$ = 0.05; Chi$^2$ = 4.24, df = 3 (P = 0.24); I$^2$ = 29%
Test for overall effect: Z = 4.91 (P < 0.00001)



**A2)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 33.7 | 11.5 | 10 | 20 | 18.3 | 10 | 11.9% | 0.86 [−0.07, 1.78] | 2001 |
| Verheyden 2009 | 4.82 | 2.69 | 17 | 3.31 | 3.59 | 16 | 15.4% | 0.47 [−0.23, 1.16] | 2009 |
| Vijayakumar 2011 | 6.96 | 1.28 | 10 | 3.13 | 1.24 | 10 | 7.6% | 2.91 [1.58, 4.25] | 2011 |
| Lee 2011 | 3.7 | 2.3 | 14 | 0.9 | 1.4 | 14 | 13.1% | 1.43 [0.58, 2.27] | 2011 |
| Saeys 2012 | 8.72 | 2.8 | 18 | 2.87 | 3.23 | 15 | 13.1% | 1.90 [1.06, 2.74] | 2012 |
| Jung 2014 | 2.4 | 1.5 | 9 | 0.1 | 2.38 | 8 | 10.4% | 1.11 [0.07, 2.16] | 2014 |
| Haruyama 2016 | 4.13 | 2.38 | 16 | 1.19 | 2.79 | 16 | 14.5% | 1.11 [0.35, 1.86] | 2016 |
| Park 2019 | 3.07 | 2.04 | 14 | 0.93 | 2.23 | 14 | 13.9% | 0.97 [0.18, 1.76] | 2018 |
| **Total (95% CI)** | | | **108** | | | **103** | **100.0%** | **1.24 [0.80, 1.69]** | |

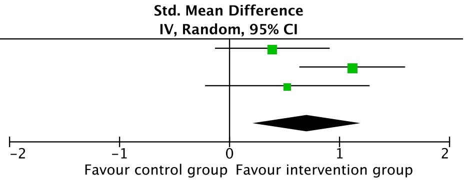
Heterogeneity: Tau$^2$ = 0.21; Chi$^2$ = 14.46, df = 7 (P = 0.04); I$^2$ = 52%
Test for overall effect: Z = 5.50 (P < 0.00001)



**B1)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Yoo 2010 | 11.29 | 13.25 | 28 | 6.32 | 11.99 | 31 | 36.2% | 0.39 [−0.13, 0.91] | 2010 |
| Cabanas-Valdés 2015 | 23.03 | 15.95 | 40 | 8.49 | 8.74 | 39 | 38.5% | 1.12 [0.64, 1.59] | 2015 |
| An 2017 | 2.93 | 2.96 | 15 | 1.36 | 2.84 | 14 | 25.3% | 0.53 [−0.22, 1.27] | 2017 |
| **Total (95% CI)** | | | **83** | | | **84** | **100.0%** | **0.70 [0.21, 1.19]** | |

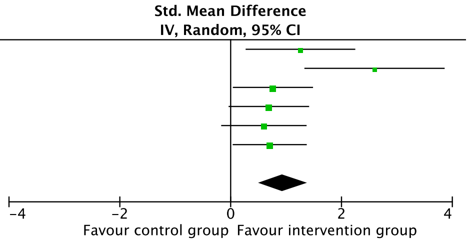
Heterogeneity: Tau$^2$ = 0.10; Chi$^2$ = 4.49, df = 2 (P = 0.11); I$^2$ = 55%
Test for overall effect: Z = 2.82 (P = 0.005)



**B2)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| De Sèze 2001 | 1.6 | 0.5 | 10 | 0.8 | 0.7 | 10 | 13.3% | 1.26 [0.28, 2.24] | 2001 |
| Vijayakumar 2011 | 7.1 | 0.88 | 10 | 4.4 | 1.1 | 10 | 9.4% | 2.60 [1.34, 3.85] | 2011 |
| Saeys 2012 | 19.39 | 12.61 | 18 | 9.2 | 13.52 | 15 | 19.3% | 0.76 [0.05, 1.48] | 2012 |
| Haruyama 2016 | 2.79 | 3.34 | 16 | 0.06 | 4.32 | 16 | 19.2% | 0.69 [−0.03, 1.41] | 2016 |
| Park 2019 | 4.79 | 3.06 | 14 | 2.86 | 3.19 | 14 | 18.0% | 0.60 [−0.16, 1.36] | 2018 |
| Min 2020 | 7.36 | 3.63 | 19 | 4.42 | 4.49 | 19 | 20.8% | 0.71 [0.05, 1.36] | 2020 |
| **Total (95% CI)** | | | **87** | | | **84** | **100.0%** | **0.95 [0.50, 1.39]** | |

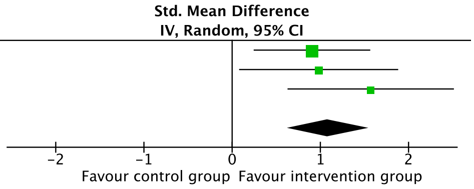
Heterogeneity: Tau$^2$ = 0.13; Chi$^2$ = 8.94, df = 5 (P = 0.11); I$^2$ = 44%
Test for overall effect: Z = 4.20 (P < 0.0001)



**C1)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Kim 2011 | 4.6 | 5.54 | 20 | 0.1 | 4.1 | 20 | 49.5% | 0.91 [0.25, 1.56] | 2011 |
| Jung 2015 | 8.28 | 5.42 | 11 | 2.37 | 6.15 | 11 | 26.4% | 0.98 [0.09, 1.88] | 2015 |
| Shin 2016 | 7.36 | 5.5 | 12 | 0.99 | 0.63 | 12 | 24.1% | 1.57 [0.63, 2.51] | 2016 |
| **Total (95% CI)** | | | **43** | | | **43** | **100.0%** | **1.09 [0.63, 1.55]** | |

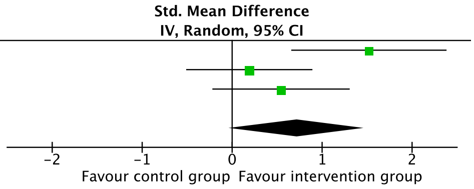
Heterogeneity: Tau$^2$ = 0.00; Chi$^2$ = 1.38, df = 2 (P = 0.50); I$^2$ = 0%
Test for overall effect: Z = 4.63 (P < 0.00001)



**C2)**

| | Experimental | | | Control | | | | Std. Mean Difference | |
|---|---|---|---|---|---|---|---|---|---|
| **Study or Subgroup** | **Mean** | **SD** | **Total** | **Mean** | **SD** | **Total** | **Weight** | **IV, Random, 95% CI** | **Year** |
| Lee 2011 | 16.5 | 9.7 | 14 | 4.1 | 5.6 | 14 | 30.7% | 1.52 [0.66, 2.38] | 2011 |
| Haruyama 2016 | 3.37 | 4.47 | 16 | 2.28 | 6.49 | 16 | 35.6% | 0.19 [−0.50, 0.89] | 2016 |
| Park 2019 | 5.69 | 6.24 | 14 | 2.71 | 4.21 | 14 | 33.7% | 0.54 [−0.21, 1.30] | 2018 |
| **Total (95% CI)** | | | **44** | | | **44** | **100.0%** | **0.72 [−0.03, 1.47]** | |

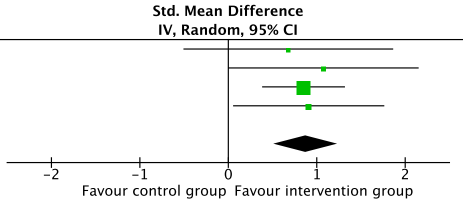
Heterogeneity: Tau$^2$ = 0.28; Chi$^2$ = 5.72, df = 2 (P = 0.06); I$^2$ = 65%
Test for overall effect: Z = 1.88 (P = 0.06)



## D1)

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| Dean 2007 | 0.41 | 0.35 | 6 | 0.21 | 0.16 | 6 | 9.4% | 0.68 [−0.50, 1.86] | 2007 |
| Chung 2013 | 14.08 | 13.9 | 8 | −0.3 | 11.24 | 8 | 11.4% | 1.08 [0.01, 2.15] | 2013 |
| Cabanas-Valdés 2015 | 5.57 | 3.97 | 40 | 2.62 | 2.78 | 39 | 61.1% | 0.85 [0.39, 1.31] | 2015 |
| Shin 2020 | 0.17 | 0.15 | 12 | 0.05 | 0.1 | 12 | 18.1% | 0.91 [0.06, 1.76] | 2019 |
| **Total (95% CI)** | | | **66** | | | **65** | **100.0%** | **0.87 [0.51, 1.23]** | |

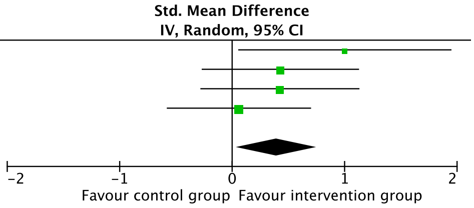
Heterogeneity: Tau² = 0.00; Chi² = 0.26, df = 3 (P = 0.97); I² = 0%
Test for overall effect: Z = 4.73 (P < 0.00001)



## D2)

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Std. Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| De Sèze 2001 | 2.2 | 1 | 10 | 1.1 | 1.1 | 10 | 14.6% | 1.00 [0.06, 1.94] | 2001 |
| Saeys 2012 | 2.45 | 1.31 | 18 | 1.86 | 1.38 | 15 | 26.9% | 0.43 [−0.27, 1.12] | 2012 |
| Haruyama 2016 | 0.5 | 0.81 | 16 | 0.12 | 0.93 | 16 | 26.4% | 0.42 [−0.28, 1.13] | 2016 |
| Min 2020 | 0.36 | 0.58 | 19 | 0.32 | 0.71 | 19 | 32.1% | 0.06 [−0.58, 0.70] | 2020 |
| **Total (95% CI)** | | | **63** | | | **60** | **100.0%** | **0.39 [0.03, 0.75]** | |

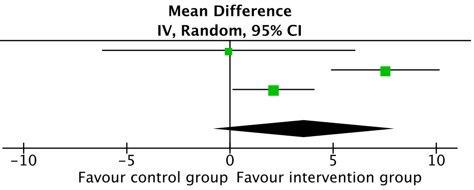
Heterogeneity: Tau² = 0.00; Chi² = 2.67, df = 3 (P = 0.44); I² = 0%
Test for overall effect: Z = 2.14 (P = 0.03)



## E1)

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| Chung 2013 | 5.42 | 5.61 | 8 | 5.48 | 6.8 | 8 | 23.4% | −0.06 [−6.17, 6.05] | 2013 |
| Shin 2016 | 9.71 | 4.46 | 12 | 2.18 | 1.13 | 12 | 37.2% | 7.53 [4.93, 10.13] | 2016 |
| An 2017 | 4.11 | 2.24 | 15 | 2 | 3.05 | 14 | 39.4% | 2.11 [0.15, 4.07] | 2017 |
| **Total (95% CI)** | | | **35** | | | **34** | **100.0%** | **3.62 [−0.78, 8.01]** | |

Heterogeneity: Tau² = 11.78; Chi² = 12.28, df = 2 (P = 0.002); I² = 84%
Test for overall effect: Z = 1.61 (P = 0.11)



## E2)

| Study or Subgroup | Experimental Mean | Experimental SD | Experimental Total | Control Mean | Control SD | Control Total | Weight | Mean Difference IV, Random, 95% CI | Year |
|---|---|---|---|---|---|---|---|---|---|
| Jung 2014 | 5 | 11.77 | 9 | 2.6 | 7.52 | 8 | 52.9% | 2.40 [−6.89, 11.69] | 2014 |
| Haruyama 2016 | 13.67 | 23.05 | 16 | 1.33 | 25.19 | 16 | 22.5% | 12.34 [−4.39, 29.07] | 2016 |
| Min 2020 | 11.69 | 21.27 | 19 | 18.32 | 28.07 | 19 | 24.6% | −6.63 [−22.47, 9.21] | 2020 |
| **Total (95% CI)** | | | **44** | | | **43** | **100.0%** | **2.41 [−6.29, 11.11]** | |

Heterogeneity: Tau² = 14.80; Chi² = 2.61, df = 2 (P = 0.27); I² = 23%
Test for overall effect: Z = 0.54 (P = 0.59)

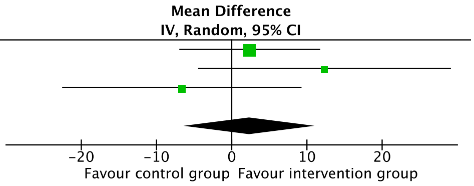


**Figure S9.** Subgroup analyses by total volume (minutes) of the additional trunk exercise programs. (A1) Effect on trunk function for studies below the median; (A2) Effect on trunk function for studies over the median; (B1) Effect on balance ability for studies below the median; (B2) Effect on balance ability for studies over the median; (C1) Effect on limits of stability forward reach of the unaffected arm for studies below the median; (C2) Effect on limits of stability forward reach of the unaffected arm for studies over the median; (D1) Effects on gait performance for studies below the median; (D2) Effects on gait performance for studies over the median; (E1) Effects on functional mobility for studies below the median; (E2) Effects on functional mobility for studies over the median.

**Table S2.** PEDro scale to assess methodological quality.

| | **Eligibility criteria specified** | **Subjects random allocation** | **Concealed allocation** | **Similar groups baseline** | **Subjects blinding** | **Therapists blinding** | **Assessors blinding** | **Outcome measurement in 85% of the subjects initially allocated** | **Intention to treat** | **Between-group statistical comparison** | **Point measures and variability** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DeSèze et al., 2001 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Howe et al., 2005 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✗ |
| Dean et al., 2007 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Verheyden et al., 2009 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Yoo et al., 2010 | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ? | ? | ✓ | ✗ |
| Kim et al., 2011 | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✗ |
| Vijayakumar et al., 2011 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ? | ? | ✓ | ✗ |
| Lee et al., 2011 | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ |
| Saeys et al., 2012 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Chung et al., 2013 | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Jung et al., 2014 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✗ |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cabanas-Valdés et al., 2015 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ |
| Jung et al., 2015 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Haruyama et al., 2016 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ |
| Shin et al., 2016 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Rose et al., 2016 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ |
| An et al., 2017 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ? | ✓ | ✗ | ✓ | ✓ |
| Park et al., 2019 | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ | ✓ | ✗ |
| Min et al., 2020 | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |

**Table S3.** Quality of evidence (GRADE approach) between additional trunk-focused exercises vs conventional rehabilitation.

| *№ of studies* | *Study design* | *Risk of bias (PEDro)* | *Inconsistency* | *Indirectness* | *Imprecision* | *Publication bias* | *Sample Experimental group* | *Sample Control group* | *Pooled effect size (95% CI)* | *Certainity* | *Importance* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Trunk function*** | | | | | | | | | | | |
| *13* | randomised trials | serious [a] | serious [b] | serious [c] | not serious | none | 211 | 208 | SMD **1.06 SD higher**<br>(0.74 higher to 1.37 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Balance ability*** | | | | | | | | | | | |
| *9* | randomised trials | serious [a] | not serious | serious [c] | not serious | none | 170 | 168 | SMD **0.83 SD higher**<br>(0.52 higher to 1.14 higher) | ⊕⊕◯◯<br>LOW | CRITICAL |
| ***Limits of stability - Forward unaffected*** | | | | | | | | | | | |
| *6* | randomised trials | serious [a] | not serious | serious [c] | serious [d] | none | 87 | 87 | SMD **0.9 SD higher**<br>(0.47 higher to 1.33 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Limits of stability - Lateral unaffected*** | | | | | | | | | | | |
| *4* | randomised trials | serious [a] | not serious | serious [c] | serious [d] | none | 52 | 55 | SMD **1.16 SD higher**<br>(0.67 higher to 1.66 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Limits of stability - Lateral affected*** | | | | | | | | | | | |
| *3* | randomised trials | serious [a] | not serious | not serious | serious [d] | none | 37 | 37 | SMD **0.89 SD higher**<br>(0.26 higher to 1.52 higher) | ⊕⊕◯◯<br>LOW | CRITICAL |
| ***Gait performance*** | | | | | | | | | | | |
| *8* | randomised trials | not serious | not serious | serious [c] | serious [d] | none | 129 | 125 | SMD **0.63 SD higher**<br>(0.38 higher to 0.89 higher) | ⊕⊕◯◯<br>LOW | CRITICAL |
| ***Functional mobility*** | | | | | | | | | | | |
| *6* | randomised trials | serious [a] | serious [b] | not serious | very serious [d, e] | none | 79 | 77 | MD **3.4 higher**<br>(-0.32 lower to 7.12 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |

**Abbreviations.** PEDro: Physiotherapy Evidence Database Scale; CI: Confidence interval; SMD: Standardized mean difference; MD: Weighted Mean difference; $I^2$: Inconsistency Statistic;

a. Downgraded one level since at least two studies scored ≤6 on the PEDro scale.

b. Downgraded one level due to an Inconsistency statistic ($I^2$) ≥ 50%.

c. Downgraded one level because different test/scales were employed to measure the outcome.

d. Downgraded one level due to a sample with less than 300 participants.

e. Downgraded one level due to large confidence intervals (Includes the 0-Hypothesis).

**Table S4.** PRISMA checklist.

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review, meta-analysis, or both. | Initial page |
| **ABSTRACT** | | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | Initial page |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | 2 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). | 2 |
| **METHODS** | | | |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | 2 |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | 3 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | 2-3 |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | Table S1 |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | Figure 1 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | 3-4 |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | 3-4 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | 4 |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | 4 |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | 4 |
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | 4 |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | 4 |
| **RESULTS** | | | |

| | | | |
|---|---|---|---|
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | Figure 1 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | Table 1 |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | Table 1 and Table S2 |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | Tables 2-4 and figures S1-9 |
| Synthesis of results | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | 14-17 |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | 14 and<br>table S3 |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | Table 4 |
| **DISCUSSION** | | | |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | 17-18 |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 18-19 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 19 |
| **FUNDING** | | | |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | 19 |

# APPENDIX 2

## STUDY 2

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# Effect of trunk-focused exercises on pain, disability, quality of life and trunk physical fitness in low back pain and how potential effect modifiers modulate their effects: systematic review with meta-analyses

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Note. This study is accepted in the *Journal of Orthopaedic & Sports Physical Therapy*

Prat-Luri A, de los Rios-Calonge J, Moreno-Navarro P, Manresa-Rocamora A, Vera-Garcia, FJ, Barbado D. Effect of trunk-focused exercises on pain, disability, quality of life and trunk physical fitness in low back pain and how potential effect modifiers modulate their effects:  systematic review with meta-analyses.

## 8.2. Appendix 2

### 8.2.1. Study 2. Effect of trunk-focused exercises on pain, disability, quality of life and trunk physical fitness in low back pain and how potential effect modifiers modulate their effects: systematic review with meta-analyses.

### ABSTRACT

**Objective.** To analyze the effect of trunk-focused exercise programs (TEPs) and moderator factors on chronic non-specific low back pain (LBP).

**Design.** Systematic review with meta-analyses.

**Literature search.** We searched the PubMed, Scopus, EMBASE, SPORTDiscus, and CENTRAL databases until June 2022.

**Study selection criteria.** We included randomized controlled trials comparing TEPs to control or general exercises.

**Data synthesis.** We used random effects models to calculate the standardized mean difference (SMD) plus confidence interval (CI), and heterogeneity (I2) for pain, disability, quality of life, and trunk performance. The impact of moderator factors was analyzed through meta-regression.

**Results.** Forty randomized controlled trials (n=2391) were included. TEPs showed positive effects for all outcomes vs control (SMD 0.90 to 2.46, 95% CI: -0.04 to 4.96, I2 61% to 98%). There were small effects in favor of TEPs vs general exercises for pain (SMD=0.20; 95% CI: 0.03 to 0.37, I2=13.4%) and disability (SMD=0.20; 95% CI: 0.02 to 0.38, I2=0%). Trunk and/or hip range of motion improvements were associated with greater reductions in pain ($p<.01$, $\beta=0.56$, 95% CI: 0.25 to 0.87) and disability ($p<.01$, $\beta=0.66$, 95% CI: 0.27 to 1.05). Low body mass was associated with higher pain reduction ($p=.03$, $\beta$ -0.17, 95% CI: -0.32 to -0.02).

**Conclusions.** TEPs had positive effects on pain, disability, quality of life and trunk performance compared to control exercises, and on pain and disability compared to general exercises. Increasing trunk and/or hip range of motion was associated with greater pain and disability reduction, and lower body mass with higher pain reduction.

**Keywords:** *Core stability, moderator factors, rehabilitation, prognostic factors.*

## INTRODUCTION

Physical exercise confers greater benefits than no intervention, minimal intervention (e.g., counseling sessions, educational), *hands-off* (e.g., ultrasound) or *hands-on* treatments (e.g., massage, manipulative therapy) for low back pain (LBP).[39,41,50,56,57] Trunk-focused exercise programs (TEPs)—programs that target the trunk/core active and/or associated passive structures—are one of the most common exercise therapies.[58] TEPs mainly target trunk strength, endurance and range of motion, which are common impairments in people with LBP.[32,35,47,53] Previous reviews have observed that motor control, core stability and Pilates programs are superior to no intervention, minimal intervention and *hands on-off* treatments for improving pain and disability.[6,9,12,41,44,45,52,56,58] Although the evidence is not as conclusive, it appears that these types of exercise programs are among the most effective exercise interventions.[26,50]

The real impact of TEPs, and how these programs should be tailored to maximize their benefits remains uncertain. Problems with study design and intervention content are common. Some studies compared TEPs to exercises that targeted the trunk,[1,15,55,59] or were considered 'trunk-focused'.[62,64] Other interventions supporting the efficacy of TEPs were multicomponent interventions that also included other physical and/or education components.[14,18,30,40,46]

Our review focused on identifying exercise programs that fit the definition for trunk-focused (i.e., targeting the trunk/core structures as the main area of interest), and that they were compared to (a) no intervention, minimal intervention, or hands *on-off* treatments, or (b) exercise interventions in which the trunk structures were not the primary focus. We aimed to (i) assess the effect of TEPs on pain, disability, and quality of life (QoL) in people with non-specific chronic LBP, and (ii) how moderator factors related to the training programs and patient characteristics modulated their effects. Although poor trunk physical fitness may predict LBP,[7,8,54] how TEPs improve these physical fitness has rarely been analyzed.[50] Therefore, we were also interested in assessing the effect of TEPs on trunk strength, endurance and range of motion.

## METHOD

This review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[42] and registered in the PROSPERO database (registration number: CRD42019122865). Data are available upon request.

### Protocol deviations

The following changes were made to the registered protocol: 1) inclusion of more databases in the search strategy; 2) comparison of TEPs effects against general exercise programs (GEPs); 3) analysis of moderator factors.

### Study selection

Included studies had to meet the following criteria: 1) studied participants with chronic non-specific LBP (including recurrent LBP);[61] 2) Randomized controlled trials (RCTs); 3) studied young or middle-aged adult participants (18-65 years); 4) an experimental group performed a TEP (i.e., a program consisting mainly of exercises that, due to their execution description, names and/or the authors' indication, targeted the trunk/core structures as the main interest area) and a second group received no intervention, minimal intervention or *hands-on/off* treatments (from now on referred to as control group, CG) or another type of exercise intervention not focused on the trunk/core structures (General exercise programs: GEPs e.g., general strengthening, balance exercises, walking exercise); 5) the exercise program duration was 4 weeks or longer; 6) the training sessions were supervised at least once per week; 7) there were pre- and immediate post-intervention assessments of pain, disability, QoL or trunk physical fitness; 8) written in English, Spanish, French and Italian.

If there was a specific injury/disease that caused the LBP, the trial was excluded; but if the method section did not specify the LBP origin, it was considered to be non-specific LBP. Articles were also excluded if: i) participants were athletes, ii) the pain duration was shorter than 12 weeks,[65] iii) TEPs were delivered in addition to another intervention, iv) they carried out yoga interventions (it is difficult to categorize yoga as TEPs or as general exercise programs (GEPs) as they focus mainly on whole-body balance rather than on the trunk/core structures. Records were excluded if the GEPs comprised more than 25% of trunk exercises. When data to estimate their effect sizes was not provided or it was presented in graphs, an email was sent to the corresponding author. If a response was not obtained, data were estimated using the *rule of three*.[36] If this was not possible, the article was excluded. Two reviewers (A.P & J.R.) independently: (i) screened the articles, and (ii) completed the data extraction and risk of bias assessment of included articles. In case of disagreement, a third reviewer (D.B.) was consulted.

### *Data sources and searches*

A Boolean search strategy was employed and adapted to each of the databases (PubMed, Scopus, EMBASE, SPORTDiscus and CENTRAL) (**TABLE S4**). To ensure the minimal loss of potential trials, a complementary manual search of the reference lists of the systematic reviews on the topic was carried out (see supplemental material for more details). The search was limited until June 2022.

### *Data extraction*

Data were extracted and registered in a specific codebook. The intra-class correlation coefficient ($ICC_{3.1}$), and the prevalence- and bias-adjusted Cohen's kappa coefficient were calculated to analyze reliability between coders of quantitative and qualitative variables, respectively.[20,48] The values obtained in both $ICC_{3.1}$ (0.98; range: 0.98-0.99) and Cohen's kappa coefficient (0.80; range: 0.60-0.95) were highly satisfactory.[34,38]

The outcomes assessed were pain, disability, QoL, trunk strength, trunk extension endurance and trunk and/or hip range of motion ($TH_{ROM}$). Pain, disability and QoL were assessed with questionnaires. Trunk strength was generally measured through isometric and isokinetic dynamometer tests, while trunk extension endurance was assessed using isometric tests. Finally, $TH_{ROM}$ was assessed through different trunk or trunk and hip range of motion tests.

### *Data synthesis*

The mean and standard deviation of the changes scores for each outcomes were noted. If the studies did not provide these data, the mean change was calculated from the pre- and post-mean. The standard deviation of the changes was calculated using a conservative $r$ value equal to 0.5.[2,13] If a trial presented two experimental groups that matched the inclusion criteria, the CG sample was divided into two to use each half with each of the experimental groups.[29] In those cases, the groups from the same trial were categorized as A and B. The effect size, standard error, and confidence intervals at 95% were calculated for each trial. To avoid an overestimated effect size bias, a correction factor [$c(gl) = 1-(3/((4*n)-9))$] was employed.[5]

The potential influence of the following moderator factors on the trial outcomes was analyzed: 1) participants' age (years), 2) body mass index (BMI) ($kg/m^2$), 3) pain duration (months), 4) initial pain level (%), 5) initial disability level (%), 6) total training volume (minutes), and 7) $TH_{ROM}$ improvement [standardized mean differences (SMD) caused by TEPs]. The initial levels of pain and disability were calculated from the pre-test scores and converted to relative scores (%) because different scales were used. The total training volume was calculated from the number of weeks of the exercise programs, the training frequency, and the duration of each session. When additional home-exercises were performed, their volume was added to the total volume if it was well described, otherwise it was not considered. In addition, if a trial provided the session volume as a range of numbers, the mean of the range was used. Training volume *B* regression coefficient was expressed per 100 min of training.

### *Data analysis*

The pooled effect sizes were calculated as the SMD.[16] Positive values indicated an effect in favor of TEPs; negative values indicated an effect for the CG and/or GEPs. The SMD scores were qualitatively categorized as trivial (SMD<0.20), small (0.20<SMD<0.50), medium (0.51<SMD<0.80) and large effect (SMD>0.80).[10] The percentage change from the baseline to the post-test was calculated to provide more clinically meaningful information about the effect. A minimal important change (MIC) ≥30% from the baseline score when comparing pre-post assessments has been proposed as a noticeable clinical change for pain and disability.[49] The small-study and/or publication bias for pain, disability, QoL and $TH_{ROM}$ was analyzed using Egger's test.[11] The prediction interval (PI) was calculated for outcomes with a sufficient number of studies (i.e.,>10).[31] A sensitivity analysis was performed with the subsequent correlation values: 0.6, 0.7, 0.8 and 0.9 to verify the strength of the results obtained with the imputed correlation value of 0.5. No relevant differences between those correlation values were considered if: (i) the statistical significance of the effect sizes did not change and (ii) the qualitative categorization of the SMD magnitude remained unchanged (i.e., trivial, small, medium, or large effect). We used a random-effect model given the variability between the samples and the training programs. The between-trials heterogeneity was verified through the $I^2$ statistic: none, 0%; low, 25%; moderate, 50%; and high, 75% to 100%.[27]

Inverse variance weighted multiple meta-regressions with *B* regression coefficient and *Z* statistic were initially used to analyze the effect of continuous moderator variables on the effect of TEPs on this study outcomes. Moderator factors with a significant association with the main outcomes through a single regression analysis (p<.05) were entered into a multiple regression model. A backward elimination procedure was used to remove all parameters that did not have a significant influence (p>.05). In addition, adjusted R-squared ($R^2$) and residual heterogeneity ($I^2_{res}$) indices were used to show the proportion of between-trial variability explained by the moderator factors, and the proportion of the variability due to the between-trial variation after including the moderator factors, respectively. Following Borenstein et al. (2011),[4] who recommend a minimum of 10 studies to perform meta-regression analyses, these were performed on pain, disability, QoL, and $TH_{ROM}$ for theTEPs *vs* CG comparisons. The Stata V.16 software (StataCorp, College Station, Texas, USA) was employed to perform all statistical tests with the significance level set at $p<.05$.

### *Methodological quality of the studies and certainty of evidence*

We used the Cochrane risk of bias II tool[28] and the PEDro scale[43] to assess risk of bias and trial quality. Likewise, the GRADE approach was used to judge the certainty of evidence of the main outcomes.[3,21–25,66] The certainty of evidence was categorized as very low, low, moderate, or high based on: (1) Risk of bias, (2) Inconsistency, (3) Indirectness, (4) Imprecision, and (5) Publication bias.

## RESULTS

### *Study selection*

5073 studies were initially identified; 825 were duplicates. Subsequently, 3947 studies were removed after title/abstract screening, resulting in 301 articles assessed in full text for eligibility. We excluded 261 articles (**TABLE S10**) that did not meet the inclusion criteria. Finally, 40 trials were included in the qualitative and quantitative (meta-analyses) syntheses (**FIGURE 1 and supplemental file**).

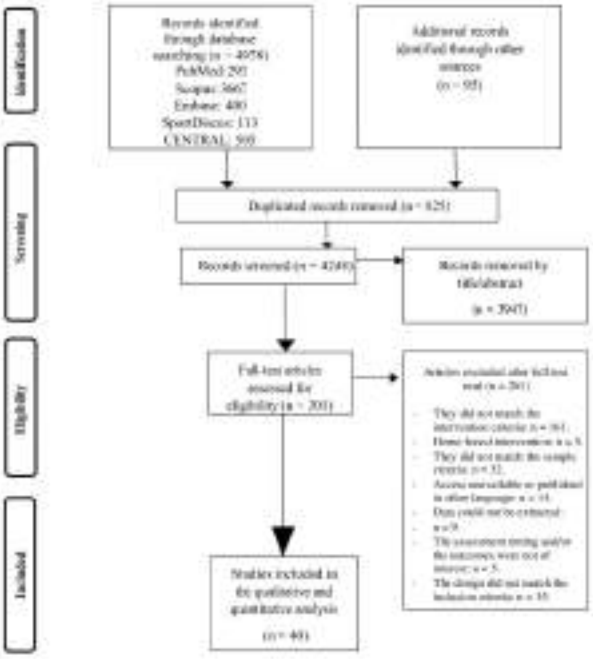

**FIGURE 1.** Flow chart diagram of the trials included.

### *Descriptive characteristics of the studies*

Participants had a mean age of 41.31±8.55 years. Regarding the training program characteristics (**TABLE S5**), a broad variety of exercises were employed. Due to the heterogeneity of the exercises within the programs, we could not classify trunk exercise methodologies. The total training volume was obtained from 31 of the 40 trials. Training volume characteristics ranged as follows: 1) training duration: 4-22.5 weeks; 2) training frequency: 1-5 days/week; 3) session duration: 20-90 min. Two trials[119,120] out of 40 (n=6 participants) reported adverse events of TEPs (due to medical attention for LBP, severe sudden LBP and development of neurological signs), which could be related to the intervention or LBP. No adverse events were reported either for GEPs or the CG.

### *Risk of bias, quality and certainty of the evidence*

The overall risk of bias was high or presented some concerns **(FIGURE S4).** The highest risk was due to deviations from the intended intervention (domain 2) and bias in the selection of the reported results (domain 5) with 1 and 9 of the trials presenting a low risk of bias, respectively**.** In bias resulting from the randomization process (domains 1), bias due to missing outcome data (domain 3) and bias in measurement of the outcomes (domain 4) over half of the trials were at low risk of bias (25, 31 and 29, respectively). Most of the trials had good or fair methodological quality **(TABLE S6).** The certainty of evidence was very low for all outcomes (**TABLE S7 and S8**).

### Outcomes

The trials included in the systematic review are presented in two groups: those comparing TEPs *vs* CGs; and those comparing a TEPs *vs* GEPs. The sensitivity analyses with 0.6, 0.7, 0.8 and 0.9 correlation values did not show noticeable changes in the statistical differences between groups (**TABLE S1**).

### *Pain*

Comparing TEPs *vs* CG (total sample, n=1630; TEPs, n=904; CG, n=726), there was a large effect in favor of TEPs (**FIGURE 2A**), (95% PI -0.5 to 3.2). From the 38 TEPs experimental groups, 27 showed a pre-post improvement over (MIC: 53.4±17.6%) and 11 below (MIC: 21.7±6.0%) the 30% threshold for a noticeable clinical change. Comparing TEPs *vs* GEPs (total sample, n=669; TEPs, n=368; GEPs, n=301), there was a small effect in favor of TEPs (**FIGURE 3A**). The MIC of TEPs was calculated in 7 groups. In TEPs experimental groups, 5 showed a pre-post improvement over (MIC: 47.2±19.1%) and 2 below (MIC: 27.7±2.1%) the 30% threshold for a noticeable clinical change. In GEPs experimental groups, 3 showed a pre-post improvement over (MIC: 35.03±5.0%) and 4 below (MIC: 27.8±1.4%) the 30%.

### *Disability*

Comparing TEPs *vs* CG (total, n=1565; TEPs, n=870; CG, n=695), there was a large effect in favor of TEPs (**FIGURE 2B**), (95% PI -0.3 to 2.1). From the 33 TEPs experimental groups, 21 showed a pre-post improvement over (MIC: 48.7±11.9%) and 12 below (MIC: 20.5±7.4%) the 30% threshold for a noticeable clinical change. Comparing TEPs *vs* GEPs (total sample, n=482; TEPs, n=238; GEPs, n=244), there was a small effect in favor of TEPs (**FIGURE 3B**). In TEPs experimental groups, 4 showed a pre-post improvement over (MIC: 50.2±15.0%) and 2 below (MIC: 11.6±9.2%) the 30%, In GEPs experimental groups, 2 studies showed a pre-post improvement over (MIC: 37.09%±8.3%) and 4 below (MIC: 17.8±10.8%) the 30%. and 2 were over.

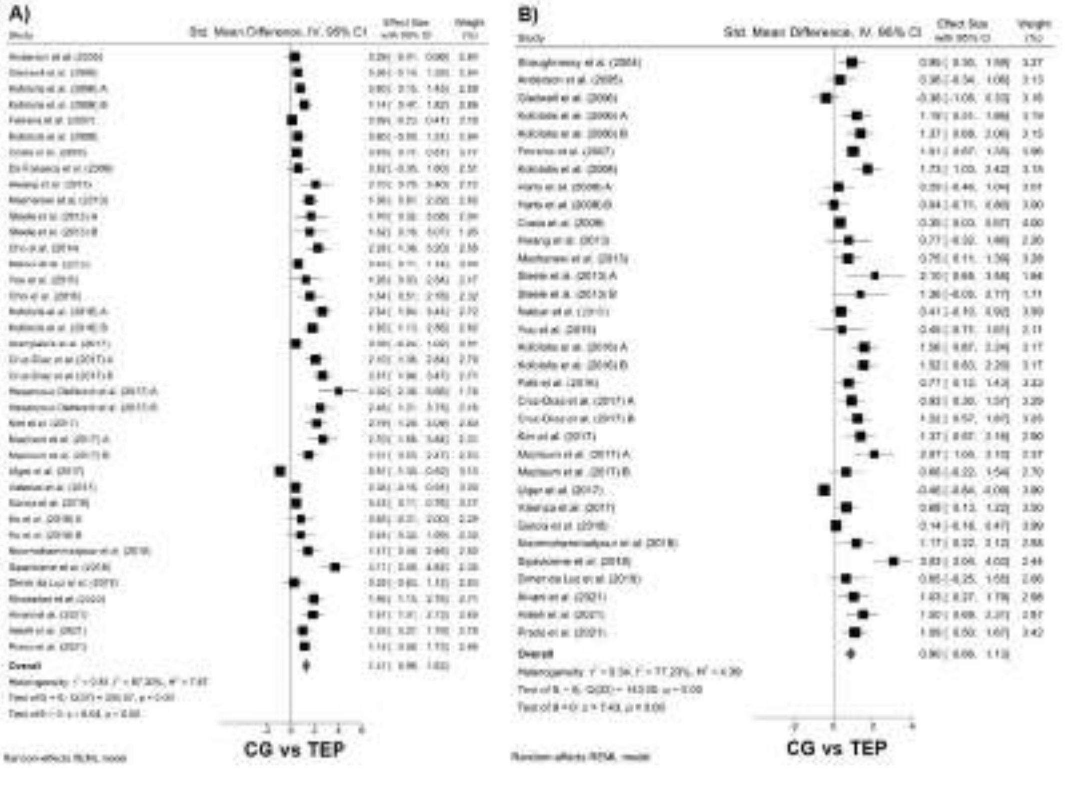

**FIGURE 2.** Standardized mean differences on pain (A) and disability (B) of the trials comparing trunk-focused exercise programs *vs* no intervention, minimal intervention or *hands-on/off* treatments.

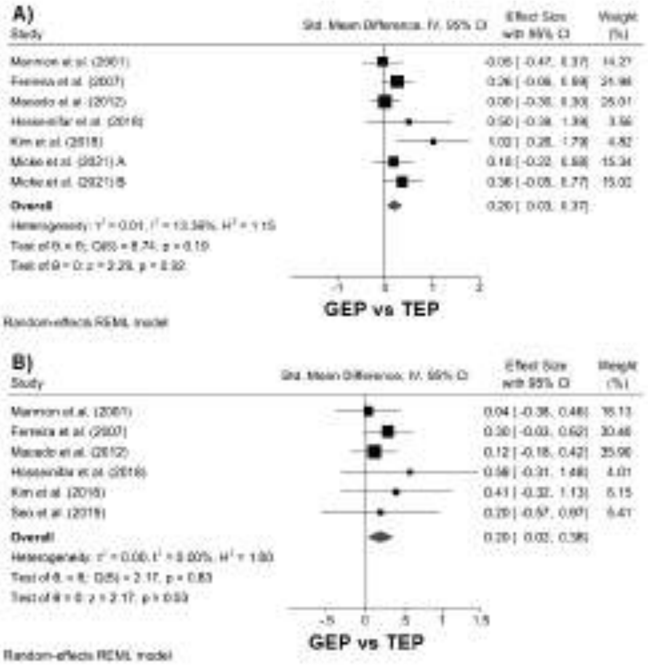

**FIGURE 3.** Standardized mean differences on pain (A) and disability (B) of the trials comparing trunk-focused exercise programs *vs* general exercise programs.

### *Quality of life*

Comparing TEPs *vs* CG (total sample, n=550; TEPs, n=315; CG, n=235), there was a large effect in favor of TEPs (**FIGURE 4**), (95% PI -0.9 to 2.5). The change from baseline was equivalent to 16.9%.

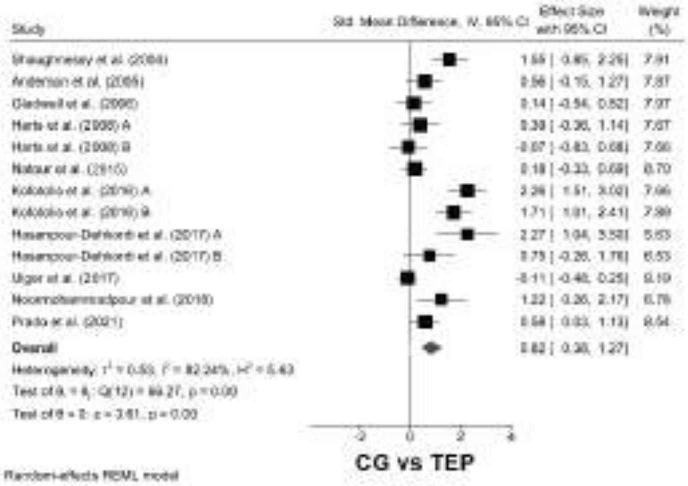

**FIGURE 4.** Standardized mean difference on quality of life of the trials comparing trunk-focused exercise programs *vs* no intervention, minimal intervention or *hands-on/off* treatments.

### *Trunk physical fitness*

- *Trunk extension endurance.* Comparing TEPs *vs* CG (total sample, n=180; TEPs, n=106; CG, n=74), there was a large effect in favor of TEPs (**FIGURE 5A**). This was equivalent to a 55.0% change from baseline.
- *Trunk strength.* Comparing TEPs *vs* CG (total sample, n=220; TEPs, n=139; CG, n=81), there was a large effect in favor of TEPs (**FIGURE 5B**). This was equivalent to a 22.5% change from baseline.
- $TH_{ROM}$. Comparing TEPs *vs* CG (total sample, n=530; TEPs, n=301; CG, n=229), there was a large effect in favor of TEPs (**FIGURE 5C**), (95% PI -0.4 to 2.3). The change from baseline was equivalent to 26.4%.

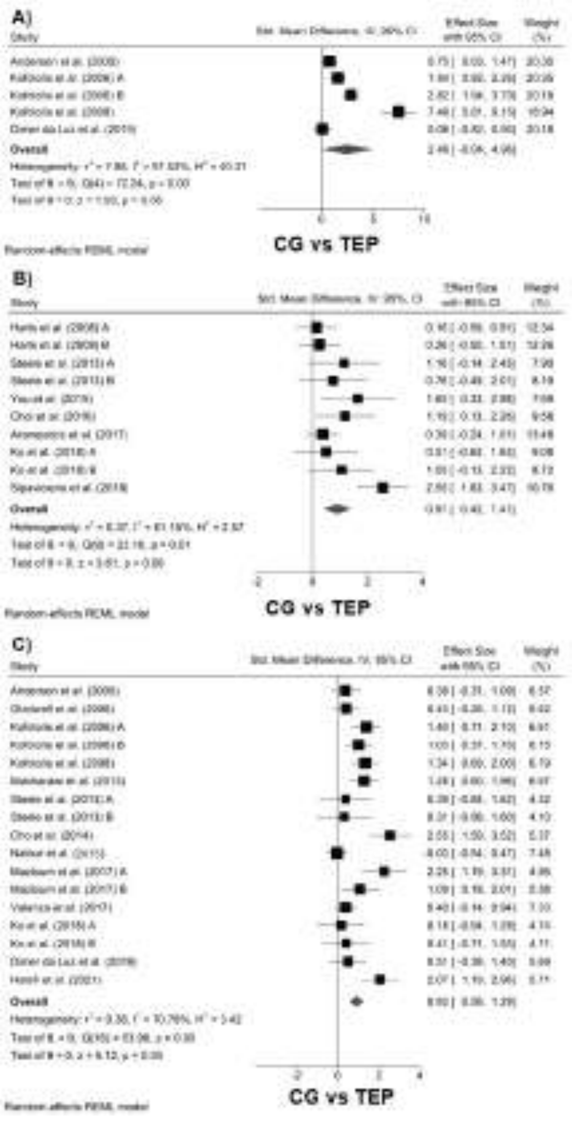

**FIGURE 5.** Standardized mean differences on trunk extension endurance (A), trunk strength (B) trunk and/or hip range of motion (C) of the trials comparing trunk-focused exercise programs *vs* no intervention, minimal intervention or *hands-on/off* treatments.

### *Meta-regression analyses*

Two factors (BMI and $TH_{ROM}$), which were independently associated with pain (**TABLE S2**), were initially entered in the multiple regression. $TH_{ROM}$ was maintained in the final model (n=17, $p$<.01, 0.25≤CI≤0.87, $R^2$=75.16%, $I^2_{res}$=27.12%). $TH_{ROM}$ had a significant effect on disability in the multiple regression model (n=14, $p$<.01, 95% CI: 0.27 to 1.05, $R^2$=73.2%, $I^2_{res}$=35%). No significant multiple meta-regression models were found for QoL and $TH_{ROM}$.

### Small-study and/or publication bias

Significant bias was observed in pain, disability, QoL, and trunk extension endurance when comparing TEPs *vs* CG, and in pain when comparing TEPs *vs* GEPs (**TABLE S3**).

## DISCUSSION

Our results support previous evidence[6,19,41,44,45,50,52,56,58] that TEPs reduce pain and disability, and improve QoL and trunk physical fitness compared to control. TEPs also had a small beneficial effect on pain and disability compared to GEPs. Greater improvements in $TH_{ROM}$ after TEPs were associated with a greater reduction in pain and disability, and lower BMI could be related to pain improvements.

### *Effect of trunk-focused exercise programs on pain, disability, quality of life and trunk impairments*

Exercises focused on the trunk structures produced significant reductions in pain and disability compared to no intervention, minimal intervention or *hands-on/off* treatments.[6,19,41,44,45,50,52,56,58] TEPs could promote a faster recovery,[37] with over half of the trials showing improvements beyond the 30% threshold from baseline (pain: 53.4±17.6%, disability: 48.7±11.9%). Previous research was uncertain about whether TEPs were more effective than other type of exercises,[19,41,58,63] partly due to a low number of RCTs. We suggest further research is needed to clarify the degree of improvement in pain and disability that can be obtained through different physical exercise programs (e.g., general exercises, cardiovascular exercises, trunk-focused exercises, etc.).

Another important result was that TEPs improved patients' QoL compared to control, with a 17% change from initial values. Our results support assessing psychosocial outcomes in LBP rehabilitation programs for a more comprehensive understanding of the multidimensional effect that these programs might produce.

Some factors related to a poor general health and physical and psychological stress have been identified as LBP risk factors,[51] and thus, they might influence the efficacy of intervention programs. Although the certainty of the evidence was low, TEPs produced a large effect on trunk extension endurance, trunk strength and $TH_{ROM}$ compared to control. These results are in line with Owen et al.[50] who found that different types of exercise programs (including TEPs) improved trunk muscle endurance and strength compared to control. TEPs are suitable to enhance trunk physical fitness, which is an important predictor for future LBP.[7,8,54]

***Moderator factors and how they modulate the effects of TEPs***

Larger gains in $TH_{ROM}$ were associated with greater reduction in pain and disability. These results do not establish a cause-effect relationship between the range of motion and pain and disability, but they show the need to explore the role of trunk, hip and pelvic flexibility in managing LBP. In addition, as people with more intense LBP usually have lower lumbar and pelvic range of motion,[35] these results may suggest the relevance of monitoring $TH_{ROM}$ to evaluate the success of LBP rehabilitation programs. Other patient characteristics (i.e., sub-clinical intermediate pain and middle-aged participants) have been associated with a better prognosis after motor control stabilization exercises.[45] However, our results only showed that BMI was significantly associated with pain. Although this association was only observed in a single meta-regression but not in the multiple regression model, this result might suggest that TEPs benefits might be enhanced by adding a weight-loss intervention. Although $TH_{ROM}$ and BMI could help to improve TEPs, both features are susceptible to ecological bias.

Although the exercise program effects depend to a great extent on the training characteristics,[44] it was not possible to analyze most training moderator factors. Many trials did not provide a detailed description of the basic training characteristics, such as training intensity, exercise progression and, in some cases, training duration, training frequency and session duration. Poor training description, and the variability of the TEPs hinder the analysis of the optimal dose-response-relationship between exercise training and LBP treatment success. In line with our results, Niederer et al.[45] found no modulation of pain effect from any of the training characteristics that they analyzed either. Nevertheless, recent work[44] indicated that 3 to 5 stabilization exercise sessions per week with a 20-30 min per session training time produced the largest effect on pain and disability. This work did not consider the total training volume within each program, so we could not compare to our work.

### *Clinical implications*

It seems that TEPs are effective in managing chronic non-specific LBP. The relationship between BMI and pain after TEPs suggests that weight loss could be an important factor to consider when supporting people to manage chronic non-specific LBP. The $TH_{ROM}$ improvement after TEPs seems to play an important role in reducing pain and disability, which reinforces the need for clinicians and researchers to take this factor into account when designing and monitoring TEPs. Assessing trunk physical capabilities, a detailed description of rehabilitation training programs and describing the dose-response relationship between TEPs and treatment success could help clinicians to tailor and maximize the benefits of a trunk-focused exercise program.

### *Limitations*

Certainty of the evidence for all the outcomes was very low, and we urge caution when interpreting our results. Few trials compared the effects of TEPs to GEPs. The number of RCTs reporting trunk physical capabilities was low, which shows the need of measuring them to: i) confirm the positive effect of TEPs; ii) obtain normative values for patients with chronic non-specific LBP; and iii) understand which trunk physical capabilities are relevant for treating LBP (improving the rehabilitation program design). Some outcomes had small-study bias, but the underlying cause cannot be identified (e.g., publication bias, outcome bias, sample heterogeneity, etc.).

Our meta-regression results should be interpreted cautiously. First, they do not imply a cause-effect relationship. Second, although multiple meta regressions were performed to account for several moderator factors, only one moderator remained significant for both pain and disability models, probably because the number of trials per predictor was not large enough. Finally, although meta-regressions reflect the variance between trials, they do not consider the individual/participant level results.[60] Patient characteristics could be affected by ecological bias as we did not have individual patient data. Future research should test the relevance of the significant moderators for modulating the effects of TEPs.

Although all the included programs involved exercises that were focused on trunk structures (such as core stability, Pilates, motor control, and McKenzie exercises), their characteristics were very diverse, and the terminology used to refer to them was ambiguous. We attempted to classify the programs with the intention of analyzing which exercise program was most effective for improving pain and disability. The high heterogeneity and the lack of information about some basic training program characteristics precluded our analysis (**TABLE S5**).

## CONCLUSIONS

Training programs focused on trunk structures were effective for managing LBP, with positive effects on pain, disability, QoL and trunk physical fitness when compared to no intervention, minimal intervention, or *hands-on/off* treatments, and on pain and disability when compared to GEPs. Patients with greater improvements in $TH_{ROM}$ after TEPs had a greater pain and disability reduction. Lower BMI was associated with higher pain improvements.

### *Key points*

*Findings:* trunk-focused exercise programs had positive effects on pain, disability, quality of life and trunk physical fitness (strength, endurance, range of motion). Increases in trunk range of motion correlated with improvements in pain and disability.

*Implications:* clinicians could consider assessing trunk physical capabilities and consider moderator factors (e.g., individuals and training programs characteristics) when designing LBP rehabilitation programs to maximize and tailor the benefits.

*Caution:* the certainty of evidence for all outcomes was very low. There is a high likelihood that the true effect is different from the effects reported in our review.

**Author contributions:** all authors made substantial contributions to the production of the present work:

- Conception and design of the work: Amaya Prat-Luri, Javier de los Rios-Calonge, Pedro Moreno-Navarro, Agustín Manresa-Rocamora, Francisco J. Vera-Garcia, David Barbado.

- Acquisition, analysis and data interpretation: Amaya Prat-Luri, Javier de los Rios-Calonge, Pedro Moreno-Navarro, Agustín Manresa-Rocamora, Francisco J. Vera-Garcia, David Barbado.

- Drafting and work revision: Amaya Prat-Luri, Francisco J. Vera-Garcia, David Barbado.

- Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Amaya Prat-Luri, Javier de los Rios-Calonge, Pedro Moreno-Navarro, Agustín Manresa-Rocamora, Francisco J. Vera-Garcia, David Barbado.

**Data sharing:** All data relevant to the study are included in the article or available in the supplementary file.

**Patient and public involvement:** There was no patient or public involvement in this research.

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## SUPPLEMENTARY MATERIAL

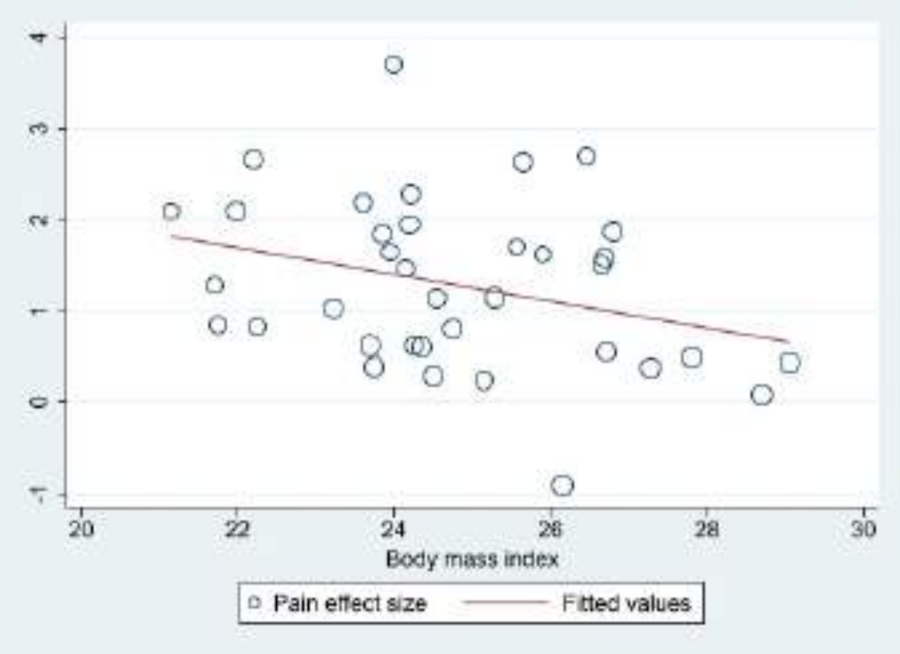


**FIGURE S1.** Meta-regression analysis of the standardized mean differences of the body mass index on pain.

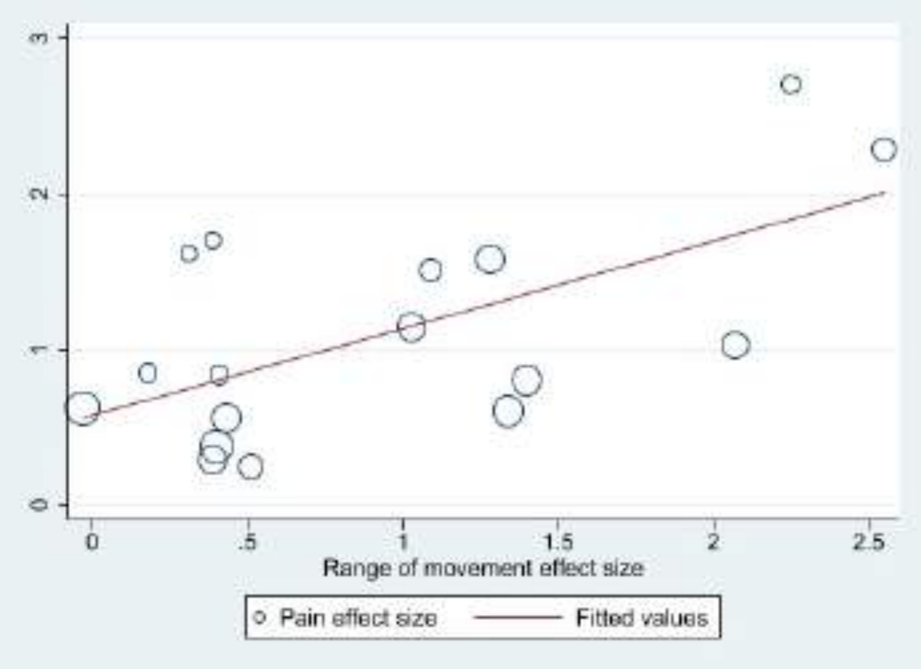


**FIGURE S2.** Meta-regression analysis of the standardized mean differences of hip and trunk range of motion on pain.

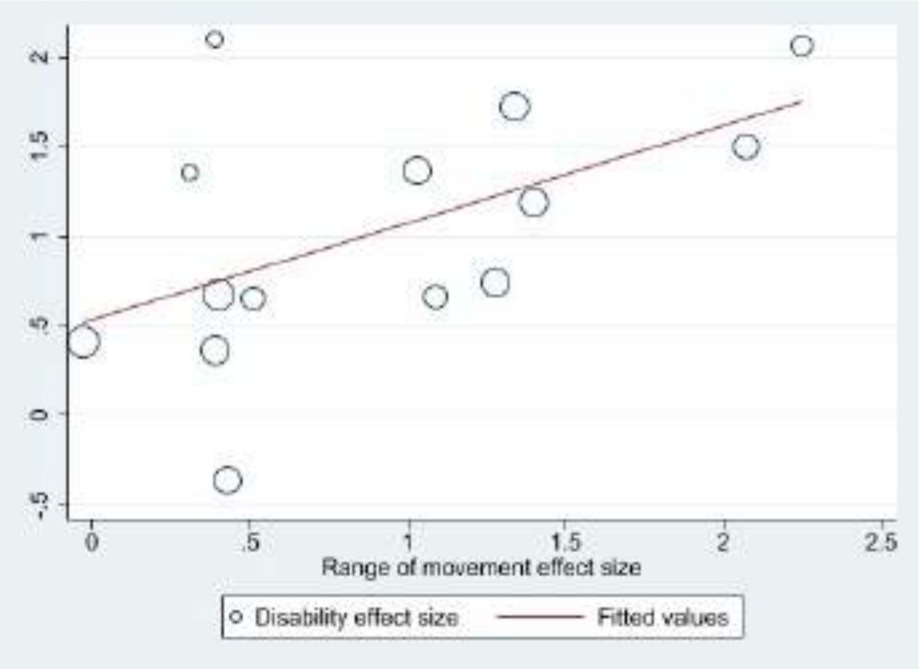
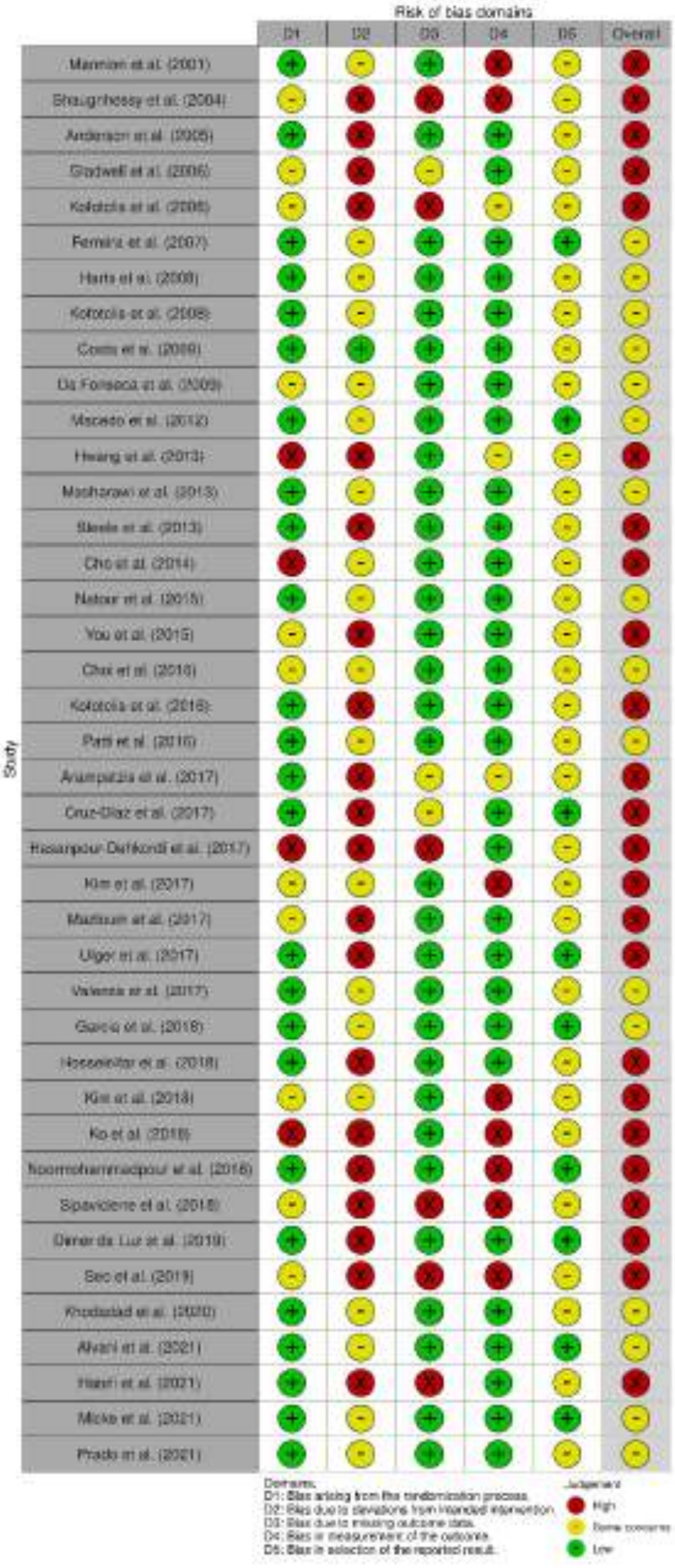


**FIGURE S3.** Meta-regression analysis of the standardized mean differences of trunk or trunk and hip range of motion on disability.



Risk of bias domains

| Study | D1 | D2 | D3 | D4 | D5 | Overall |
|---|---|---|---|---|---|---|
| Mannion et al. (2001) | + | - | + | X | - | X |
| Shaughnessy et al. (2004) | - | X | X | X | - | X |
| Anderson et al. (2005) | + | X | + | + | - | X |
| Gladwell et al. (2006) | - | X | - | + | - | X |
| Kofotolis et al. (2006) | - | X | X | - | - | X |
| Ferreira et al. (2007) | + | - | + | + | + | - |
| Harts et al. (2008) | + | - | + | + | - | - |
| Kofotolis et al. (2008) | + | - | + | + | - | - |
| Costa et al. (2009) | + | + | + | + | - | - |
| Da Fonseca et al. (2009) | - | - | + | + | - | - |
| Macedo et al. (2012) | + | - | + | + | + | - |
| Hwang et al. (2013) | X | X | + | - | - | X |
| Masharawi et al. (2013) | + | - | + | + | - | - |
| Steele et al. (2013) | + | X | + | + | - | X |
| Cho et al. (2014) | X | - | + | + | - | X |
| Natour et al. (2015) | + | - | + | + | - | - |
| You et al. (2015) | - | X | + | + | - | X |
| Choi et al. (2016) | - | - | + | + | - | - |
| Kofotolis et al. (2016) | + | X | + | + | - | X |
| Patti et al. (2016) | + | - | + | + | - | - |
| Arampatzis et al. (2017) | + | X | - | - | - | X |
| Cruz-Díaz et al. (2017) | + | X | - | + | + | X |
| Hasanpour-Dehkordi et al. (2017) | X | X | X | + | - | X |
| Kim et al. (2017) | - | - | + | X | - | X |
| Mazloum et al. (2017) | - | X | + | + | - | X |
| Ulger et al. (2017) | + | X | + | + | + | X |
| Valenza et al. (2017) | + | - | + | + | - | - |
| García et al. (2018) | + | - | + | + | + | - |
| Hosseinifar et al. (2018) | + | X | + | + | - | X |
| Kim et al. (2018) | - | - | + | X | - | X |
| Ko et al. (2018) | X | X | + | X | - | X |
| Noormohammadpour et al. (2018) | + | X | + | X | + | X |
| Sipaviciene et al. (2018) | - | X | X | X | - | X |
| Dener da Luz et al. (2019) | + | X | + | + | + | X |
| Seo et al. (2019) | - | X | X | X | - | X |
| Khodadad et al. (2020) | + | - | + | + | - | - |
| Alvani et al. (2021) | + | - | + | + | + | - |
| Hasri et al. (2021) | + | X | X | + | - | X |
| Micke et al. (2021) | + | - | + | + | + | - |
| Prado et al. (2021) | + | - | + | + | - | - |

Domains:
D1: Bias arising from the randomization process.
D2: Bias due to deviations from intended intervention.
D3: Bias due to missing outcome data.
D4: Bias in measurement of the outcome.
D5: Bias in selection of the reported result.

Judgement
X High
- Some concerns
+ Low

**FIGURE S4.** Cochrane risk of bias tool II of the studies included.

**TABLE S1.** Sensitivity analysis of the pooled effects sizes for the outcomes using different imputation correlation values.

| | **TEPs vs CG** | | **TEPs vs GEPs** | |
|---|---|---|---|---|
| | **SMD** | **LCL - UCL** | **SMD** | **LCL - UCL** |
| *0.6 correlation value* | | | | |
| Pain | 1.43 | 1.08 - 1.77 | 0.22 | 0.03 - 0.41 |
| Disability | 0.99 | 0.73 - 1.25 | 0.22 | 0.04 - 0.40 |
| QoL | 0.89 | 0.41 - 1.37 | | |
| Trunk extension endurance | 2.73 | -0.04 - 5.51 | | |
| Trunk strength | 1.01 | 0.47 - 1.55 | | |
| TH<sub>ROM</sub> | 1.01 | 0.63 - 1.39 | | |
| *0.7 correlation value* | | | | |
| Pain | 1.60 | 1.22 - 1.99 | 0.25 | 0.04 - 0.46 |
| Disability | 1.11 | 0.82 - 1.40 | 0.24 | 0.06 - 0.42 |
| QoL | 0.98 | 0.45 - 1.50 | | |
| Trunk extension endurance | 3.12 | -0.05 - 6.28 | | |
| Trunk strength | 1.15 | 0.55 - 1.75 | | |
| TH<sub>ROM</sub> | 1.12 | 0.69 - 1.54 | | |
| *0.8 correlation value* | | | | |
| Pain | 1.87 | 1.42 - 2.31 | 0.30 | 0.04 - 0.55 |
| Disability | 1.31 | 0.97 - 1.64 | 0.28 | 0.10 - 0.47 |
| QoL | 1.12 | 0.52 - 1.72 | | |
| Trunk extension endurance | 3.73 | -0.05 - 7.51 | | |
| Trunk strength | 1.38 | 0.67 - 2.08 | | |
| TH<sub>ROM</sub> | 1.28 | 0.79 - 1.77 | | |
| *0.9 correlation value* | | | | |
| Pain | 2.37 | 1.80 - 2.95 | 0.38 | 0.04 - 0.72 |
| Disability | 1.68 | 1.25 - 2.11 | 0.37 | 0.13 - 0.61 |
| QoL | 1.41 | 0.63 - 2.19 | | |
| Trunk extension endurance | 4.96 | -0.05 - 9.97 | | |
| Trunk strength | 1.82 | 0.89 - 2.75 | | |
| TH<sub>ROM</sub> | 1.62 | 0.98 - 2.25 | | |

*Abbreviations:* TEPs, Trunk-focused exercise programs; CG, Control group; GEPs, General exercise programs; SMD, Standardized mean differences; LCL, Lower Confidence Limit, UCL, Upper Confidence Limit; QoL, Quality of Life; TH<sub>ROM</sub>, trunk or trunk and hip range of movement.

**TABLE S2.** Simple meta-regression analyses on pain, disability, quality of life and trunk or trunk and hip range of movement of the studies comparing trunk-focused exercises vs no intervention, minimal intervention or hand-on/off treatment.

*Pain perceived*

| Moderator variable | *K* | *B* 95% CI (lower, upper) | Z | *p* | $R^2$ (%) | $I^2_{res}$ (%) |
|---|---|---|---|---|---|---|
| Participant age | 38 | 0.07 (-0.04, 0.05) | 0.32 | .75 | 0.00 | 87.30 |
| BMI | 36 | -0.17 (-0.32, -0.02) | 2.19 | .03 | 14.72 | 84.04 |
| Pain duration | 17 | -0.00 (-0.01, 0.01) | 0.25 | .80 | 0.00 | 80.79 |
| Initial pain | 37 | -0.01 (-0.04, 0.01) | 1.29 | .20 | 2.27 | 87.14 |
| Initial disability | 29 | 0.00 (-0.02, 0.03) | 0.19 | .85 | 0.00 | 89.10 |
| SMD TH$_{ROM}$ | 17 | 0.56 (0.25, 0.87) | 3.51 | <.01 | 75.16 | 27.12 |
| Total volume (x100) | 27 | 0.02 (-0.04, 0,09) | 0.65 | .52 | 0.00 | 89.58 |

*Disability perceived*

| Moderator variable | *K* | *B* 95% CI (lower, upper) | Z | *p* | $R^2$ (%) | $I^2_{res}$ (%) |
|---|---|---|---|---|---|---|
| Participant age | 33 | -0.01 (-0.04, 0.02) | 0.65 | .52 | 0.00 | 76.73 |
| BMI | 30 | -0.11 (-0.23, 0.01) | 1.74 | .08 | 12.69 | 75.42 |
| Pain duration | 16 | -0.00 (-0.01, 0.01) | 0.22 | .83 | 0.00 | 75.93 |
| Initial pain | 28 | -0.02 (-0.03, 0.00) | 1.85 | .06 | 13.22 | 77.44 |
| Initial disability | 33 | -0.00 (-0.02, 0.01) | 0.35 | .73 | 0.00 | 77.12 |
| SMD TH$_{ROM}$ | 14 | 0.66 (0.27, 1.05) | 3.31 | <.01 | 73.20 | 34.69 |
| Total volume (x100) | 21 | 0.00 (-0.01, 0,01) | 1.65 | .10 | 10.79 | 79.51 |

*Quality of life*

| Moderator variable | *K* | *B* 95% CI (lower, upper) | Z | *p* | $R^2$ (%) | $I^2_{res}$ (%) |
|---|---|---|---|---|---|---|
| Participant age | 13 | 0.03 (-0.10, 0.16) | 0.41 | .68 | 0.00 | 83.17 |
| Initial pain | 10 | -0.03 (-0.08, 0.02) | 1.14 | .25 | 5.55 | 82.31 |
| Initial disability | 11 | 0.00 (-0.02, 0.03) | 0.17 | .86 | 0.00 | 83.62 |
| Total volume (x100) | 10 | 0.01 (-0.01, 0,01) | 0.24 | .81 | 0.00 | 87.14 |

*Trunk or trunk and hip range of movement*

| Moderator variable | *K* | *B* 95% CI (lower, upper) | Z | *p* | $R^2$ (%) | $I^2_{res}$ (%) |
|---|---|---|---|---|---|---|
| Participant age | 17 | -0.04 (-0.09, 0.02) | 1.30 | .19 | 4.92 | 69.50 |
| BMI | 17 | 0.02 (-0.22, 0.26) | 0.17 | .87 | 0.00 | 72.30 |
| Pain duration | 11 | -0.01 (-0.01, 0.00) | 1.45 | .15 | 2.58 | 65.11 |
| Initial pain | 16 | -0.00 (-0.03, 0.02) | 0.17 | .87 | 0.00 | 73.51 |
| Initial disability | 14 | 0.00 (-0.03, 0.03) | 0.10 | .92 | 0.00 | 69.13 |

*Abbreviations: B,* Regression coefficient; *CI,* Confidence Interval; $I^2_{res}$, Residual heterogeneity after including the moderator variable; *K,* Number of studies; *p,* Probability level associated to the *Z* statistic; $R^2$, Adjusted *R*-squared; *BMI*, Body Mass Index; *SMD*, Standardized Mean Difference; *TH$_{ROM}$,* Trunk or trunk and hip range of motion; *Z,* Statistic for testing the significance of the moderator variable.

**TABLE S3.** Publication bias with Egger test.

| **Trunk-focused exercise programs vs control group** | | | | |
|---|---|---|---|---|
| | *Coefficient* | *Typical error* | *Z* | *Prob > /z/* |
| Pain | 4.11 | 0.799 | 5.14 | <0.0001 |
| Disability | 2.66 | 0.874 | 3.04 | 0.0023 |
| Quality of life | 4.33 | 1.892 | 2.29 | 0.0223 |
| Trunk extension endurance | 13.39 | 3.428 | 3.91 | 0.0001 |
| Trunk strength | 2.54 | 1.928 | 1.32 | 0.1875 |
| $TH_{ROM}$ | 0.83 | 1.603 | 0.52 | 0.6049 |
| **Trunk-focused exercise programs vs General exercise programs** | | | | |
| | *Coefficient* | *Typical error* | *Z* | *Prob > /z/* |
| Pain | 2.42 | 1.199 | 2.02 | 0.0438 |
| Disability | 0.79 | 1.051 | 0.75 | 0.4503 |

*Abbreviations:* $TH_{ROM}$, trunk or trunk and hip range of movement.

**TABLE S4.** Boolean search strategy for each database.

| | |
|---|---|
| **PubMed** | (("trunk strength*" OR “trunk stab*” OR “trunk endurance” OR “trunk flex*” OR “trunk stretch*” OR “trunk control” OR "core strength*" OR “core stab*” OR “core endurance” OR “core flex*” OR “core control” OR "lumbar strength*" OR “lumbar stab*” OR “lumbar endurance” OR “lumbar flex*” OR “lumbar control” OR “lumbopelvic stab*” OR “lumbopelvic endurance” OR “lumbopelvic flex*” OR “lumbopelvic control” OR "spine strength*" OR “spine stab*” OR “spine flex*” OR “spine control” OR "spinal strength*" OR “spinal stab*” OR “spinal flex*” OR “spinal stretch*” OR “spinal control”) AND (“training” OR “exercise” OR “program” OR “intervention”) AND (“randomized” OR “randomised”) AND (“low back pain” OR "back pain" OR “lumbago” OR “backache”) NOT (“cell”)) |
| **Scopus** | ("trunk strength" OR "trunk strengthening" OR "trunk stability" OR "trunk stabilization" OR "trunk endurance" OR "trunk flexibility" OR "trunk stretching" OR "trunk control" OR "core strength" OR "core strengthening" OR "core stability" OR "core stabilization" OR "core endurance" OR "core flexibility" OR "core stretching" OR "core control" OR "lumbar strength" OR "lumbar strengthening" OR "lumbar stability" OR "lumbar stabilization" OR "lumbar endurance" OR "lumbar flexibility" OR "lumbar stretching" OR "lumbar control" OR "lumbopelvic strength" OR "lumbopelvic strengthening" OR "lumbopelvic stability" OR "lumbopelvic stabilization" OR "lumbopelvic endurance" OR "lumbopelvic flexibility" OR "lumbopelvic stretching" OR "lumbopelvic control" OR "spine strength" OR "spine strengthening" OR "spine stability" OR "spine stabilization" OR "spine endurance" OR "spine flexibility" OR "spine stretching" OR "spine control" OR "spinal strength" OR "spinal strengthening" OR "spinal stability" OR "spinal stabilization" OR "spinal endurance" OR "spinal flexibility" OR "spinal stretching" OR "spinal control") AND ("training" OR "exercises" OR "program" OR "intervention") AND ("low back pain" OR "back pain" OR "lumbago" OR "backache") AND (“randomised” OR “randomized”) AND NOT ("cell") AND (LIMIT-TO (DOCTYPE , "ar" )) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "Spanish" ) OR LIMIT-TO (LANGUAGE , "French")) |
| **Embase** | ('trunk strength*' OR 'trunk stab*' OR 'trunk endurance' OR 'trunk flex*' OR 'trunk stretch*' OR 'trunk control'/exp OR 'trunk control' OR 'core strength*' OR 'core stab*' OR 'core endurance' OR 'core flex*' OR 'core control' OR 'lumbar strength*' OR 'lumbar stab*' OR 'lumbar endurance' OR 'lumbar flex*' OR 'lumbar control' OR 'lumbopelvic stab*' OR 'lumbopelvic endurance' OR 'lumbopelvic flex*' OR 'lumbopelvic control' OR 'spine strength*' OR 'spine stab*' OR 'spine flex*' OR 'spine control' OR 'spinal strength*' OR 'spinal stab*' OR 'spinal flex*' OR 'spinal stretch*' OR 'spinal control') AND ('training'/exp OR 'training' OR 'exercise'/exp OR 'exercise' OR 'program'/exp OR 'program' OR 'intervention'/exp OR 'intervention') AND ('low back pain'/exp OR 'low back pain' OR 'back pain'/exp OR 'back pain' OR 'lumbago'/exp OR 'lumbago' OR 'backache'/exp OR 'backache') AND ('randomised'/exp OR 'randomised' OR 'randomized'/exp OR 'randomized') |
| **SPORTDiscus** | (("trunk strength*" OR “trunk stab*” OR “trunk endurance” OR “trunk flex*” OR “trunk stretch*” OR “trunk control” OR "core strength*" OR “core stab*” OR “core endurance” OR “core flex*” OR “core stretch*” OR “core control” OR "lumbar strength*" OR “lumbar stab*” OR “lumbar endurance” OR “lumbar flex*” OR “lumbar stretch*” OR “lumbar control” OR "lumbopelvic strength*" OR “lumbopelvic stab*” OR “lumbopelvic endurance” OR “lumbopelvic flex*” OR “lumbopelvic stretch*” OR “lumbopelvic control” OR "spine strength*" OR “spine stab*” OR “spine endurance” OR “spine flex*” OR “spine stretch*” OR “spine control” OR "spinal strength*" OR “spinal stab*” OR “spinal endurance” OR “spinal flex*” OR “spinal stretch*” OR “spinal control”) AND (“training” OR “exercise” OR “program” OR “intervention”) AND (“low back pain” OR "back pain" OR “lumbago” OR “backache”) AND (“randomized” OR “randomized”) NOT (“cell”)) |

| | |
|---|---|
| **Cochrane (CENTRAL)** | (("trunk strength" OR "trunk strengthening" OR “trunk stability” OR “trunk stabilization” OR “trunk endurance” OR “trunk flexibility” OR “trunk stretching” OR “trunk control” OR "core strength" OR "core strengthening” OR “core stability” OR “core stabilization” OR “core endurance” OR “core flexibility” OR “core stretching” OR “core control” OR "lumbar strength" OR "lumbar strengthening" OR “lumbar stability” OR “lumbar stabilization” OR “lumbar endurance” OR “lumbar flexibility” OR “lumbar stretching” OR “lumbar control” OR "lumbopelvic strength" OR "lumbopelvic strengthening” OR “lumbopelvic stability” OR “lumbopelvic stabilization” OR “lumbopelvic endurance” OR “lumbopelvic flexibility” OR “lumbopelvic stretching” OR “lumbopelvic control” OR "spine strength" OR "spine strengthening" OR “spine stability” OR “spine stabilization” OR “spine endurance” OR “spine flexibility” OR “spine stretching” OR “spine control” OR "spinal strength" OR "spinal strengthening" OR “spinal stability” OR “spinal stabilization” OR “spinal endurance” OR “spinal flexibility” OR “spinal stretching” OR “spinal control”) AND (“training” OR “exercise” OR “program” OR “intervention”) AND (“low back pain” OR "back pain" OR “lumbago” OR “backache”) AND (“randomized” OR “randomised”) NOT (“cell”)) |

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**TABLE S5.** Characteristics of the studies included in the systematic review.

| **Study** | **Outcomes** | **N Total (EG, CG)** | **Age (mean±SD)** | **LBP rehabilitation programs** | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **TEPs, GEPs and control group** | **Weeks** | **Frequency** | **Session duration** | **Total volume** |
| **Studies comparing TEPs *VS* no exercise interventions (i.e., control group)** | | | | | | | | |
| Shaughnessy et al. (2004) | Disability (ODQ), quality of life (SF-36) | 41<br>(20, 21) | **TEP** (43.0±9.0) | **TEP:** lumbar stabilization exercises: 1. Transversus and multifidus activation. 2. Low-load non-functional position (Prone lying, four-point kneeling, knee-flexed supine lying). When participants could perform 10 contractions with a 10 s hold exercises progressed adding limb movement. Participants also performed a daily maintenance exercise program at home. | 10 | 1-2 (10 sessions in total) | 30-60 | 360 |
| | | | **CG** (46.0±11.0) | **CG:** no intervention. | - | - | - | - |
| Anderson et al. (2005) | Pain (Miami back index pain scale), disability (ODQ), quality of life (combined questionnaires), trunk endurance (mBST), THROM (mST) | 32<br>(17, 15) | **TEP** (42.0±11.0) | **TEP:** Pilates exercises with *Pilates Allegro Reformer* machine (exercises from supine and quadruped positions to sitting, kneeling and standing position). | 6 | 2 | 50 | 600 |
| | | | **CG** (44.0±12.0) | **CG:** massage therapy. | 6 | 2 | 30 | 360 |
| Gladwell et al. (2006) | Pain (RMVAS), disability (ODQ), quality of life (SF-12), THROM (SRT) | 34<br>(20, 14) | **TEP** (36.9±8.1) | **TEP:** Pilates exercises + postural education (side kick, one leg stretches, shoulder bridge, hundred, swimming-four-point base, swan dive, roll up, spine twist, double arm stretch, one leg circle). Exercises progressed in different ways: limb movements, removing points of support, leverage arm increase. The exercises were repeated each week at home without supervision (2 sessions of 30 min). | 6 | 1<br>+<br>2<br>(home) | 60<br>+<br>30<br>(home) | 720 |
| | | | **CG** (45.9±8.0) | **CG:** no intervention: normal activities + pain relief. | - | - | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Kofotolis et al. (2006) | Pain (Borg back pain intensity scale), disability (ODQ), trunk endurance (BST), $TH_{ROM}$ (degrees of trunk flexion) | 58 (28, 30) | **TEP(A)** (41.8±7.7) | **TEP(A):** proprioceptive neuromuscular facilitation, combination of isotonic exercises without relaxation. Alternated concentric and eccentric contractions of trunk flexion and extensions for 5 s. Participants performed 3 sets of 15 repetitions with 30 s rest between trials and 60 s between sets. | 4 | 5 | 30-45 (35.7) | 714 |
| | | | **TEP(B)** (40.6±6.4) | **TEP(B):** proprioceptive neuromuscular facilitation, rhythmic stabilization training. Alternation of trunk flexion-extension isometric contractions. Participants performed 3 sets of 15 repetitions with 30 s rest between trials and 60 s between sets. | 4 | 5 | 30-45 (35.7) | 714 |
| | | | **CG** (42.1±8.4) | **CG:** no intervention. | - | - | - | - |
| Ferreira et al. (2007) | Pain (VAS variation), disability (RMDQ) | 147 (74, 77) | **TEP** (54.8±15.3) | **TEP:** motor control exercises specifically targeting the trunk muscles to control inter-segmental spine motion (transversus abdominis, multifidus, the diaphragm and pelvic floor muscles). Exercises progressed by introducing more functional positions tailored to each individual. | 8 | NE (12 sessions in total) | - | - |
| | | | **CG** (54.0±14.4) | **CG:** spinal manipulative therapy. | 8 | NE (12 sessions in total) | - | - |
| Harts et al. (2008) | Disability (RMDQ), quality of life (SF-36), trunk extension strength (net isometric extension strength) | 41 (20, 21) | **TEP(A)** (44.0±10.0) | **TEP(A):** high intensity lumbar strength training (initial load of 50% of their maximal lumbar extension isometric strength). The aim of each session was to perform 15-20 repetitions, the load was increased or reduced by 2.5 kg depending on their performance. | 8 | 2-1 (10 sessions in total) | - | - |
| | | | **TEP(B)** (42.0±10.0) | **TEP(B):** low intensity lumbar strength training (performed at a maximum of 20% of their maximal lumbar extension isometric strength). | 8 | 2-1 (10 sessions in total) | - | - |
| | | | **CG** (41.0±9.0) | **CG:** no intervention. | - | - | - | - |
| Kofotolis et al. (2008) | Pain (Borg back pain intensity scale), disability (ODQ), trunk extension | | **TEP** (41.0±5.5) | **TEP:** proprioceptive neuromuscular facilitation, rhythmic stabilization exercises. Isometric contractions (during 10 s) alternating trunk flexion and extension. They | 4 | 5 | 30-45 (35.7) | 714 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | endurance (mBST), TH$_{ROM}$ (degrees of trunk flexion) | | | performed 3 sets of 15 repetitions. Intensity progressed depending on the mobility progress perceived by the physical therapist. | | | | |
| | | | **CG** (42.2±7.8) | **CG:** placebo (they placed inactive transcutaneous electrical nerve stimulation on the participants). | 4 | 5 | 40-45 (42.5) | 850 |
| Costa et al. (2009) | Pain (NPRS), disability (RMDQ) | 152 (77, 75) | **TEP** (54.6±13.0) | **TEP:** motor control exercises (stage 1: focus on transversus abdominis and multifidus, exercises for the pelvic-floor muscles, breathing, spine control and movement; stage 2: functional tasks coordinating trunk and limb movement, maintaining proper trunk stability and improvement of posture and movement patterns). Participants progressed to stage 2 when they were able to maintain isolated contractions for 10 s in 10 repetitions breathing normally (biofeedback with ultrasound). | 8 | 2-1 (12 sessions in total) | 30 | 360 |
| | | | **CG** (52.8±12.7) | **CG:** placebo (detuned shortwave diathermy and detuned ultrasound). | 8 | 2-1 (12 sessions in total) | 30 | 360 |
| Da Fonseca et al. (2009) | Pain (VAS variation) | 17 (8, 9) | **TEP** (31.6±10.3) | **TEP:** Pilates exercises that progressed from low load positions (supine, prone, and side-lying positions) to body functional positions (box and sitting positions). The program included 4 stages: 1. Isolated contraction of core muscles; 2. Co-contraction of the transversus abdominis, multifidus and pelvic floor muscles; 3. Co-contraction of core muscles and limb movement; 4. Co-contraction of core muscles during dynamic functional movements of the trunk. | 8 | 2 (15 sessions in total) | 60 | 900 |
| | | | **CG** (34.4±13.1) | **CG:** no intervention. | - | - | - | - |
| Hwang et al. (2013) | Pain (VAS variation), disability (ODQ) | 14 (7, 7) | **TEP** (45.7±8.6) | **TEP:** sensorimotor training (core stability exercises including bridges with leg raise, the bird-dog exercise and hollowing and bracing techniques). | 4 | 5 | 40 | 800 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **CG** (44.9±7.9) | **CG:** ordinary physical therapy (includes hot compress, ultrasound and transcutaneous electrical nerve stimulation). | 4 | 5 | 40 | 800 |
| Masharawi et al. (2013) | Pain (VAS variation), disability (RMDQ), THROM (degrees of trunk flexion) | 40 (20, 20) | **TEP** (52.5±10.6) | **TEP:** non-weight bearing exercises (lumbar mobility/flexibility: anterior and posterior pelvic tilts, lumbar left and right rotation, and stability: multifidus, erector spine, transverse and rectus abdominis, internal/external abdominal oblique, and glutei muscles). Participants performed 10 repetitions of 10 exercises in each session. | 4 | 2 | 45 | 360 |
| | | | **CG** (53.6±9.5) | **CG:** no intervention, only daily life activities guidance. | - | - | - | - |
| Steele et al. (2013) | Pain (VAS), disability (ODQ), trunk extension strength (isometric strength), THROM (ST) | 17 (10, 7) | **TEP(A)** (46.0±12.4) | **TEP(A):** lumbar extension training at 80% (isokinetic device) of their maximal isometric force performed with their full range of motion. Resistance increased by 5% in the following session if the participants could perform longer than 105 s. | 12 | 1 | - | - |
| | | | **TEP(B)** (41.9±17.5) | **TEP(B):** lumbar extension training at 80% (isokinetic device) of their maximal isometric force performed with the 50% of their range of motion. Resistance increased 5% if the participants could perform longer than 105 s in the following session. | 12 | 1 | - | - |
| | | | **CG** (41.7±15.1) | **CG:** no intervention. | - | - | - | - |
| Cho et al. (2014) | Pain (VAS), THROM (degrees of trunk flexion) | 30 (15, 15) | **TEP** (38.1±7.9) | **TEP:** core exercise program (not described. Reference to *Brill P: The Core Programme: Fifteen Minutes Excercise A Day That Can Change Your Life: Ebury Digital; 2010).* | 4 | 3 | 30 | 360 |
| | | | **CG** (36.5±7.7) | **CG:** routine care (not described). | - | - | - | - |
| Natour et al. (2014) | Pain (VAS variation), quality of life (SF-36), THROM (SRT) | 60 (30, 30) | **TEP** (48.1±12.9) | **TEP:** Pilates exercises mat and equipment-based (exercises in prone, supine, quadruped, kneeling and standing, such as swan, prone extension, standing leg pump). The non-steroidal anti-inflammatory drug was also provided in this group. | 12 | 2 | 50 | 1200 |
| | | | **CG** (47.79±11.47) | **CG:** non-steroidal anti-inflammatory drug. | - | - | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| You et al.<br>(2015) | Pain (VAS variation), disability (ODQ Chinese version), trunk extension strength (isometric strength) | 12<br>(7, 5) | **TEP** (27.6±5.6) | **TEP:** sling exercise program (bridge exercises with a sling device targeting mainly trunk flexors and extensors). The exercise intensity was adjusted through lever arm modifications. Exercise progressions were based on the researchers' criteria, modulating the number of repetitions, duration, and intensity of the exercises. | 6 | 3 | 40 | 720 |
| | | | **CG** (27.6±6.7) | **CG:** no intervention. | - | - | - | - |
| Choi et al.<br>(2016) | Pain (VAS variation), trunk strength (isometric strength) | 16<br>(8, 8) | **TEP** (45.1±2.2) | **TEP:** two rehabilitation therapy programs that focused on muscular back strength and the subjective degree of pain. Exercises progressed increasing the time spent in each repetition. | 8 | 8 | - | - |
| | | | **CG** (41.6±4.2) | **CG:** not described. | - | - | - | - |
| Kofotolis et al.<br>(2016) | Pain (pain item SF-36), disability (RMDQ), quality of life (SF-36) | 65<br>(37, 28) | **TEP(A)** (41.2±8.5) | **TEP(A):** Pilates exercises mat-based (roll down, mermaid, spine stretching, pelvic curl, criss-cross, double leg stretches, hundred, double knee fold, tabletop, swimming, swan, cat stretch, child's pose, hip stretch). Participants progressed from: weeks 1-2 (2 sets of 15 repetitions), weeks 3-4 (2 sets of 20 repetitions), weeks 5-6 (3 sets of 15 repetitions), and weeks 7-8 (3 sets of 20 repetitions). | 8 | 3 | 60 | 1440 |
| | | | **TEP(B)** (41.2±8.5) | **TEP(B):** trunk strengthening exercises targeting abdominal and back muscles (abdominal and oblique crunches, abdominal curls on ball, lifting the trunk from prone to neutral position, single-leg trunk extension, bridges...). Participants progressed from: weeks 1-2 (2 sets of 10 repetitions), weeks 3-4 (2 sets of 15 repetitions), weeks 5-6 (3 sets of 10 repetitions), and weeks 7-8 (3 sets of 15 repetitions). | 8 | 3 | 60 | 1440 |
| | | | **CG** (39.1±8.7) | **CG:** no intervention. | - | - | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Patti et al. (2016) | Disability (ODQ) | 38 (19, 19) | **TEP** (41.3±11.2) | **TEP:** Pilates Matwork (the hundred, roll up, single leg circles with bent leg, spine stretching, rolling like a ball, single leg stretch, breathing exercises). Two levels of difficulty: basic and intermediate. | 14 | 3 | 50 | 2100 |
| | | | **CG** (41.6±13.0) | **CG:** social activities and usual care. | - | - | - | - |
| Arampatzis et al. (2017) | Pain (VAS variation), trunk extension strength (isometric strength) | 40 (20, 20) | **TEP** (31.9±6.0) | **TEP:** random-perturbation training (variable and unpredictable disturbances were applied to the spine). Progression was performed through the increase in the perturbation amplitude and the spring stiffness. | 13 | 2 | 90 | 2340 |
| | | | **CG** (31.4±5.5) | **CG:** no intervention. | - | - | - | - |
| Cruz-Díaz et al. (2017) | Pain (VAS variation), disability (RMDQ) | 64 (34, 30) | **TEP(A)** (36.9±12.5) | **TEP(A):** Pilates exercises mat-based (leg stretch, criss-cross, single straight leg, roll up, rolling, side kick, spine twist, rowing, pull strap, swimming, teaser, leg pull back and front, mermaid, rolling down). Participants progressed based on their level and skills. | 12 | 2 | 50 | 1200 |
| | | | **TEP(B)** (36.9±12.5) | **TEP(B):** Pilates exercises equipment-based (footwork toes, leg series, shoulder bridge, hundred, arm pull, kneeling pull back, seated rotations, camel, elephant, spine stretch, back extensions, mermaid, roll down). Participants progressed based on their level and skills. | 12 | 2 | 50 | 1200 |
| | | | **CG** (36.3±10.7) | **CG:** no intervention. | - | - | - | - |
| Hasanpour-Dehkordi et al. (2017) | Pain (McGill pain questionnaire), quality of life (GHQ-28) | 24 (12, 12) | **TEP(A, B) and CG:** range of age 40-55 years. | **TEP(A):** Pilates exercises (no details provided). | 6 | 3 | 60 | 1080 |
| | | | | **TEP(B):** McKenzie exercises (four extension and two flexion exercises in supine and sitting positions). | 6 | 3 (+ 20 individual sessions of 1 hour) | 60 | 2280 |
| | | | | **CG:** no intervention. | - | - | - | - |
| Kim et al. (2017) | Pain (VAS variation), disability (ODQ) | 30 (15, 15) | **TEP** (39.8±5.5) | **TEP:** proprioceptive neuromuscular facilitation and abdominal muscle strengthening training (exercises in supine, prone, side-lying and sitting positions performing different trunk, upper and lower | 6 | 5 | 50 | 1500 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | extremities movement aiming at the trunk structures). | | | | |
| | | | **CG** (39.4±5.7) | **CG:** traditional physical therapy (hot pack, interfacial current therapy and ultrasound). | 6 | 5 | 50 | 1500 |
| Mazloum et al. (2017) | Pain (VAS variation), disability (ODQ), TH$_{ROM}$ (mST) | 32 (16, 16) | **TEP(A)** (37.1±9.5) | **TEP(A):** Pilates exercises mat-based (shoulder bridge, side kick, hundred, roll up, swan dive, swimming, one leg circle, double arm stretch, spine twist). | 6 | 3 | - | - |
| | | | **TEP(B)** (37.1±9.5) | **TEP(B):** trunk extension-based exercise (deep breathing in prone, passive trunk extension on elbows and on hands in prone position, passive trunk extension in standing, knee to chest in crook lying, trunk flexion sitting on a chair). | 6 | 3 | - | - |
| | | | **CG** (39.3±9.8) | **CG:** no intervention. | - | - | - | - |
| Ulger et al. (2017) | Pain (VAS variation), disability (ODQ), QoL (SF-36 turkish version) | 113 (56, 57) | **TEP** (43.1±14.3) | **TEP:** spinal stabilization exercises (co-contraction of the transversus abdominis, multifidus and core muscles). Exercises progressed in levels through limb movement and through different positions (e.g., sitting, standing), with the criteria to progress being contract transversus abdominis and multifidus muscles for 10 s and repeat it 10 times for all the exercises of the stage. | 6 | 3 | 60 | 1080 |
| | | | **CG** (41.6±12.9) | **CG:** manual therapy (soft tissue mobilizations, muscle-energy techniques, joint mobilization and/or manipulations provided by the therapist). | 6 | 3 | 60 | 1080 |
| Valenza et al. (2017) | Pain (VAS variation), disability (ODQ), TH$_{ROM}$ (mST) | 54 (27, 27) | **TEP** (38.0±12.0) | **TEP:** Pilates exercises mat-based (spine stretch, saw, mermaid, one leg stretches, double-leg stretch, criss-cross, swan dive, swimming, spine twist, one-leg kick, double leg kick, shoulder bridge, one-leg circle, side kick). Exercises progressed at 3 levels of difficulty adapted to each individual. | 8 | 2 | 45 | 720 |
| | | | **CG** (40.0±16.0) | **CG:** booklet information. | - | - | - | - |
| Garcia et al. (2018) | Pain (NPRS), disability (RMDQ) | 147 (74, 73) | **TEP** (57.4±12.2) | **TEP:** McKenzie Method of Mechanical Diagnosis, which consists of repeating the | 5 | 2 | 30-40 (35) | 350 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | exercises in a single direction. Participants were divided into three groups: 1. Derangement syndrome (exercises performed in the preferred direction, which was identified as without pain); 2. Dysfunction syndrome (exercises performed in the direction that produced pain at the end of the range of movement); 3. Postural syndrome (poor postures were treated). | | | | |
| | | | **CG** (55.4±13.6) | **CG:** placebo intervention (detuned pulsed ultrasound in side-lying and detuned short-wave diathermy in pulsed mode). | 5 | 2 | 30-40<br>(35) | 350 |
| Ko et al. (2018) | Pain (NPRS), trunk strength (isokinetic trunk flexion and extension strength), $TH_{ROM}$ (SRT) | 19<br>(10, 9) | **TEP(A)** (43.1±3.7) | **TEP(A):** lumbar stabilization exercises on floor (sit up, superman exercise, quadruped arm and leg raise, squat, lower body fixation plank, upper body fixation plank, side plank and hip bridge). | 12 | 3 | 60 | 2160 |
| | | | **TEP(B)** (43.6±4.5) | **TEP(B):** lumbar exercises with sling device (sit up, superman exercise, quadruped arm and leg raise, squat, lower and upper body fixation plank, side plank and hip bridge). | 12 | 3 | 60 | 2160 |
| | | | **CG** (41.3±3.8) | **CG:** no intervention. | - | - | - | - |
| Noormohammadpour et al. (2018) | Pain (VAS), disability (RMDQ), quality of life (SF-36) | 20<br>(10, 10) | **TEP** (43.3±7.5) | **TEP:** multi-step core stability exercises (exercises on floor and swiss ball emphasizing in abdominal hollowing and paraspinal muscles. The exercises were performed in prone, supine and lateral positions, from floor to sitting and standing positions and in dynamic and static conditions). Exercises progressed based on participants' tolerance. | 8 | - | - | - |
| | | | **CG** (41.3±6.4) | **CG:** no intervention. | - | - | - | - |
| Sipaviciene et al. (2018) | Pain (VAS variation), disability (ODQ), trunk strength (isokinetic | 36<br>(25, 11) | **TEP** (53.3±5.3) | **TEP:** lumbar stabilization exercises (stretching, pelvic tilt, trunk flexion and extension strengthening, e.g., prone, side-lying and back bridge, etc.). | 12 | 2 | 45 | 1080 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | trunk flexion and extension strength) | | **CG** (51.5±8.9) | **CG:** no intervention. | - | - | - | - |
| Dimer da Luz et al. (2019) | Pain (VAS variation), disability (ODQ), THROM (SRT) | 20 (10, 10) | **TEP** (26.4±3.4) | **TEP:** core stability exercises (prone, supine and side bridges and bird-dog. Progressions were made increasing the difficulty of the exercises (e.g., upper and lower-limb movement and use of unstable surfaces). Exercises were performed 10 times maintaining position during 10 s. | 4 | 3 | - | - |
| | | | **CG** (25.5±5.3) | **CG:** neuromuscular electrical stimulation. | 4 | 3 | 25 | 300 |
| Khodadad et al. (2020) | Pain (VAS variation) | 35 (17, 18) | **TEP** (42.2±3.8) | **TEP:** lumbar stabilization exercises (five exercises aiming at the deep lumbar stabilizing muscles). | 8 | 3 | 60 | 1440 |
| | | | **CG** (44.4±2.2) | **CG:** Traditional physical therapy (does not specify the treatment). | - | - | - | - |
| Alvani et al. (2021) | Pain (VAS), disability (ODI) | 30 (15, 15) | **TEP** (40.6±6.03) | **TEP:** Neuromuscular exercises: specific exercises that enhance the stability of the vertebral column, improve the stamina of the abdominal muscles, improve balance and control posture, increase back muscle strength, and increase the lumbar and pelvic range of motion. | 8 | 3 | 60 | 960 |
| | | | **CG** (30.67±7.84) | **CG:** no intervention. | - | - | - | |
| Hatefi et al. (2021) | Pain (VAS), disability (ODQ) and THROM (degrees of hip pasive extension) | | **TEP** (26.27±2.13) | **TEP:** static stretching exercises: 1. stretching in the modified Thomas test position; 2. modified launch stretch; 3. lifting the leg while lying in a prone position with the knee bent; 4. lifting the leg in a prone position with a straight knee. Participants performed 10 repetitions of 30 s of each stretch, with 8 s rest between repetitions. | 8 | 3 | 20 | 480 |
| | | | **CG** (26.43±2.52) | **CG:** no intervention. | - | - | - | - |
| Prado et al. (2021) | Pain (VAS variation), disability | 54 (27, 27) | **TEP** (35±9.8) | **TEP:** isostretching (global postural exercise method). The exercises were performed in | 22.5 | 2 | 45 | 2025 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (RMDQ), and quality of life (SF-36) | | | dorsal decubitus, sitting, and standing positions. In each position, three variations of pelvis and shoulder positioning were performed three times. All the exercises were performed in a position of vertebral stabilization within the span of one exhalation and self-alignment movement in the vertical direction, providing stretching, isometric strengthening, vertebral stabilization, and diaphragm mobility. | | | | |
| | | | **CG** (33±11.3) | **CG:** no intervention. | - | - | - | - |
| **Studies comparing TEPs *VS* GEPs** | | | | | | | | |
| Manion et al. (2001) | Pain (VAS), disability (RMQ) | | **TEP** (43.7±10.1) | **TEP:** Four exercise devices (DBC International, Finland) provided progressive, isoinertial loading to the trunk in the three cardinal planes. | 12 | 2 | 60 | 1440 |
| | | | **GEP** (46.3±10.1) | **GEP:** Individual physiotherapy sessions focused on improving functional capacity using strengthening, co-ordination and aerobic exercises, and with instruction on ergonomics. | 12 | 2 | 30 | 720 |
| Ferreira et al. (2007) | Pain (VAS variation), disability (RMDQ) | 34 (74,76,77) | **TEP** (51.9±15.3) | **TEP:** motor control exercises specifically targeting the trunk muscles to control inter-segmental spine motion (transversus abdominis, multifidus, the diaphragm and pelvic floor muscles). Exercises progressed by introducing more functional positions tailored to each individual. | 8 | NE (12 sessions in total) | - | - |
| | | | **GEP** (54.8±14.4) | **GEP:** general exercises (strengthening and stretching of the main muscle groups and cardiovascular exercises). | 8 | NE (12 sessions in total) | 60 | 720 |
| Macedo et al. (2012) | Pain (NPRS), disability (RMDQ) | 172 (86,86) | **TEP** (49.6±16.3) | **TEP:** motor control exercises (first focused on transversus abdominis, multifidus, pelvic floor muscles, and diaphragm recruitment. Afterwards functional tasks were implemented, through static and dynamic | 8 | 2-1 (12 sessions in total) | 60 | 720 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | activities). Progression to functional activities, first with static tasks, afterwards dynamic. | | | | |
| | | | **GEP** (48.7±13.7) | **GEP:** graded activity (whole body strength, cardiovascular and stretching exercises following cognitive-behavioral principles). Participants progressed in a time-contingent manner. | 8 | 1-3 | 60 | 720 |
| Hosseinifar et al. (2018) | Pain (Oswestry pain questionnaire), disability (ODQ) | 20 (10, 10) | **TEP** (26±5.6) | **TEP:** stabilizing trainings performed in five steps: 1º. abdominal drawing; 2º. co-contraction of the transverse abdominal and multifidus muscles in sitting, standing, procumbent and supine positions (being able to repeat the muscle contraction 10 times and maintaining each contraction for 10 s); 3º. adding limb motion; 4º. maintaining the mentioned muscles active during everyday activities; 5º. aerobic activities of walking and balance (such as maintaining the contraction while the participant is placed on unstable surfaces). | 6 | 4 | - | - |
| | | | **GEP** (37.33±9.8) | **GEP:** balance trainings with Biodex balance system, including postural stability, stability range, weight transferring and random control training. Training difficulty was modulated by modifying the stiffness of the Biodex balance system. | 6 | 4 | - | - |
| Kim et al. (2018) | Pain (VAS variation), disability (ODQ) | 30 (15, 15) | **TEP** (22.3±1.6) | **TEP:** McGill's exercises (curl-up, side bride and the bird-dog exercises). After 4 weeks they progressed to a higher level of difficulty. How or which it is not specified. | 8 | 3 | 30 | 720 |
| | | | **GEP** (22.9±1.6) | **GEP:** balance exercises (standing, sitting, spot walking, one leg standing with unstable devices). After 4 weeks they progressed to a higher level of difficulty. How or which it is not specified. | 8 | 3 | 30 | 720 |
| Seo et al. (2019) | Disability (ODQ Korean version) | 26 (13, 13) | **TEP** (22.9±1.6) | **TEP:** trunk stability exercises (the exercises were performed on mat and swiss ball). | 4 | 3 | - | - |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | **GEP**<br>(22.3±1.6) | **GEP:** Gyrotonic exercises (they used the pulley tower combination ULTIMA device, and performed movements in the arch and curl, hamstring, upper body and abdominal series). | 4 | 3 | - | - |
| Micke et al. (2021) | Pain (NPRS) | 240<br>(80,80,80) | **TEP(A)**<br>(54.1±7.8) | **TEP(A):** whole-body electromyostimulation (EMS). Each session consisted of 3 sets of 6 repetitions of 6 trunk specific exercises. The EMS intensity was subjectively adjusted via the BORG CR10 required to train at a rate of perceived exertion (between “strong” 5 and “very strong” 7). | 12 | 1 | 20 | 240 |
| | | | **TEP(B)**<br>(58.3±7.5) | **TEP(B):** conventional back-strengthening training. Circuit training with 10 static or dynamic exercises for back strength/core stability. The exercises were performed twice, in a circuit training structure, with 50 s of execution followed by 25 s of rest. Participants were supervised and instructed to train at a rate of perceived exertion (between “strong” 5 and “very strong” 7). | 12 | 1 | 45 | 540 |
| | | | **GEP**<br>(54.3±7.8) | **GEP:** whole-body vibration. Each session consisted of 2 sets of 5–8 repetitions of 5 exercises: dynamic cable squats, squats with arm extension, calf raises, static squats with arm movement, and static cable squats with calf raises. One minute of exercise was intermitted by 30 s of active rest. | 12 | 2 | 15 | 360 |

*Abbreviations: LBP, Low Back Pain; SD, Standard Deviation; TEPs, Trunk-focused Exercise Programs; GEPs, General Exercise Programs; PEDro, Physiotherapy Evidence Database;* $TH_{ROM}$, *Trunk or trunk and hip range of motion; NE, Non-specified; VAS, Visual Analogue Scale; MVAS, Million Visual Analogue Scale; NPRS, Numeric Pain Rating Scale; ODQ, Oswestry Disability Questionnaire; RMDQ, Rolland Morris Disability Questionnaire; SF-36, Short form 36; SF-12, Short form 12; GHQ-28, General Health Questionnaire 28; BST, Biering-Sorensen Test; mBST, modified Biering-Sorensen Test; ST, Schober Test; mST, modified Schober Test; SRT, Sit and Reach Test. TEP(A) and TEP(B) refer to different experimental groups from the same study performing trunk-focused exercises.*

**TABLE S6.** PEDro scale to assess methodological quality.

| **Study** | **Eligibility criteria specified** | **Random subject allocation** | **Concealed allocation** | **Similar groups baseline** | **Subjects blinding** | **Therapists blinding** | **Assessors blinding** | **Outcome measurement in 85% of the subjects initially allocated** | **Intention to treat** | **Between-group statistical comparison** | **Point measures and variability** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mannion et al. (2001) | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Saughnessy et al. (2004) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✗ | ✓ | ✓ |
| Anderson et al. (2005) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Gladwell et al. (2006) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Kofotolis et al. (2006) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ |
| Ferreira et al. (2007) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ |
| Harts et al. (2008) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Kofotolis et al. (2008) | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Costa et al. (2009) | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Da Fonseca et al. (2009) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✗ |
| Macedo et al. (2012) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Hwang et al. (2013) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ |
| Masharawi et al. (2013) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Steele et al. (2013) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ |
| Cho et al. (2014) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✗ |
| Natour et al. (2015) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| You et al. (2015) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| Choi et al. (2016) | ✗ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✗ |
| Kofotolis et al. (2016) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ |
| Patti et al. (2016) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✗ | ✗ |
| Arampatzis et al. (2017) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ | ✗ | ✓ | ✓ |
| Cruz-Díaz et al. (2017) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✗ |
| Hasanpour-Dehkordi et al. (2017) | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Kim et al. (2017) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✗ |
| Mazloum et al. (2017) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Ulger et al. (2017) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Valenza et al. (2017) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| García et al. (2018) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Hosseinifar et al. (2018) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Kim et al. (2018) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ |
| Ko et al. (2018) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ | ✗ |
| Noormohammadpour et al. (2018) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ |
| Sipaviciene et al. (2018) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✗ |
| Dimer da Luz et al. (2019) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✗ | ✓ | ✗ |
| Seo et al. (2019) | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ | ✗ | ✗ | ✓ | ✓ |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Khodadad et al. (2020) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Alvani et al. (2021) | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Hatefi et al. (2021) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ | ✗ | ✓ | ✓ |
| Micke et al. (2021) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Prado et al. (2021) | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✓ | ✓ | ✓ | ✗ |

*Abbreviations: PEDro, Physiotherapy Evidence Database.*

**TABLE S7.** Quality of evidence (GRADE approach) between trunk-focused exercise programs vs control group.

| *Number of studies* | **Study design** | **Risk of bias (PEDro)**[a] | **Inconsistency**[b] | **Indirectness**[c] | **Imprecision**[d] | **Publication bias**[e] | **Sample Experimental group** | **Sample Control group** | **Pooled effect size (95% CI)** | **Certainity** | **Importance** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Pain*** | | | | | | | | | | | |
| *38* | RCT | very serious | very serious | serious | not serious | publication bias is strongly suspected | 904 | 726 | SMD **1.31 SD higher**<br>(0.99 higher to 1.63 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Disability*** | | | | | | | | | | | |
| *33* | RCT | very serious | very serious | serious | not serious | publication bias is strongly suspected | 870 | 695 | SMD **0.90 SD higher**<br>(0.66 higher to 1.13 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Quality of life*** | | | | | | | | | | | |
| *13* | RCT | very serious | very serious | serious | not serious | publication bias is strongly suspected | 315 | 235 | SMD **0.82 SD higher**<br>(0.38 higher to 1.27 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Trunk extension endurance*** | | | | | | | | | | | |
| *5* | RCT | serious | very serious | not serious | serious | publication bias is strongly suspected | 106 | 74 | SMD **2.46 SD higher**<br>(-0.04 higher to 4.96 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Trunk strength*** | | | | | | | | | | | |
| *10* | RCT | very serious | very serious | serious | serious | none | 139 | 81 | SMD **0.91 SD higher**<br>(0.42 higher to 1.41 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |
| ***Trunk or trunk and hip range of motion*** | | | | | | | | | | | |
| *17* | RCT | very serious | very serious | serious | not serious | none | 301 | 229 | SMD **0.93 SD higher**<br>(0.58 higher to 1.29 higher) | ⊕◯◯◯<br>VERY LOW | CRITICAL |

*Abbreviations: PEDro, Physiotherapy Evidence Database Scale; CI, Confidence Interval; RCT, Randomized Controlled Trials; SMD, Standardized Mean Difference;* $I^2$, *Inconsistency Statistic.*

a. No quality downgrade was applied if ≥ 75% of the sample of the studies had good quality on the PEDro scale (i.e., 6 or more points); Quality was downgraded one level if ≥ 50-74.9% of the sample of the studies had good quality on the PEDro scale (i.e., 6 or more points); Quality was downgraded two levels if ≤ 50% of the sample of the studies had good quality on the PEDro scale (i.e., 6 or more points).

b. Quality was downgraded if the inconsistency statistic ($I^2$) ≥ 50% and/or there was a wide variation of the effect size across studies and there was an overlap of the confidence intervals associated with the effect size. If neither of the two was met, no downgrade was applied; if one of the two was met, one level was downgraded; if the two were met, two levels were downgraded.

c. Quality was downgraded one level if the outcome included studies employing different test/scales to register the outcome; if not, no downgrade was applied.

d. Quality was downgraded if the total sample was less than 400 participants and/or the upper or lower confidence intervals crossed the effect size 0.5 in either direction. If neither of the two was met, no downgrade was applied; if one of the two was met, one level was downgraded; if the two were met, two levels were downgraded.

e. Quality was downgraded if the Egger test was significant.

**TABLE S8.** Quality of evidence (GRADE approach) between trunk-focused exercise programs vs general exercise programs.

| ***Number of studies*** | **Study design** | **Risk of bias (PEDro)[a]** | **Inconsistency[b]** | **Indirectness[c]** | **Imprecision[d]** | **Publication bias[e]** | **Sample Experimental group** | **Sample Control group** | **Pooled effect size (95% CI)** | **Certainity** | **Importance** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Pain*** | | | | | | | | | | | |
| *7* | RCT | serious | serious | serious | not serious | publication bias is strongly suspected | 368 | 301 | SMD **0.20 SD higher**<br>(0.03 higher to 0.37 higher) | ⊕○○○<br>VERY LOW | CRITICAL |
| ***Disability*** | | | | | | | | | | | |
| *6* | RCT | very serious | serious | serious | not serious | none | 238 | 244 | SMD **0.20 SD higher**<br>(0.02 higher to 0.38 higher) | ⊕○○○<br>VERY LOW | CRITICAL |

*Abbreviations: PEDro, Physiotherapy Evidence Database Scale; CI, Confidence Interval; RCT, Randomized Controlled Trials; SMD, Standardized Mean Difference; $I^2$, Inconsistency Statistic.*

a. No quality downgrade was applied if ≥ 75% of the sample of the studies had good quality on the PEDro scale (i.e., 6 or more points); Quality was downgraded one level if ≥ 50-74.9% of the sample of the studies had good quality on the PEDro scale (i.e., 6 or more points); Quality was downgraded two levels if ≤ 50% of the sample of the studies had good quality on the PEDro scale (i.e., 6 or more points).

b. Quality was downgraded if the inconsistency statistic ($I^2$) ≥ 50% and/or there was a wide variation of the effect size across studies and there was an overlap of the confidence intervals associated with the effect size. If neither of the two was met, no downgrade was applied; if one of the two was met, one level was downgraded; if the two were met, two levels were downgraded.

c. Quality was downgraded one level if the outcome included studies employing different test/scales to register the outcome; if not, no downgrade was applied.

d. Quality was downgraded if the total sample was less than 400 participants and/or the upper or lower confidence intervals crossed the effect size 0.5 in either direction. If neither of the two was met, no downgrade was applied; if one of the two was met, one level was downgraded; if the two were met, two levels were downgraded.

e. Quality was downgraded if the Egger test was significant.

**TABLE S9.** PRISMA checklist.

| Section/topic | # | Checklist item | Reported on page # |
|---|---|---|---|
| **TITLE** | | | |
| Title | 1 | Identify the report as a systematic review, a meta-analysis, or both. | Title page |
| **ABSTRACT** | | | |
| Structured summary | 2 | Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number. | Abstract page |
| **INTRODUCTION** | | | |
| Rationale | 3 | Describe the rationale for the review in the context of what is already known. | 2 |
| Objectives | 4 | Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS). | 2-3 |
| **METHODS** | | | |
| Protocol and registration | 5 | Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number. | 3 |
| Eligibility criteria | 6 | Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. | 3-4 |
| Information sources | 7 | Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched. | 4 |
| Search | 8 | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | Table S4 |
| Study selection | 9 | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | 3-4 |
| Data collection process | 10 | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | 5 |
| Data items | 11 | List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made. | 5-6 |
| Risk of bias in individual studies | 12 | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | 7 |
| Summary measures | 13 | State the principal summary measures (e.g., risk ratio, difference in means). | 6 |
| Synthesis of results | 14 | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | 6-7 |
| Section/topic | # | Checklist item | Reported on page # |
| Risk of bias across studies | 15 | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | 6-7 |
| Additional analyses | 16 | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | 6-7 |
| **RESULTS** | | | |

| | | | |
|---|---|---|---|
| Study selection | 17 | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram. | 8 and<br>Figure 1 |
| Study characteristics | 18 | For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations. | 9 and Table S5 |
| Risk of bias within studies | 19 | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | 9 Figure S4 and Table S6 |
| Results of individual studies | 20 | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot. | Figures 2-5 |
| Synthesis of results | 21 | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | 9-13 |
| Risk of bias across studies | 22 | Present results of any assessment of risk of bias across studies (see Item 15). | 14 and Tables S7 and S8 |
| Additional analysis | 23 | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | 14 and Table S1 and S2 |
| **DISCUSSION** | | | |
| Summary of evidence | 24 | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers). | 14-17 |
| Limitations | 25 | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 17-18 |
| Conclusions | 26 | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 18 |
| **FUNDING** | | | |
| Funding | 27 | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | 19 |

*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(6): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: **www.prisma-statement.org**.

## OBTAINANCE OF STANDARD DEVIATION OF THE CHANGES FOR THE STUDIES INCLUDED IN THE SYSTEMATIC REVIEW

### Pain outcome

- *Studies in which an imputation correlation value was used:*

- Mannion et al. (2001).

- Anderson et al. (2005).

- Gladwell et al. (2006).

- Kofotolis et al. (2006).

- Ferreira et al. (2007).

- Kofotolis et al. (2008).

- Costa et al. (2009).

- Da Fonseca et al. (2009).

- Macedo et al. (2012).

- Hwang et al. (2013).

- Masharawi et al. (2013).

- Cho et al. (2014).

- Natour et al. (2015).

- You et al. (2015).

- Choi et al. (2016).

- Kofotolis et al. (2016).

- Arampatzis et al. (2017).

- Cruz-Díaz et al. (2017).

- Kim et al. (2017).

- Mazloum et al. (2017).

- Ulger et al. (2017).

- García et al. (2018).

- Hosseinifar et al. (2018).

- Ko et al. (2018).

- Noormohammadpour et al. (2018).

- Sipaviciene et al. (2018).

- Dimer da Luz et al. (2019).

- Khodadad et al. (2020).

- Alvani et al. (2021).

- Hatefi et al. (2021).

- Prado et al. (2021).

- *Studies in which the standard deviation of the changes was provided:*

- Steele et al. (2013).
- Hasanpour-Dehkordi et al. (2017).
- Valenza et al. (2017).
- Kim et al. (2018).
- Micke et al. (2021).

<u>*Disability outcome*</u>

- *Studies in which an imputation correlation value was used:*

- Mannion et al. (2001).
- Anderson et al. (2005).
- Gladwell et al. (2006).
- Kofotolis et al. (2006).
- Ferreira et al. (2007).
- Kofotolis et al. (2008).
- Costa et al. (2009).
- Macedo et al. (2012).
- Hwang et al. (2013).
- Masharawi et al. (2013).
- Natour et al. (2015).
- You et al. (2015).
- Kofotolis et al. (2016).
- Patti et al. (2016).
- Cruz-Díaz et al. (2017).
- Kim et al. (2017).
- Mazloum et al. (2017).
- Ulger et al. (2017).
- García et al. (2018).
- Hosseinifar et al. (2018).
- Noormohammadpour et al. (2018).
- Sipaviciene et al. (2018).
- Dimer da Luz et al. (2019).
- Alvani et al. (2021).
- Hatefi et al. (2021).

- Prado et al. (2021).

- *Studies in which the standard deviation of the changes was provided:*

- Shaughessy et al. (2004).
- Harts et al. (2008).
- Steele et al. (2013).
- Valenza et al. (2017).
- Kim et al. (2018).
- Seo et al. (2019).

<u>*Quality of life outcome*</u>

- *Studies in which an imputation correlation value was used:*

- Anderson et al. (2005).
- Gladwell et al. (2006).
- Natour et al. (2015).
- Kofotolis et al. (2016).
- Ulger et al. (2017).
- Noormohammadpour et al. (2018).
- Prado et al. (2021).

- *Studies in which the standard deviation of the changes was provided:*

- Shaughnessy et al. (2004).
- Harts et al. (2008).
- Hasanpour-Dehkordi et al. (2017).

<u>*Trunk extension endurance outcome*</u>

- *Studies in which an imputation correlation value was used:*

- Anderson et al. (2005).
- Kofotolis et al. (2006).
- Kofotolis et al. (2008).
- Dimer da Luz et al. (2019).

### *Trunk strength outcome*

- *Studies in which an imputation correlation value was used:*

- Steele et al. (2013).
- You et al. (2015).
- Choi et al. (2016).
- Arampatzis et al. (2017).
- Ko et al. (2018).
- Sipaviciene et al. (2018).

- *Studies in which the standard deviation of the changes was provided:*

- Harts et al. (2008).

### *Trunk or trunk and hip range of movement outcome*

- *Studies in which an imputation correlation value was used:*

- Anderson et al. (2005).
- Gladwell et al. (2006).
- Kofotolis et al. (2006).
- Kofotolis et al. (2008).
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**TABLE S10.** Articles excluded from the systematic review.

**The interventions did not match the inclusion criteria (n = 161)**

| *Year* | *Authors* | *Title* | *Additional comments* |
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| 1997 | Bentsen et al. | The effect of dynamic strength back exercise and/or a home training program in 57-year-old women with chronic low back pain. Results of a prospective randomized study with a 3-year follow-up period. | The intervention of one of the experimental groups was unsupervised. |
| 1988 | Manniche et al. | Clinical trial of intensive muscle training for chronic low back pain. | All groups performed exercises focused on the trunk structures. |
| 1991 | Manniche et al. | Intensive dynamic back exercises for chronic low back pain: a clinical trial. | All groups performed exercises focused on the trunk structures. |
| 1993 | Callaghan et al. | Evaluation of a back rehabilitation group for chronic low back pain in an out-patient setting. | The back rehabilitation group included exercises focusing on several body regions. |
| 1996 | Kuukkanen et al. | Muscular performance after a 3-month progressive physical exercise program and 9-month follow-up in subjects with low back pain. A controlled study. | The intervention groups included exercises targeting several body regions, not only the trunk structures, as the main area of interest. |
| 1999 | Leggett et al. | Restorative exercise for clinical low back pain: A prospective two-center study with 1-year follow-up. | The intervention group included exercises targeting several body regions, not only the trunk structures, as the main area of interest, and there is no control group. |
| 2002 | Rittweger et al. | Treatment of chronic lower back pain with lumbar extension and whole-body vibration exercise: a randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2004 | Helmhout et al. | Comparison of a high-intensity and a low-intensity lumbar extensor training program as minimal intervention treatment in low back pain: A randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2005 | Gagnon | Efficacy of Pilates exercises as therapeutic intervention in treating patients with low back pain [thesis]. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2005 | Koumantakis et al. | Supplementation of general endurance exercise with stabilisation training versus general exercise only. Physiological and functional outcomes of a randomised controlled trial of patients with recurrent low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2005 | Miller et al. | A comparison of the McKenzie approach to a specific spine stabilization program for chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area (McKenzie vs stabilization exercises). |
| 2006 | Cairns et al. | Randomized controlled trial of specific spinal stabilization exercises and conventional physiotherapy for recurrent low back pain. | Both groups received standardized educational information, manual therapy, electrotherapy, and lumbar traction. |
| 2006 | Donzelli et al. | Two different techniques in the rehabilitation treatment of low back pain: a randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area (‘back school’ vs Pilates). |
| 2006 | Goldby et al. | A randomized controlled trial investigating the efficiency of musculoskeletal physiotherapy on chronic low back disorder. | The two experimental and control groups attended the back school program, and the experimental groups performed an additional spine stabilization programs and manual therapy programs, respectively. |
| 2008 | Akbari et al. | The effect of motor control exercise versus general exercise on lumbar local stabilizing muscles thickness: randomized controlled trial of patients with chronic low back pain. | The general exercises group only performed exercises focused on the trunk structures (trunk flexion and extension). |
| 2008 | Carpes et al. | Effects of a program for trunk strength and stability on pain, low back and pelvis kinematics, and body balance: A pilot study. | There was only one experimental group. |
| 2008 | Norris et al. | The role of an integrated back stability program in patients with chronic low back pain. | The intervention not only included exercises focused on the trunk structures (e.g., general strengthening). It also employed physiotherapy pain relief modalities (e.g., electrotherapy, joint mobilization, acupuncture). |
| 2008 | Rajpal et al. | A study on efficacy of Pilates & Pilates & McKenzie exercise in postural low back pain - a rehabilitative protocol. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2008 | Tavafian et al. | A randomized study of back school in women with chronic low back pain: Quality of life at three, six, and twelve months follow-up. | The experimental groups performed a multidimensional program. |
| 2009 | Kell et al. | A comparison of two forms of periodized exercise rehabilitation programs in the management of chronic nonspecific low-back pain. | No group performed an intervention of exercises that targeted the trunk structures as the main area (aerobic training vs resistance training). |
| 2009 | Mannion et al. | Spinal segmental stabilisation exercises for chronic low back pain: programme adherence and its influence on clinical outcome. | There was only one experimental group. |
| 2009 | Sertpoyraz et al. | Comparison of isokinetic exercise versus standard exercise training in patients with chronic low back pain: A randomized controlled study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2009 | Tsauo et al. | The effectiveness of a functional training programme for patients with chronic low back pain - a pilot study. | The experimental group performed an additional training. |
| 2010 | Dufour et al. | Treatment of chronic low back pain: A randomized, clinical trial comparing group-based multidisciplinary biopsychosocial rehabilitation and intensive individual therapist-assisted back muscle strengthening exercises. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2010 | França et al. | Segmental stabilization and muscular strengthening in chronic low back pain: a comparative study. | Both groups performed exercises focused on the trunk structures as the main area and it is an additional training. |
| 2010 | Unsgaard-Tondel et al. | Motor control exercises, sling exercises, and general exercises for patients with chronic low back pain: a randomized controlled trial with 1-year follow-up. | Two experimental groups performed exercises focused on the trunk structures as the main area and more than 25% of the exercises of the general exercises group were focused on the trunk structures. |
| 2010 | Safikhani et al. | Three different treatment methods on rehabilitation of patient with low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2011 | Mohseni-Bandpei et al. | The effect of pelvic floor muscle exercise on women with chronic non-specific low back pain. | No group performed an intervention of exercises that targeted the trunk structures as the main area. |
| 2011 | Ammar et al. | McGill exercises versus conventional exercises in chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2011 | Andrusaitis et al. | Trunk stabilization among women with chronic lower back pain: a randomized, controlled, and blinded pilot study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2011 | Garcia et al. | Effects of two physical therapy interventions in patients with chronic non-specific low back pain: feasibility of a randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2011 | Gatti et al. | Efficacy of trunk balance exercises for individuals with chronic low back pain: a randomized clinical trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2011 | Ota et al. | Effectiveness of lumbar stabilization exercises for reducing chronic low back pain and improving quality-of-life. | There was only one experimental group. |
| 2011 | George et al. | Brief psychosocial education, not core stabilization, reduced incidence of low back pain: results from the Prevention of Low Back Pain in the Military (POLM) cluster randomized trial. | All the groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2011 | Morone et al. | Quality of life improved by multidisciplinary back school program in patients with chronic non-specific low back pain: A single blind randomized controlled trial. | The experimental group performed a multidisciplinary intervention (half of the intervention had to do with educational concepts). |
| 2011 | Saner et al. | Movement control exercise versus general exercise to reduce disability in patients with low back pain and movement control impairment. A randomised controlled trial. | All the groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2011 | Smith et al. | The effect of lumbar extension training with and without pelvic stabilization on lumbar strength and low back pain. | The control group included exercises focused on the trunk structures (McKenzie protocol). |
| 2012 | Ciriello et al. | Dynamic training of the lumbar musculature to prevent recurrence of acute low back pain: A randomized controlled trial using a daily pain recall for 1 year. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2012 | França et al. | Effects of muscular stretching and segmental stabilization on functional disability and pain in patients with chronic low back pain: a randomized, controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2012 | Javadian et al. | The effects of stabilizing exercises on pain and disability of patients with lumbar segmental instability. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2012 | Mannion et al. | Spine stabilisation exercises in the treatment of chronic low back pain: A good clinical outcome is not associated with improved abdominal muscle function. | There was only one experimental group. |
| 2012 | Sadeghi-Abdollahi et al. | The efficacy of Back School on chronic low back pain of workers of a pharmaceutical company in a Tehran Suburb. COPCORD stage II study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2012 | Stankovic et al. | Lumbar stabilization exercises in addition to strengthening and stretching exercises reduce pain and increase function in patients with chronic low back pain: randomized clinical open-label study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2012 | Young-Dae et al. | The effect of core stabilization exercises using a sling on pain and muscle strength of patients with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area (sling-based vs mat based). |
| 2012 | Vasseljen et al. | Effect of core stability exercises on feed-forward activation of deep abdominal muscles in chronic low back pain: a randomized controlled trial. | All the groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2012 | Wajswelner et al. | Clinical Pilates versus general exercise for chronic low back pain: randomized trial. | Both groups performed exercises focused on the trunk structure as the main area and there was no control group. |
| 2012 | Yoo et al. | The effect of core stabilization exercises using a sling on pain and muscle strength of patients with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2013 | Carmo et al. | Trunk stabilizing exercise and strengthening exercises in patients with non-specific chronic low back pain: a pilot blinded randomized trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2013 | Garcia et al. | Effectiveness of back school versus McKenzie exercises in patients with chronic nonspecific low back pain: a randomized controlled trial. | The back school group also included exercises and the McKenzie group received an educational component. |
| 2013 | Moon et al. | Effect of lumbar stabilization and dynamic lumbar strengthening exercises in patients with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2013 | Hosseinifar et al. | The effects of stabilization and McKenzie exercises on transverse abdominis and multifidus muscle thickness, pain, and disability: a randomized controlled trial in nonspecific chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area (stabilization vs McKenzie exercises) and there was no control group. |

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| 2013 | Inani et al. | Effect of core stabilization exercises versus conventional exercises on pain and functional status in patients with non-specific low back pain: a randomized clinical trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2013 | Ali et al. | Effectiveness of core stabilization exercises versus McKenzie's exercises in chronic lower back pain. | Both groups performed exercises focused on the trunk structures as the main area (core stability vs McKenzie exercises) and there was no control group. |
| 2013 | Chung et al. | Effects of stabilization exercise using a ball on multifidus cross-sectional area in patients with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area (with Fitball vs no Fitball) and there was no control group. |
| 2013 | Bayraktar et al. | Core stability exercises: in water or on land? Comparison of the effects of two different core stabilization trainings. | Both groups performed exercises focused on the trunk exercises as the main area (land-based vs water-based) and there was no control group. |
| 2013 | Miyamoto et al. | Efficacy of the addition of modified Pilates exercises to a minimal intervention in patients with chronic low back pain: a randomized controlled trial. | Control and experimental (Pilates) groups received an educational intervention. |
| 2013 | Park et al. | The effects of the Nintendo Wii exercise program on chronic work-related low back pain in industrial workers. | The experimental groups added lumbar stabilization exercises or Nintendo Wii exercises to the traditional physical therapy. |
| 2013 | Sung et al. | Disability and back muscle fatigability changes following two therapeutic exercise interventions in participants with recurrent low back pain. | Both groups perform trunk exercises as the main area and there was no control group. |
| 2014 | Alp et al. | Efficacy of core-stabilization exercise and its comparison with home-based conventional exercise in low back pain patients. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2014 | Da Luz et al. | Effectiveness of mat Pilates or equipment-based Pilates in patients with chronic non-specific low back pain: a protocol of a randomised controlled trial. | Both groups performed exercises focused on the trunk structures as the main area (mat-based Pilates vs Pilates with specific equipment) and there was no control group. |

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| 2014 | Durmus et al. | How effective is a modified exercise program on its own or with back school in chronic low back pain? A randomized-controlled clinical trial. | Both groups performed exercises focused on the trunk structures as the main area and one group performed an additional educational back school program. |
| 2014 | Günay et al. | The effect of the muscle endurance training on the chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2014 | Pieber et al. | Long-term effects of an outpatient rehabilitation program in patients with chronic recurrent low back pain. | The exercises were for all major muscle groups, they did not only focus on the trunk structures. |
| 2014 | Shamsi et al. | Comparing core stability and general exercise on chronic low back pain patients using three functional lumbopelvic stability tests. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2014 | Lomond et al. | Altered postural responses persist following physical therapy of general versus specific trunk exercises in people with low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2014 | Rostami et al. | The effect of lumbar support on the ultrasound measurements of trunk muscles: a single-blinded randomized controlled trial. | No group performed exercises. The experimental group wore a lumbopelvic belt during walking hours. |
| 2014 | You et al. | The effect of a novel core stabilization technique on managing patients with chronic low back pain: a randomized, controlled, experimenter-blinded study. | Both groups performed exercises focused on the trunk structures as the main area, but one group additionally performed exercises with ankle dorsiflexion. |
| 2014 | Zhang et al. | The effect of health education in patients with chronic low back pain. | Both groups performed exercises focused on the trunk structures. |
| 2015 | Anandani et al. | Effectiveness of device-based therapy for conservative management of low back pain. | There was no control group. |
| 2015 | Bergamin et al. | Effects of a Pilates exercise program on muscle strength, postural control and body composition: results from a pilot study in a group of post-menopausal women. | There was no control group. |
| 2015 | Ganesh et al. | Effect of trunk muscles training using a star excursion balance test grid on strength, endurance and disability in persons with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2015 | Halliday et al. | A randomized controlled trial comparing McKenzie therapy and motor control exercises on the recruitment of trunk muscles in people with chronic low back pain: A trial protocol. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2015 | Heo et al. | The effect of lumbar stabilization exercises and thoracic mobilization and exercises on chronic low back pain. | The experimental groups added lumbar stabilization exercises or thoracic mobilization exercises to the traditional physiotherapy. |
| 2015 | Jeong et al. | The effects of gluteus muscle strengthening exercise and lumbar stabilization exercise on lumbar muscle strength and balance in chronic low back pain patients. | Both groups performed exercises focused on the trunk exercises as the main area and there was no control group. |
| 2015 | Mostagi et al. | Pilates versus general exercise effectiveness on pain and functionality in non-specific chronic low back pain subjects. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2015 | Vikranth et al. | Effectiveness of core stabilization exercises and motor control exercises in patients with low back ache. | Both groups performed exercises focused on the trunk structures as the main area (motor control vs core stability exercises) and there was no control group. |
| 2016 | Akodu et al. | Comparative efficacy of core stabilization exercise and Pilates exercise on patients with non-specific chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area (core stability vs Pilates) and they additionally performed infrared based therapy. |
| 2016 | Balasubramaniam | Effect of motor control exercises on psychological variables in chronic low back pain in computer professionals. | Both groups performed exercises focused on the trunk structures as the main area (general back and motor control exercises) and there was no control group. |
| 2016 | Cruz-Diaz et al. | Short- and long-term effects of a six-week clinical Pilates program in addition to physical therapy on postmenopausal women with chronic low back pain: A randomized controlled trial. | The experimental group performed additional Pilates exercises to the physical therapy (electrotherapy and joint mobilization). |
| 2016 | Daulat, A. | A pragmatic randomized controlled trial to compare a novel group physiotherapy programme with a standard group exercise programme for managing chronic low back pain in primary care. | Both groups performed multimodal programs. |
| 2016 | Ghaderi et al. | Effects of Stabilization Exercises Focusing on Pelvic Floor Muscles on Low Back Pain and Urinary Incontinence in Women. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2016 | Shamsi et al. | Does core stability exercise improve lumbopelvic stability (through endurance tests) more than general exercise in chronic low back pain? A quasi-randomized controlled trial. | The general exercises group only performed exercises focused on the trunk structures as the main area (trunk flexion and extension exercises). |
| 2016 | Shamsi et al. | The effect of core stability and general exercise on abdominal muscle thickness in non-specific chronic low back pain using ultrasound imaging. | The general exercises group only performed exercises focused on the trunk structures as the main area (trunk flexion and extension exercises). |
| 2016 | Salvati et al. | Effect of spinal stabilization exercise on dynamic postural control and visual dependency in subjects with chronic nonspecific low back pain. | The control group included trunk exercises (McKenzie exercises). |
| 2016 | Mayer et al. | Effect of lumbar progressive resistance exercise on lumbar muscular strength and core muscular endurance in soldiers. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2016 | Nava-Bringas et al. | Adherencia al programa de ejercicios de estabilización lumbar en pacientes con dolor crónico de espalda baja. | There is only one experimental group, and no control group. |
| 2016 | Ogston et al. | Graded group exercise and fear avoidance behavior modification in the treatment of chronic low back pain. | There is only one experimental group (multicomponent program including aerobic exercises, educational…), and no control group. |
| 2016 | Soundararajan et al. | Efficacy of the multifidus retraining program in computer professionals with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2016 | Halliday et al. | A randomized controlled trial comparing the McKenzie method to motor control exercises in people with chronic low back pain and a directional preference. | Both groups performed exercises focused on the trunk structures as the main area (McKenzie vs motor control exercises) and there was no control group. |
| 2016 | Woo et al. | The effects of lumbar stabilization exercise with thoracic extension exercise on lumbosacral alignment and the low back pain disability index in patients with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2017 | Areeudomwong et al. | A randomized controlled trial on the long-term effects of proprioceptive neuromuscular facilitation training, on pain-related outcomes and back muscle activity, in patients with chronic low back pain. | Apart from receiving an educational booklet which had that educational component, the participants from the control group performed the recommended exercises every day. |

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| 2017 | Akhtar et al. | Effectiveness of core stabilization exercises and routine exercise therapy in management of pain in chronic nonspecific low back pain: A randomized controlled clinical trial. | Both groups performed exercises focused on the trunk structures and there was no control group. |
| 2017 | Farajzadeh et al. | Effects of McGill stabilization exercise on pain and disability, range of motion and dynamic balance indices in patients with chronic nonspecific low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2017 | Helmhout et al. | The effects of lumbar extensor strength on disability and mobility in patients with persistent low back pain. | There was only one experimental group and there was no control group. |
| 2017 | Pérez-de-la-Cruz et al. | Effectiveness of a program of Romana's pilates for non-specific low back pain. A pilot study. | There was no control group. |
| 2017 | Salamat et al. | Effect of movement control and stabilization exercises in people with extension related non-specific low back pain: a pilot study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2017 | Bhadauria et al. | Comparative effectiveness of lumbar stabilization, dynamic strengthening, and Pilates on chronic low back pain: randomized clinical trial. | All the groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2018 | Areeudomwong et al. | Proprioceptive neuromuscular facilitation training improves pain-related and balance outcomes in working-age patients with chronic low back pain: a randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2018 | Nabavi et al. | The effect of 2 different exercise programs on pain intensity and muscle dimensions in patients with chronic low back pain: a randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2018 | Aliyu et al. | Effects of a combined lumbar stabilization exercise and cognitive behavioral therapy on selected variables of individuals with non-specific low back pain: a randomized clinical trial. | Both groups performed exercises focused on the trunk structures as the main area and the experimental group performed additional cognitive behavioral therapy. |
| 2018 | Ghorbanpour et al. | Effects of McGill stabilization exercises and conventional physiotherapy on pain, functional disability and active back range of motion in patients with chronic non-specific low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2018 | Bae et al. | Effects of assisted sit-up exercise compared to core stabilization exercise on patients with non-specific low back pain: a randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area (assisted sit-up vs core stability exercises) and there was no control group. |

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| 2018 | Chung et al. | Effects of stabilization exercise using flexi-bar on functional disability and transverse abdominis thickness in patients with chronic low back pain. | Both groups performed lumbar stabilization exercises, but the experimental group used a flexi-bar. |
| 2018 | Ibrahim et al. | Motor control exercise and patient education program for low resource rural community dwelling adults with chronic low back pain: A pilot randomized clinical trial. | The motor control exercises group also performed aerobic and stretching exercises, which was common to the rest of groups. |
| 2018 | Kim et al. | Comparison of the Therapeutic Effects of a Sling Exercise and a Traditional Stabilizing Exercise for Clinical Lumbar Spinal Instability. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2019 | Alrwaily et al. | Stabilization exercises combined with neuromuscular electrical stimulation for patients with chronic low back pain: a randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and the experimental group received additional neuromuscular electrical stimulation. |
| 2019 | Areeudomwong et al. | Comparison of core stabilization exercise and proprioceptive neuromuscular facilitation training on pain-related and neuromuscular response outcomes for chronic low back pain: a randomized controlled trial. | All groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2019 | Berry et al. | The effect of high-intensity resistance exercise on lumbar musculature in patients with low back pain: A preliminary study. | There was no control group. |
| 2019 | Gasior, P. | Comparison of the effectiveness of physical treatments with central stabilization training in the treatment of patients with lower back pain syndrome. | All groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2019 | Demirel et al. | Stabilization exercise versus yoga exercise in non-specific low back pain: Pain, disability, quality of life, performance: a randomized controlled trial. | There was no control group, and the second experimental group performed yoga exercises. |
| 2019 | Mane et al. | Effect of motor control training on isolated lumbar stabilizer and core muscle training in chronic low back pain patients. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2019 | Halliday et al. | A randomized clinical trial comparing the McKenzie method and motor control exercises in people with chronic low back pain and a directional preference: 1-year follow-up. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2019 | Jaroenlarp et al. | Comparison between swiss ball exercise and sling exercise on lumbar stability and postural stability in patients with non-specific chronic low back pain: a pilot study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2019 | Pakbaz et al. | Effectiveness of the back school program on the low back pain and functional disability of Iranian nurse. | The intervention was an educational back school program. |
| 2019 | Waseem et al. | Treatment of disability associated with chronic non-specific low back pain using core stabilization exercises in Pakistani population. | The control group performed exercises focused on the trunk structures as the main area. |
| 2019 | Wegener et al. | Effects of whole-body vibration therapy and classic physiotherapy on postural stability in people with back pain: A randomized trial. | Two experimental groups performed exercises focused on the trunk structures as the main area and more than 25% of the exercises of the general exercises group were focused on the trunk structures. |
| 2019 | Weissenfels et al. | Comparison of whole-body electromyostimulation versus recognized back-strengthening exercise training on chronic nonspecific low back pain: a randomized controlled study. | Both groups performed exercises focused on the trunk structures and there was no control group. |
| 2020 | Abass et al. | Effects of an eight-week lumbar stabilization exercise programme on selected variables of patients with chronic low back pain. | The experimental group performed additional lumbar stabilization exercises to the conventional therapy. |
| 2020 | Amaral et al. | Examination of a subgroup of patients with chronic low back pain likely to benefit more from Pilates-based exercises compared to an educational booklet. | Both groups received an educational booklet and one group also performed Pilates-based exercises. |
| 2020 | Atta et al. | Effect of lumbar stabilization exercises versus kinesio taping on non-specific low back pain in post-menopausal women. A randomized controlled trial. | The experimental group performed lumbar stabilization exercises in addition to the traditional physical therapy. |
| 2020 | Bagheri et al. | Cognitive Behavioral Therapy With Stabilization Exercises Affects Transverse Abdominis Muscle Thickness in Patients With Chronic Low Back Pain: A Double-Blinded Randomized Trial Study. | Both groups performed exercises focused on trunk structures and one group performed additional cognitive behavioral therapy. |
| 2020 | Calatayud et al. | Effectiveness of a group-based progressive strength training in primary care to improve the recurrence of low back pain exacerbations and function: a randomized trial | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Divya et al. | Effect of lumbar stabilization exercises and thoracic mobilization with strengthening exercises on pain level, thoracic kyphosis, and functional disability in chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2020 | Ehsani et al. | The effects of stabilization exercise on the thickness of lateral abdominal muscles during standing tasks in women with chronic low back pain: a randomized triple-blinded clinical trial study. | Both groups performed exercises focused on the trunk structures as the main area. |
| 2020 | Hahm et al. | Mud therapy combined with core exercise for chronic nonspecific low back pain: a pilot study, single-blind, randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area, and the experimental group performed additional mud therapy. |
| 2020 | Fisher et al. | Short-term effects of thoracic spine thrust manipulation, exercise, and education in individuals with low back pain: A randomized controlled trial. | Both groups performed exercises focused on the trunk exercises as the main area, and additionally one of the groups performed thoracic manipulation. |
| 2020 | Oh et al. | Comparison of effects of abdominal draw-in lumbar stabilization exercises with and without respiratory resistance on women with low back pain: A randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area, but additionally one of the groups performed respiratory exercises. |
| 2020 | Sipaviciene et al. | Effect of different exercise programs on non-specific chronic low back pain and disability in people who perform sedentary work. | Both groups performed exercises focused on the trunk exercises as the main area (stabilization vs strengthening exercises) and there was no control group. |
| 2020 | Nambi et al. | Isokinetic back training is more effective than core stabilization training on pain intensity and sports performances in football players with chronic low back pain: A randomized controlled trial. | All the groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Chan et al. | The short-term effects of progressive vs conventional core stability exercise in rehabilitation of nonspecific chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Ibrahim et al. | Interactive low back pain intervention module based on the back school program: a cluster-randomized experimental study evaluating its effectiveness among nurses in public hospitals. | The experimental group performed a multicomponent program, and the training was not supervised all the weeks. |
| 2020 | Kim et al. | Core stability and hip exercises improve physical function and activity in patients with non-specific low back pain: A randomized controlled trial. | All the groups performed exercises focused on the trunk structures and there was no control group. |

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| 2020 | Kwon et al. | The effects of lumbar stabilization exercise on transversus abdominis muscle activation capacity and function in low back pain patients. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Matarán-Peñarrocha et al. | Comparison of efficacy of a supervised versus non-supervised physical therapy exercise program on the pain, functionality and quality of life of patients with non-specific chronic low-back pain: a randomized controlled trial. | Both groups performed exercises focused on the trunk structures, one supervised and the other not supervised at home. |
| 2020 | Mayana et al. | Effect of Pilates exercise on cross-sectional area of multifidus muscle, pain and disability in people with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area (Pilates exercises vs conventional back strengthening exercises) and there was no control group. |
| 2020 | Minobes-Molina et al. | Effectiveness of specific stabilization exercise compared with traditional trunk exercise in women with non-specific low back pain: A pilot randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Sarker et al. | Comparative clinical effects of spinal manipulation, core stability exercise, and supervised exercise on pain intensity, segmental instability, and health-related quality of life among patients with chronic nonspecific low back pain: A randomized control. | The intervention lasted 2 weeks, whilst the minimal period established to be included in this review was 4 weeks or more. |
| 2020 | Shamsi et al. | Comparison of muscle activation imbalance following core stability or general exercises in nonspecific low back pain: A quasi-randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Villarin et al. | Swiss ball exercises as an alternative to Mckenzie exercises in treating chronic low back pain among poultry workers. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Yalfani et al. | Effects of eight-week water versus mat pilates on female patients with chronic nonspecific low back pain: Double-blind randomized clinical trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2020 | Yuvarani et al. | To compare the effectiveness of laser, EMG biofeedback assisted core stability exercise versus laser and core stability exercise alone on pain and disability in patients with non-specific low back pain. | Both groups performed exercises focused on the trunk structures as the main area (one with feedback, the other group without it) and there was no control group. |

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| 2021 | Ahmed et al. | Effects of dynamic stabilization exercises and muscle energy technique on selected biopsychosocial outcomes for patients with chronic non-specific low back pain: a double-blind randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2021 | Abdel-Aziem et al. | The Effects of Stabilization Exercises Combined With Pelvic Floor Exercise in Women With Nonspecific Low Back Pain: A Randomized Clinical Study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2021 | Baskan et al. | Effectiveness of a clinical pilates program in women with chronic low back pain: A randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2021 | Goldberg et al. | Effect of a full Pilates group exercise program on transversus abdominis thickness, daily function and pain in women with chronic low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was a control group with healthy subjects. |
| 2021 | Kanwal et al. | Effects of core muscle stability on low back pain and quality of life in post-menopausal women: a comparative study. | The experimental group performed core stability exercises in addition to the traditional therapy. |
| 2021 | Nambi et al. | Virtual reality or isokinetic training; Its effect on pain, kinesiophobia and serum stress hormones in chronic low back pain: A randomized controlled trial. | All groups performed exercises focused on trunk structures and there was no control group. |
| 2021 | Muntaz et al. | Effect of core stability exercises with conventional physiotherapy in reducing pain among patients with non-specific low back pain: RCT. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2021 | Park et al. | The Effects Of Lumbar Stabilization Exercise Program Using Respiratory Resistance On Pain, Dysfunction, Psychosocial Factor, Respiratory Pressure In Female Patients In ’40s With Low Back Pain: Randomized Controlled Trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2021 | Rabiei et al. | Comparing Pain Neuroscience Education Followed by Motor Control Exercises With Group-Based Exercises for Chronic Low Back Pain: A Randomized Controlled Trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2021 | Sengul et al. | Effects of stabilization exercises on disability, pain and core stability in patients with non-specific low back pain: A randomized controlled trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |

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| 2021 | Shu et al. | Observation on the curative effect of massage manipulation combined with core strength training in patients with chronic nonspecific low back pain. | All groups received health education, which included exercises for strengthening the trunk back muscles. |
| 2021 | Soni et al. | Efficacy of backschool program versus Swiss ball exercise on pain and core endurance in individuals with non-specific low back pain: a comparative study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2021 | Songjaroen et al. | Combined neuromuscular electrical stimulation with motor control exercise can improve lumbar multifidus activation in individuals with recurrent low back pain. | Both groups performed exercises focused on trunk structures and the control group was formed by healthy subjects. |
| 2021 | Verbrugghe et al. | High intensity training is an effective modality to improve long-term disability and exercise capacity in chronic nonspecific low back pain: A randomized controlled trial. | Multimodal exercises (cardiorespiratory training, general resistance training, and core muscle training, all at high intensity). |
| 2022 | De Castro et al. | Effects of Pilates with and without elastic resistance on health variables in postmenopausal women with low back pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2022 | Dos Santos et al. | Effects of two training programs on health variables in adults with chronic low back pain: a randomized clinical trial. | There was no control group and the experimental group performed additional core stability exercises to a general resistance training. |
| 2022 | Gorji et al. | Pain Neuroscience Education and Motor Control Exercises versus Core Stability Exercises on Pain, Disability, and Balance in Women with Chronic Low Back Pain. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2022 | Kim et al. | Effects of Pain Neuroscience Education Combined with Lumbar Stabilization Exercise on Strength and Pain in Patients with Chronic Low Back Pain: Randomized Controlled Trial. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2022 | Peng et al. | Efficacy of Therapeutic Aquatic Exercise vs Physical Therapy Modalities for Patients with Chronic Low Back Pain: A Randomized Clinical Trial. | There was no experimental group performing a trunk-focused exercise program. |
| 2022 | Zheng et al. | The Effect of M-Health-Based Core Stability Exercise Combined with Self-Compassion Training for Patients with Nonspecific Chronic Low Back Pain: a Randomized Controlled Pilot Study. | Both groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| **Home-based intervention for at least one of the groups of the study (n = 5)** | | | |

| *Year* | *Authors* | *Title* | *Additional comments* |
|---|---|---|---|
| 2012 | Del Pozo-Cruz | An occupational, internet-based intervention to prevent chronicity in subacute lower back pain: a randomized controlled trial. | It was an internet-based intervention. |
| 2016 | Kapetanovic et al. | Effect of core stabilization exercises on functional disability in patients with chronic low back pain. | Home-based exercises. |
| 2019 | Suh et al. | The effect of lumbar stabilization and walking exercises on chronic low back pain. | Home-based exercises. |
| 2020 | Ahmadi et al. | Comparison of the effects of the Feldenkrais method versus core stability exercise in the management of chronic low back pain: a randomised control trial. | The control group performed home-based core stability exercises. |
| 2020 | Batibay et al. | Effect of Pilates mat exercise and home exercise programs on pain, functional level, and core muscle thickness in women with chronic low back pain. | One group performed home-based exercises and there was no control group. |

**The sample did not match the inclusion criteria of the review (n = 32)**

| *Year* | *Authors* | *Title* | *Additional comments* |
|---|---|---|---|
| 1991 | Elnaggar et al. | Effects of spinal flexion and extension exercises on low-back pain and spinal mobility in chronic mechanical low-back pain patients. | The sample included participants with mechanical low back pain and the two groups performed exercises focused on the trunk structures as the main area and there was no control group. |
| 2002 | Petersen et al. | The effect of McKenzie therapy as compared with that of intensive strengthening training for the treatment of patients with subacute or chronic low back pain: A randomized controlled trial. | The sample included participants with subacute and chronic low back pain with at least 8 weeks of symptom duration. |
| 2003 | Rasmussed-Barr et al. | Stabilizing training compared with manual treatment in sub-acute and chronic low-back pain. | The sample included participants with subacute, chronic, or recurrent low back pain with pain duration longer than 6 weeks. |
| 2006 | Rydeard et al. | Pilates-based therapeutic exercise: effect on subjects with nonspecific chronic low back pain and functional disability: a randomized controlled trial. | The sample consisted in participants with a low back pain duration longer than 6 weeks, but not the minimum 12 weeks required for this review. |

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| 2008 | Helmouth et al. | Isolated lumbar extensor strengthening versus regular physical therapy in an army working population with nonacute low back pain: a randomized controlled trial. | The sample consisted in participants with a low back pain duration longer than 4 weeks, but not the minimum 12 weeks required for this review. |
| 2008 | Petrofsky et al. | Improving the outcomes after back injury by a core muscle strengthening program. | The sample had a back injury with a non-specific low back pain duration longer than 4 weeks, but not the minimum 12 weeks required for this review. |
| 2009 | Kumar et al. | Efficacy of dynamic muscular stabilization techniques (DMST) over conventional techniques in rehabilitation of chronic low back pain. | The sample consisted in athletes (hockey players) with subacute and chronic low back pain. |
| 2010 | Muthukrishnan et al. | The differential effects of core stabilization exercise regime and conventional physiotherapy regime on postural control parameters during perturbation in patients with movement and control impairment chronic low back pain. | The sample consisted in participants with subacute and chronic low back pain (onset of their current episode of pain not less than 8 weeks). |
| 2010 | Kumar et al. | Comparative efficacy of two multimodal treatments on male and female sub-groups with low back pain (part II). | The sample consisted in participants with subacute and chronic low back pain. |
| 2011 | Bronfort et al. | Supervised exercise, spinal manipulation, and home exercise for chronic low back pain: a randomized clinical trial. | The sample consisted in participants with a mechanical low back pain duration longer than 6 weeks, but not the minimum 12 weeks required for this review. |
| 2012 | Kachanatu et al. | Chronic low back pain in fast bowlers a comparative study of core spinal stabilization and conventional exercises. | The sample consisted in athletes (bowlers). Furthermore, the control group performed exercises focused on trunk structures. |
| 2012 | Rhee et al. | A randomized controlled trial to determine the effect of spinal stabilization exercise intervention based on pain level and standing balance differences in patients with low back pain. | The sample consisted in participants with work-related low back pain episodes. |
| 2012 | Zeada | Efects of pilates on low back pain and urine catecholamine. | The sample consisted in athletes. |

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| 2013 | Kline et al. | Core strength training using a combination of home exercises and a dynamic sling system for the management of low back pain in pre-professional ballet dancers a case series. | They were athletes (pre-professional ballet dancers). |
| 2013 | Shakeri et al. | Effect of functional lumbar stabilization exercises on pain, disability, and kinesiophobia in women with menstrual low back pain: a preliminary trial. | The participants did not have chronic low back pain as the episodes were related to menstrual low back pain. |
| 2014 | Hagovska et al. | Changes in the muscle tension of erector spinae after the application of the McKenzie method in patients with chronic low back pain. | Participants were diagnosed of discopathy, and the control group consisted in healthy subjects. |
| 2014 | Vincent et al. | Back strength predicts walking improvement in obese, older adults with chronic low back pain. | The sample consisted in older adults (>65 years of mean age), and the range of this review was between 20-65 years. |
| 2014 | Karimi et al. | The effects of consecutive supervised functional lumbar stabilizing exercises on the postural balance and functional disability in low back pain. | The sample included participants with a low back pain duration longer than 8 weeks, but not the minimum 12 weeks required for this review. |
| 2015 | Brandt et al. | A randomized controlled trial of core strengthening exercises in helicopter crewmembers with low back pain. | The sample consisted in participants with a low back pain duration longer than 4 weeks, but not the minimum 12 weeks required for this review. |
| 2015 | Thomas et al. | Comparative analysis of motor control stability and strengthening program in treatment of chronic low back pain among male weightlifters. | The sample consisted in athletes (weightlifters). |
| 2016 | Park et al. | Effects of Motor Control Exercise Vs Muscle Stretching Exercise on Reducing Compensatory Lumbopelvic Motions and Low Back Pain: A Randomized Trial. | The sample consisted in participants with a low back pain duration longer than 7 weeks, but not the minimum 12 weeks required for this review. |
| 2018 | Shahvarpour et al. | Trunk postural balance and low back pain: Reliability and relationship with clinical changes following a lumbar stabilization exercise program. | The control group consisted in healthy subjects. |
| 2018 | Bello et al. | Effects of lumbar stabilisation and treadmill exercise on function in patients with chronic mechanical low back pain. | The sample consisted in participants with mechanical low back pain. |

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| 2018 | Larivière et al. | The effects of an 8-week stabilization exercise program on lumbar multifidus muscle thickness and activation as measured with ultrasound imaging in patients with low back pain: an exploratory study. | The control group consisted in healthy subjects. |
| 2018 | Boucher et al. | Trunk postural adjustments: Medium-term reliability and correlation with changes of clinical outcomes following an 8-week lumbar stabilization exercise program. | The control group consisted in healthy subjects. |
| 2018 | Joseph et al. | Comparison of effects between core stability training and sports massage therapy among Elite weightlifters with chronic non-specific low back pain. | The sample consisted in athletes (weightlifters). |
| 2018 | Suni et al. | Effectiveness and cost-effectiveness of neuromuscular exercise and back counseling in female healthcare workers with recurrent non-specific low back pain: a blinded four-arm randomized controlled trial. | The exclusion criteria indicate people with chronic low back pain. |
| 2019 | Larivière et al. | Ultrasound measures of the abdominal wall in patients with low back pain before and after an 8-week lumbar stabilization exercise program, and their association with clinical outcomes. | The control group consisted in healthy subjects. |
| 2019 | Priyadarshini et al. | Efficacy of core musculature strengthening on postural sway. | There was no control group with low back pain. |
| 2019 | Bagheri et al. | The effect of core stabilization exercises on trunk-pelvis three-dimensional kinematics during gait in non-specific chronic low back pain. | The control group consisted in healthy subjects. |
| 2020 | Kitagawa et al. | Efficacy of abdominal trunk muscles-strengthening exercise using an innovative device in treating chronic low back pain: a controlled clinical trial. | The sample consisted in older adults (>65 years of mean age), and the range of this review was between 20-65 years. |
| 2020 | Carvalho et al. | Effects of lumbar stabilization and muscular stretching on pain, disabilities, postural control and muscle activation in pregnant woman with low back pain. | The sample consisted in pregnant women with low back pain. |

**Articles not found, their access was unavailable or the language was other than the languages included in this review (n = 14)**

| *Year* | *Authors* | *Title* | *Additional comments* |
|---|---|---|---|
| 2001 | Dolan et al. | The Pilates based exercise programme in the management of low back pain. | Access unavailable. |
| 2006 | O'Brien et al. | Randomised, controlled trial comparing physiotherapy and Pilates in the treatment of ordinary low back pain. | Access unavailable. |

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| 2007 | Nam et al. | The influence of sling and mat exercise to have on lumbar stability in patients with chronic low back pain. | Access unavailable. |
| 2008 | Ekici et al. | Is there any effect of Pilates exercises on emotional status of patients with chronic low back pain? | Article written in Turkish. |
| 2008 | Yi et al. | Comparisons of spinal stabilization exercise and lumbar extensor strengthening exercise in chronic low back pain. | Article written in Korean. |
| 2009 | Ekici et al. | Effects of pilates based exercises on tranversus abdominus in females with non-specific chronic low back pain: a pilot study. | Article written in Turkish. |
| 2011 | Hemmati et al. | Effects of consecutive supervised core stability training on pain and disability in women with nonspecific chronic low back pain. | Article written in Farsi. |
| 2011 | Hu et al. | Evaluation of stabilizing exercise of the lumbar spine in the treatment of chronic non-specific low back pain. | Access unavailable. |
| 2011 | Noori et al. | Effect of exercise therapy and physiotherapy on patients with chronic low back pain. | Article written in Arabic. |
| 2012 | Coskun et al. | Effects of dynamic and static stabilization exercises on pain and functionality in chronic low back pain. | Article written in Turkish. |
| 2012 | Xueqiang et al. | Effect of core stability training on patients with chronic low back pain. | Access unavailable. |
| 2014 | Shahrjerdi et al. | The effect of Pilates-based exercises on pain, functioning and lumbar lordosis in women with non-specific chronic low back pain and hyperlordosis. | Article written in Arabic. |
| 2016 | Alfuth et al. | Chronic low back pain: Comparison of mobilization and core stability exercises. | Article written in German. |
| 2018 | Heidari et al. | Comparison of the effects of 8 weeks of core stability exercise on ball and sling exercise on the quality of life and pain in the female with non-specific chronic low back pain. | Article written in Arabic. |
| **Data could not be extracted (n = 9)** | | | |
| *Year* | *Authors* | *Title* | *Additional comments* |

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| 2007 | Critchley et al. | Effectiveness and cost-effectiveness of three types of physiotherapy used to reduce chronic low back pain disability: a pragmatic randomized trial with economic evaluation. | Data provided were not pre-post intervention. The post-test data reported is 6, 12, and 18 months after finishing the intervention. |
| 2009 | Ferreira et al. | Changes in recruitment of transversus abdominis correlate with disability in people with chronic low back pain. | Data duplicated from Ferreira et al. (2007). |
| 2009 | Rasmussed-Barr et al. | Graded exercise for recurrent low-back pain. | Data is reported in median and interquartile range. |
| 2011 | Quinn et al. | Do patients with chronic low back pain benefit from attending Pilates classes after completing conventional physiotherapy treatment? | Data could not be extracted, they reported the baseline mean and standard deviation, and the mean change. |
| 2012 | Brooks et al. | Specific trunk and general exercise elicit similar changes in anticipatory postural adjustments in patients with chronic low back pain. | Data was reported in mean change and confidence intervals at 95%. |
| 2013 | Marshall et al. | Pilates exercise or stationary cycling for chronic nonspecific low back pain: does it matter? | Data was reported in mean change and confidence intervals at 95%. |
| 2015 | Steele et al. | A randomized controlled trial of the effects of isolated lumbar extension exercise on lumbar kinematic pattern variability during gait in chronic low back pain. | Data duplicated from Steele et al. (2013). |
| 2016 | Boucher et al. | The effects of an 8-week stabilization exercise program on lumbar movement sense in patients with low back pain. | Data was presented stratified by sex and not by groups. |
| 2021 | Bellido-Fernández | Clinical relevance of massage therapy and abdominal hypopressive gymnastics on chronic nonspecific low back pain: a randomized controlled trial. | Data was reported in median and interquartile range. |

**The assessment timing or the outcomes registered were not of interest (n = 5)**

| *Year* | *Authors* | *Title* | *Additional comments* |
|---|---|---|---|
| 2009 | Karimi et al. | The effects of consecutive supervised stability training on postural balance in patients with chronic low back pain. | No post-test data is reported regarding the outcome of interest. |
| 2010 | Vasseljen et al. | Abdominal muscle contraction thickness and function after specific and general exercises: a randomized controlled trial in chronic low back pain patients. | No outcomes of interest were assessed. |

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| 2014 | Kehinde et al. | Effect of stabilization exercise on lumbar multifidus muscle thickness in patients with non-specific chronic low back pain. | No outcomes of interest were assessed. |
| 2017 | Dulger et al. | The effect of stabilization exercises on diaphragm muscle thickness and movement in women with low back pain. | No outcomes of interest were assessed. |
| 2020 | Park et al. | Effects of lumbar segmental stabilization exercise and respiratory exercise on the vital capacity in patients with chronic back pain. | No outcomes of interest were assessed. |
| **The design of the study did not match the inclusion criteria (n = 35)** | | | |
| *Year* | *Authors* | *Title* | *Additional comments* |
| 2003 | Hodges | Core stability exercise in chronic low back pain. | Review. |
| 2004 | Maher | Effective physical treatment for chronic low back pain. | Review. |
| 2005 | Hurwitz et al. | Effects of recreational physical activity and back exercises on low back pain and psychological distress: Findings from the UCLA Low Back Pain Study. | They registered physical activity and the frequency with which participants performed back exercises, but they did not perform an exercise intervention. |
| 2006 | Rackwitz et al. | Segmental stabilizing exercises and low back pain. What is the evidence? A systematic review of randomized controlled trials. | Review. |
| 2007 | Petersen et al. | One-year follow-up comparison of the effectiveness of McKenzie treatment and strengthening training for patients with chronic low back pain: outcome and prognostic factors. | It analyzed prognostic factors, but no pre-post intervention data was provided. |
| 2006 | Baerga-Varela et al. | Core strengthening exercises for low back pain. | Review. |
| 2008 | La Touche et al. | Treating non-specific chronic low back pain through the Pilates Method. | Review. |
| 2008 | Sorosky et al. | Yoga and pilates in the management of low back pain. | Review. |
| 2010 | van Middelkoop et al. | Exercise therapy for chronic nonspecific low-back pain. | Review. |
| 2013 | Ebadi et al. | A study of therapeutic ultrasound and exercise treatment for muscle fatigue in patients with chronic non specific low back pain: a preliminary report. | There was only one experimental group and no control group. |

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| 2014 | Garcia et al. | Efficacy of the McKenzie Method in Patients With Chronic Nonspecific Low Back Pain: A Protocol of Randomized Placebo-Controlled Trial. | It was a study protocol. |
| 2014 | Parnian | The effect of 8 weeks of treatment chosen, the amount of pain and disability and flexor muscle strength, and the trunk is straight, in patients with chronic low back pain. | There was only one experimental group and no control group. |
| 2014 | Wells et al. | The effectiveness of pilates exercise in people with chronic low back pain: a systematic review. | Review. |
| 2014 | Moussoli et al. | Effects of stabilization exercises on health-related quality of life in women with chronic low back pain. | There was no randomization process that allowed the allocation of the participants in the experimental and control groups. |
| 2015 | Cho et al. | Effects of lumbar stabilization exercise on functional disability and lumbar lordosis angle in patients with chronic low back pain. | The sample division into the groups was not randomized. |
| 2015 | Hwangbo et al. | The effects of trunk stability exercise and a combined exercise program on pain, flexibility, and static balance in chronic low back pain patients. | The sample division into the groups was not randomized. |
| 2015 | Sipaviciene et al. | Effects of 12-week programme of spine-stabilizing exercises on trunk muscles area, strength and function in women with chronic low back pain. | Congress article. |
| 2016 | Lee et al. | The effect of individualized gradable stabilization exercises in patients with chronic low back pain: Case-control study. | The sample division into the groups was not randomized. |
| 2016 | Niederer et al. | Medicine in spine exercise (MiSpEx) for nonspecific low back pain patients: study protocol for a multicentre, single-blind randomized controlled trial. | It was a study protocol. |
| 2016 | Miyamoto et al. | Effectiveness and Cost-Effectiveness of Different Weekly Frequencies of Pilates for Chronic Low Back Pain: Randomized Controlled Trial. | It was a study protocol. |
| 2016 | Park et al. | Effects of complex rehabilitation training on low back strength in chronic low back pain. | There was only one experimental group and no control group. |
| 2016 | Paungmali et al. | Improvements in tissue blood flow and lumbopelvic stability after lumbopelvic core stabilization training in patients with chronic non-specific low back pain. | It was a 48h intervention, but not the minimum 4 weeks required for this review. |

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| 2017 | Bagheri et al. | A protocol for clinical trial study of the effect of core stabilization exercises on spine kinematics during gait with and without load in patients with non-specific chronic low back pain. | It was a study protocol. |
| 2017 | Columbe et al. | Core stability exercise versus general exercise for chronic low back pain. | Commentary article. |
| 2017 | Paungmali et al. | Lumbopelvic Core Stabilization Exercise and Pain Modulation Among Individuals with Chronic Nonspecific Low Back Pain. | It was a 48h intervention of, but not the minimum 4 weeks required for this review. |
| 2018 | Miranda et al. | Comparison of low back mobility and stability exercises from pilates in non-specific low back pain: a study protocol of a randomized controlled trial. | It was a study protocol. |
| 2019 | Oliveira et al. | Association between clinical tests related to motor control dysfunction and changes in pain and disability after lumbar stabilization exercises in individuals with chronic low back pain. | It was a prospective cohort study. |
| 2019 | Cho et al. | Immediate effects of isometric trunk stabilization exercises with suspension device on flexion extension ratio and strength in chronic low back pain patients. | They assessed the acute effects of isometric trunk stabilization exercises. |
| 2019 | Kim et al. | Effects of mckenzie exercise on back pain and physical fitness. | The sample division into the groups was not randomized. |
| 2019 | Majeed et al. | The effectiveness of a simplified core stabilization program (TRICCS - Trivandrum Community-based Core Stabilisation) for community-based intervention in chronic non-specific low back pain. | There was only one experimental group. |
| 2021 | Abadi et al. | The impact of combination of core stabilization exercise and walking on pain perception and low back pain disability. | It was a conference abstract. |
| 2021 | Akodu et al. | Effects of core stabilization exercise and cognitive behavioral therapy in the management of patients with non-specific chronic low back pain. | Protocol registration. |
| 2022 | Ferri-Caruana | Effects of a Pilates exercise program on the flexion-relaxation rate in women with chronic low back pain. | The study was not randomized. |
| 2022 | Lin et al. | The Effectiveness of Group-Based Core Stability Exercise and Educational Booklet for Hospital Workers in Taiwan with Nonspecific Low Back Pain: A Preliminary Study. | The study was not randomized. |

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| 2022 | Mendes et al. | Core stabilisation exercises reduce chronic low back pain in Air Force fighter pilots: a randomised controlled trial. | Protocol registration. |

# APPENDIX 3

## STUDY 3

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# Effect of two core stability exercise programs on core performance and whole-body balance based on smartphone-accelerometry monitorization: a double-blind randomised controlled trial

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Note. This study has been submitted to the *Journal of Sport and Health Sciences*

Prat-Luri A, Vera-Garcia FJ, Moreno-Navarro P, Juan-Recio C, Rios-Calonge J, Heredia-Elvar JR, Elvira JLL, Barbado D. Effect of two core stability exercise programs on core performance and whole-body balance based on smartphone-accelerometry monitorization: a double-blind randomised controlled trial.

## 8.5. Appendix 3

### 8.5.1. Study 3. Effect of two core stability exercise programs on core performance and whole-body balance based on smartphone-accelerometry monitorization: a double-blind randomised controlled trial.

**Abstract**

**Objectives:** To compare the effect of two core stability exercise (CSE) programs designed and monitored through smartphone-accelerometry on core stability, core endurance, and whole-body dynamic balance in young physically active males.

**Methods:** Sixty volunteers were randomised into a control and two CSE experimental groups, one performing a higher intensity program ($EG_{HI}$) and the other a higher volume program ($EG_{HV}$). Pelvic accelerations were quantified during the CSE through smartphone-accelerometry to set and control training intensity. Both the $EG_{HI}$ and the $EG_{HV}$ performed a 6-week program consisting of 15-second higher intensity CSE (pelvic acceleration: 0.40-0.50 $m/s^2$) and 30-second lower intensity CSE (pelvic acceleration: 0.20-0.30 $m/s^2$), respectively. The relative delta of change ($\Delta\%$) was calculated for the following pre- and post-training testing: (i) for core stability, pelvic acceleration measurements during CSE and unstable sitting and sudden loading tests; (ii) for core endurance, prone plank, dominant side bridge and Biering-Sorensen tests; (iii) for whole-body dynamic balance, Y-Balance, tandem and single-leg posturography and triple-hop tests.

**Results:** Although no significant differences were observed between the $EG_{HI}$ and the $EG_{HV}$, the $EG_{HI}$ showed significant lumbopelvic acceleration reductions in the CSE ($\Delta\%$ for composite score: $EG_{HI}$=-15.5; $EG_{HV}$=-10.6; CG=-4.1) compared to controls. Conversely, the $EG_{HV}$ showed a significant endurance increase ($\Delta\%$ for composite score: $EG_{HV}$=15.9; $EG_{HI}$=9.4; CG=2.5) with respect to controls. No significant between-group differences were observed for any other test.

**Conclusion:** The smartphone-accelerometry was useful to characterize specific core stability and endurance adaptations caused by two different CSE programs. Conventional lying and quadruped CSE seem not to be effective to enhance balance in young active males.

**Keywords:** *Trunk exercises, accelerometry, wearable devices*

## INTRODUCTION

Core stability exercises (CSE) refer to those exercises that challenge the trunk's ability to maintain or restore a steady position (usually a neutral lumbopelvic posture) against internal and/or external loads.[1] Although the current evidence confirms the positive effects of CSE programs on motor performance of tasks with high balance demands (e.g., those involving jumping, landing, cutting manoeuvres, etc.)[2] and lower-limb injury prevention and treatment,[3,4] the poor training load characterization[2] limits the understanding of how to manipulate the characteristics of these exercise programs to optimize each individual's response to the training stimuli. Due to the lack of information in the literature, how to establish exercise intensity is one of the most important challenges to know and control the CSE training load.[1,5,6] CSE intensity is commonly modulated modifying the exercise mechanical parameters (e.g., increasing the lever arm, using unstable surfaces…);[7,8] however, this process is generally not based on objective assessments but rather on the personal criteria of the professionals who develop and conduct these programs.[1,5,6]

Considering the above-mentioned limitation, our research group has proposed the use of force platforms and accelerometers embedded into smartphones as potential tools to objectively quantify the intensity of some variants of the most popular CSE: bridging and bird-dog exercises.[1,5] Specially, smartphone-accelerometry has been revealed as a handy and low-cost technique to reliably assess the CSE intensity by measuring the lumbopelvic accelerations during the exercises (i.e., higher acceleration means higher CSE intensity).[5] Recently, Heredia-Elvar et al[6] analysed the relationships between pelvic accelerations recorded during several CSE and the experts' assessments of whether these exercises represented adequate challenge/intensity levels or not for the participants. That study revealed that the experts' observations were related to different smartphone-based acceleration thresholds, which may represent the minimum level of CSE intensity needed to produce adaptations in young and physically active individuals. Despite these efforts, no experimental studies have been carried out yet to verify whether different CSE training intensities, set on the basis of the smartphone acceleration thresholds, induce different core stability adaptation magnitudes.

In order to improve the dose-response characterization of CSE training programs, this study aimed to compared the effects of two different CSE programs, designed and monitored through smartphone-accelerometry, on different core stability and core endurance parameters in young physically active individuals. Specifically, each group performed a 6-week training program using bridging and bird-dog exercises that produced pelvic accelerations above or below the acceleration thresholds established by Heredia-Elvar et al.[6] Since performing CSE below the acceleration thresholds could minimize the impact of the CSE program, the exercise duration was adjusted to the intensity of each program, which resulted in one CSE program with higher intensity and lower volume and another CSE program with higher volume and lower intensity. Considering the core training and testing specificity,[9] it was hypothesized that the higher intensity CSE program and the higher volume CSE program would have a greater impact on core stability and core endurance parameters, respectively. In addition, as it has been stated that CSE might be useful to improve whole-body balance in young athletes,[10-12] the impact of both CSE programs on different dynamic balance tests was also assessed, hypothesizing that the higher intensity CSE program would have a greater effect on the participants' dynamic balance than the higher volume CSE program.

## METHOD

### *Participants*

Sixty-three healthy males were initially recruited. They were physically active, practicing 2-5 sessions per week of 30-120 min of light to vigorous physical exertion. Participants were excluded if they: i) were high-performance athletes whose sport modality required high demands of trunk performance (e.g., judokas or gymnasts); ii) followed a structured training program targeting the trunk structures; or iii) presented a disease that contraindicated performing physical exercise (e.g., musculoskeletal injuries, coronary diseases, visual or vestibular problems, etc.). Prior to the beginning of the study, all participants filled in an informed consent. The study protocol was approved by the University Office for Research Ethics (DPS.FVG.02.14).

### *Experimental design and randomisation*

This study was a double-blinded randomised controlled trial (ClinicalTrials.gov: registration reference: NCT03459430) paired according to participants' initial core stability level. There were two experimental groups and one control group (CG). One of the experimental groups performed the higher intensity CSE program ($EG_{HI}$) and the other performed the higher volume CSE program ($EG_{HV}$), while the CG participants did not train and continued with their regular activity. Participants were randomised to the groups by an independent researcher through opaque envelopes and informed not to start any new exercise programs during the study period. There were no deviations from the registered protocol.

### *Testing protocols*

All the participants followed two weeks of physical assessments before the training period (pre-test) and one week of physical assessments after the training period (post-test). These assessments were performed by the same blinded researchers for all the groups, who were not involved in the intervention. The following measurements were performed in each of the three assessment weeks:

*Core stability tests:* (i) the protocol previously described by Heredia-Elvar et al[6] was used to quantify the lumbopelvic accelerations during the execution of seven 15-s variations of front bridge, back bridge, dominant side bridge and bird-dog exercises (figure 1); (ii) the unstable sitting test[9] was used to measure trunk postural control while trying to keep a center of pressure circular trajectory seated on an labile chair placed on a force platform (9287CA, Kistler®, Switzerland); (iii) a sudden loading protocol[9] was used to assess the trunk's passive and reflex response to quick external perturbations applied (in anterior, posterior and right-lateral directions) to the upper-body center of mass with a pneumatic piston.

*Core endurance tests:* the maximum holding times during the execution of the prone plank test,[13] the dominant side bridge test,[14] and the Biering-Sorensen test[15] were measured to evaluate trunk flexion, lateral bending and extension endurance, respectively.

*Whole-body dynamic balance tests:* (i) the Y-Balance test was performed to explore stability limits in single-leg stance in three directions (anterior, posteromedial, and posterolateral);[16] (ii) the tandem stance balance test and the single-leg stance balance test were used to measure the whole-body dynamic balance through circular tracking tasks while standing on a force platform (9286AA, Kistler, Winterthur, Switzerland);[17] (iii) the triple hop test was used to assess the jumping performance in a single-leg power task with high balance demands. The Y-Balance test, single-leg stance balance test and triple hop test were performed with both limbs (preferred and non-preferred limb), whilst in the tandem stance balance test participants placed their preferred foot ahead. A brief familiarization of 3 repetitions per leg was performed in the Y-Balance test and in the triple hop test.

Due to the high number of trials performed, each assessment week comprised two testing sessions spaced by a one-day rest. The pelvic accelerations during the CSE (2 sets x 7 variations x 4 CSE = 56 trials) were recorded in the first testing session, whilst the rest of the testing protocols were performed in the second testing session.

### *Interventions*

Each CSE program lasted 6 weeks, with 2 weekly sessions spaced 48 h apart. In each of the 12 sessions, participants in the experimental groups performed four repetitions of front bridge, back bridge, dominant side bridge, left side bridge and bird-dog exercises at an intensity level corresponding to the group they belonged to (i.e., $EG_{HI}$ or $EG_{HV}$) based on the pelvic accelerations recorded during the execution of these exercises at the pre-test (figure 1). In this sense, for each of the five CSE, the participants in the $EG_{HI}$ performed an exercise variation (out of the seven recorded) in which pelvic accelerations between 0.40 and 0.50 m/s$^2$ were obtained, whilst the participants in the $EG_{HV}$ performed an exercise variation in which pelvic accelerations between 0.20 and 0.30 m/s$^2$ were recorded. These pelvic acceleration ranges were established based on the pelvic acceleration thresholds proposed by Heredia-Elvar et al.[6] As stated before, the exercise duration was adjusted to the intensity of each CSE program, i.e., each repetition lasted 15 s and 30 s for the $EG_{HI}$ and the $EG_{HV}$, respectively. Both groups rested 1 min between each exercise and 30 s between repetitions, resulting in approximately 21.5 and 16.5 min of session duration for the $EG_{HV}$ and the $EG_{HI}$, respectively. For both groups the session started with a warm-up performed as previously described by Heredia et al.[6]

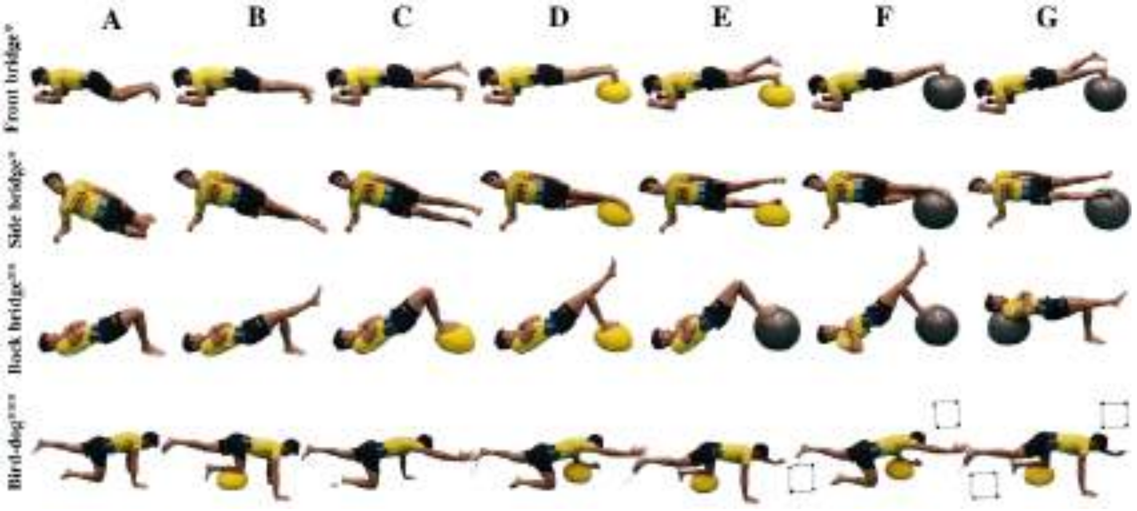

**Figure 1.** Core stability exercises: **Front and side bridge variations*: A) short bridge; B) long bridge; C) bridging with single leg support; D) bridging with double leg support on a hemisphere ball; E) bridging with single leg support on a hemisphere ball; F) bridging with double leg support on a fitball; G) bridging with single leg support on a fitball. ***Back bridge variations*: A) short bridge; B) bridging with single leg support; C) bridging with double leg support on a hemisphere ball; D) bridging with single leg support on a hemisphere ball; E) bridging with double leg support on a fitball; F) bridging with single leg support on a fitball; G) bridging with single leg support and with the upper back on a fitball. ****Bird-dog variations*: A) three-point position with an elevated leg; B) three-point position with the knee on a hemisphere ball; C) classic two-point bird-dog position with elevated contralateral leg and arm; D) two-point bird-dog position with the forearm on a hemisphere ball; E) two-point bird-dog position with the knee on a hemisphere ball; F) two-point bird-dog position with the forearm on a hemisphere ball while drawing squares in the air with the elevated limbs; G) two-point bird-dog position with the knee on a hemisphere ball while drawing squares in the air with the elevated limbs.

In order to adjust the intensity of each exercise throughout both CSE programs, pelvic accelerations were recorded in the fourth and eighth training session. In these sessions, the first two repetitions of each CSE were carried out using the CSE variation performed during the last three sessions, and the last two repetitions were performed using the variation that obtained the next highest pelvic acceleration during the pre-test (see an example of these procedures for each experimental group in the supplementary material figure S1). Of both variations, the one that fell within the corresponding acceleration range of each group (i.e., 0.40-0.50 m/s$^2$ or 0.20-0.30 m/s$^2$)

was selected as the new exercise variation for each participant. In the case that both variations fell within the training range, the one showing the lowest pelvic acceleration was selected. The exercise programs were conducted and supervised by two researchers (CSE experts) that were not involved in the assessment sessions.

### *Data reduction and study outcomes*

Participants' pelvic acceleration during each CSE variation was computed as previously reported.[5] In order to reduce the large number of acceleration parameters obtained from the 28 CSE variations, participants' lumbopelvic postural control during each CSE was quantified as the average of the three most difficult variations performed by each participant (i.e., the three highest acceleration scores). On the other hand, participants' trunk postural control during the unstable sitting test and whole-body dynamic balance during the tandem stance and single-leg stance balance tests were computed through the mean radial error, as described by Moreno-Navarro et al.[17] In addition, participants' trunk response to sudden perturbations was computed in each direction as the angular displacement observed at 110 ms after the perturbation.[9] Finally, an average of both legs (from the two best trials) for the Y-Balance test, the single-leg stance balance test and the triple hop test was performed for further analysis.

### *Statistical analysis*

Mean and standard deviation were calculated for all the outcomes. In addition, the absolute delta of change (Δ) was computed for all parameters. The relative Δ (Δ%) was also calculated to provide a clinically interpretable index of the effect size caused by each CSE program.[18,19] Data normal distribution was analysed through the Kolmogorov-Smirnov test with the Lillefors' correction. The homogeneity of variance was verified using the Levene's test. To assess whether the CSE programs elicited different effects on Δ and Δ% in core stability, core endurance and whole-body balance parameters, several one-way ANOVA for independent measures were carried out, being *group* the between-subject factor (three levels: CG, $EG_{HV}$, $EG_{HI}$). Student t-tests for independent measures were carried out for between-group pairwise comparisons. In addition, Student t-tests for repeated measures were used to analyse pre- and post-test differences for each group. Per-protocol and intention-to-treat analyses were carried out for all parameters. The statistical package SPSS (version 22.0, SPSS Inc., Chicago, IL, USA) was used, with a significance level set at $p<.05$.

## RESULTS

Fifty-six out of the sixty-three initially recruited participants (88.88%) completed the study (figure 2). Regarding participants' baseline characteristics (pre-test), no differences were observed for any of the variables with exception for the posterolateral direction of the Y-Balance test. There was full training attendance in 82.05% of the participants, whilst the rest of participants assisted to at least 10 of the 12 training sessions. No adverse events related to this research were reported by the participants during the experimental period.

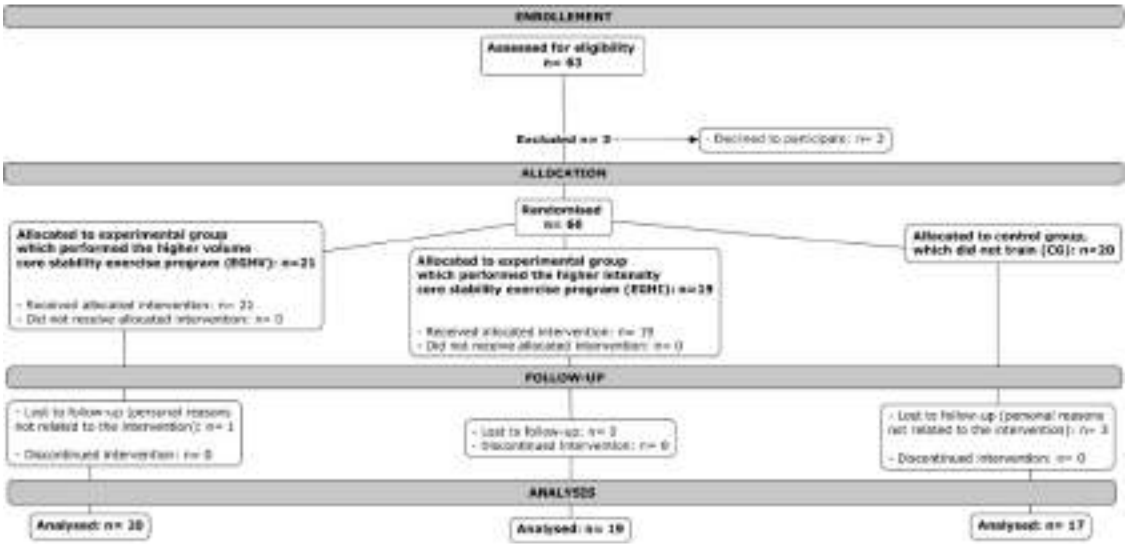

**Figure 2.** Diagram flow process of the randomised controlled trial.

**Table 1.** Baseline characteristics and main outcomes of the participants who completed the study.

| | **CG (n=17)** | **$EG_{HV}$ (n=20)** | **$EG_{HI}$ (n=19)** | ***p* value** |
|---|---|---|---|---|
| Age (years) | 25.9 ± 4.4 | 23.7 ± 4.2 | 22.4 ± 5.0 | 0.07 |
| Height (m) | 1.7 ± 0.1 | 1.8 ± 0.1 | 1.75 ± 0.1 | 0.53 |
| Weight (kg) | 73.3 ± 9.0 | 77.1 ± 8.8 | 73.2 ± 6.6 | 0.26 |
| BMI (kg/m$^2$) | 24.0 ± 2.2 | 24.5 ± 2.3 | 23.7 ± 1.7 | 0.44 |
| ***Core stability tests - Outcome (units)*** | | | | |
| *Core stability exercise accelerometry tests - Lumbopelvic acceleration (m/s$^2$)* | | | | |
| Front bridge | 0.45 ± 0.10 | 0.48 ± 0.09 | 0.47 ± 0.11 | 0.70 |
| Back bridge | 0.44 ± 0.12 | 0.48 ± 0.10 | 0.50 ± 0.10 | 0.32 |
| Dominant side bridge | 0.45 ± 0.10 | 0.43 ± 0.08 | 0.47 ± 0.09 | 0.34 |
| Bird-dog | 0.40 ± 0.11 | 0.44 ± 0.07 | 0.43 ± 0.09 | 0.47 |
| CSE composite | 0.44 ± 0.08 | 0.46 ± 0.06 | 0.47 ± 0.08 | 0.47 |
| *Unstable sitting test - Mean radial error (mm)* | | | | |
| | 6.91 ± 1.63 | 6.83 ± 1.63 | 6.85 ± 1.50 | 0.99 |
| *Sudden loading protocol - Maximal angular displacement at 110 ms (º)* | | | | |
| Anterior direction | 5.36 ± 0.92 | 5.04 ± 0.75 | 4.99 ± 0.73 | 0.35 |
| Lateral direction | 4.59 ± 0.94 | 4.40 ± 0.93 | 4.55 ± 1.21 | 0.84 |
| Posterior direction | 9.86 ± 1.12 | 9.28 ± 1.20 | 9.66 ± 1.45 | 0.39 |
| ***Core endurance tests – Maximal holding time (s)*** | | | | |
| Prone plank test | 161.5 ± 65.9 | 156.8 ± 48.5 | 164.2 ± 52.1 | 0.91 |
| Dominant side bridge test | 93.7 ± 24.5 | 93.3 ± 22.3 | 95.8 ± 33.2 | 0.95 |
| Biering-Sorensen test | 118.0 ± 43.0 | 120.1 ± 37.4 | 117.3 ± 31.1 | 0.97 |
| Core endurance composite | 124.4 ± 35.0 | 123.4 ± 28.5 | 125.8 ± 30.2 | 0.97 |
| ***Whole-body dynamic balance tests (units)*** | | | | |
| *Y-Balance test - Distance reached normalized to the leg length (%)* | | | | |
| Anterior direction | 59.4 ± 6.6 | 61.1 ± 4.8 | 60.0 ± 6.3 | 0.67 |
| Posterolateral direction | 102.7 ± 7.6 | 108.8 ± 3.9 | 104.5 ± 8.4 | 0.03 |
| Posteromedial direction | 108.7 ± 7.1 | 110.9 ± 5.6 | 107.7 ± 7.3 | 0.30 |
| Y-Balance composite | 90.3 ± 6.8 | 93.6 ± 3.9 | 90.7 ± 6.9 | 0.18 |
| *Triple hop test - Distance reached normalized to the leg length (m)* | | | | |
| | 4.99 ± 0.63 | 4.96 ± 0.68 | 4.90 ± 0.48 | 0.90 |
| *Tandem stance balance test - Mean radial error (mm)* | | | | |
| | 9.87 ± 1.96 | 10.60 ± 2.21 | 9.40 ± 0.97 | 0.13 |
| *Single-leg stance balance test - Mean radial error (mm)* | | | | |
| | 11.93 ± 1.43 | 11.46 ± 2.37 | 10.72 ± 1.86 | 0.51 |

*Data are presented as Mean ± SD. SD: standard deviation; CG: control group; $EG_{HV}$: experimental group which performed the higher volume program; $EG_{HI}$: experimental group which performed the higher intensity program; CSE: core stability exercise. The initial sample differed from the indicated in the table in the following baseline outcomes: 1) Trunk acceleration during the CSE: CG=17, $EG_{HV}$=19, $EG_{HI}$=19; 2) Sudden loading in anterior direction: CG=17, $EG_{HV}$=20, $EG_{HI}$=18; 3) Sudden loading in lateral direction: CG=17, $EG_{HV}$=20, $EG_{HI}$=18; 4) Sudden loading in posterior direction: CG=16, $EG_{HV}$=20, $EG_{HI}$=17; 5) Triple hop test: CG=14, $EG_{HV}$=18, $EG_{HI}$=19; 6) Single-leg and tandem balance tests: CG=17, $EG_{HV}$=19, $EG_{HI}$=18.*

*Core stability outcomes*

One-way ANOVA showed overall between-group differences in the lumbopelvic acceleration scores for the front bridge (Δ: F=3.684, *p*=.03; Δ%: F=4.101, *p*=.02), the bird-dog (Δ: F=4.193, *p*=.02; Δ%: F=4.498, *p*=.01), and the CSE composite (Δ: F=3.432, *p*=.04; Δ%: F=3.660, *p*=.03). As seen in table 2, pairwise comparisons indicated that $EG_{HV}$ presented significant lumbopelvic acceleration reductions in three of the four CSE and in the CSE composite score (-10.6≤Δ%≤-13.5); however, these changes were only significantly different from the CG for the front bridge. On the other hand, the $EG_{HI}$ showed significant lumbopelvic acceleration reductions in all the CSE and in the CSE composite (-11.7≤Δ%≤-19.1), from which, the reductions in the front bridge, the bird-dog and the CSE composite were significantly different with respect to the CG. No significant differences were observed for the lumbopelvic acceleration reductions between the $EG_{HV}$ and the $EG_{HI}$.

Regarding the unstable sitting test, all the groups showed a significant mean radial error improvement in the post-test; however, no significant between-group differences were observed. In addition, no significant pre-post changes nor between-group differences were observed in the sudden loading protocol.

*Core endurance outcomes*

One-way ANOVA showed overall differences between groups in the core endurance composite score (Δ: F=4.848, *p*=.01). As seen in table 3, pairwise comparisons showed that $EG_{HV}$ presented a significant increase in the three endurance tests and in the core endurance composite (11.5≤Δ%≤20.5), from which, the improvements in the prone plank test and in the composite were significantly different from the CG. On the other hand, the $EG_{HI}$ presented a significant increase in the Biering-Sorensen test and in the core endurance composite (9.4≤Δ%≤15.5), but no significant differences were observed compared to the CG. Similarly, no significant differences were observed for the endurance time increases between the $EG_{HV}$ and the $EG_{HI}$.

*Whole-body dynamic balance outcomes*

One-way ANOVA did not show overall differences between groups in any of the whole-body dynamic balance tests. As seen in table 4, all groups showed pre-post changes in the Y-Balance test except for the anterior direction in the $EG_{HI}$ and for the posterolateral direction in the $EG_{HI}$ and the CG. In addition, the $EG_{HI}$ and the CG showed pre-post differences in the single-leg stance balance test. Pairwise comparisons did not show significant differences between groups.

**Table 2.** Per-protocol analyses of the core stability outcomes before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| *Core stability exercise accelerometry tests - Lumbopelvic acceleration (m/s$^2$)* | | | | | |
| Front bridge | CG (17) | 0.45 ± 0.10 | 0.44 ± 0.09 | -0.01 ± 0.07 | -0.1 ± 17.7 |
| | $EG_{HV}$ (19) | 0.48 ± 0.09 | 0.41 ± 0.09* | -0.07 ± 0.08$^{A}$ | -13.5 ± 14.7$^{A}$ |
| | $EG_{HI}$ (19) | 0.47 ± 0.11 | 0.40 ± 0.09* | -0.06 ± 0.07$^{A}$ | -11.9 ± 13.2$^{A}$ |
| Back bridge | CG (17) | 0.44 ± 0.12 | 0.40 ± 0.12 | -0.04 ± 0.09 | -9.0 ± 16.9 |
| | $EG_{HV}$ (19) | 0.48 ± 0.10 | 0.42 ± 0.08* | -0.06 ± 0.09 | -11.7 ± 15.7 |
| | $EG_{HI}$ (19) | 0.50 ± 0.10 | 0.40 ± 0.07* | -0.09 ± 0.08 | -17.0 ± 14.0 |
| Dominant side bridge | CG (17) | 0.45 ± 0.10 | 0.43 ± 0.09 | -0.02 ± 0.10 | -0.8 ± 21.3 |
| | $EG_{HV}$ (19) | 0.43 ± 0.08 | 0.42 ± 0.13 | -0.01 ± 0.10 | -1.7 ± 21.8 |
| | $EG_{HI}$ (19) | 0.47 ± 0.09 | 0.41 ± 0.10* | -0.06 ± 0.08 | -11.7 ± 22.2 |
| Bird-dog | CG (17) | 0.40 ± 0.11 | 0.38 ± 0.09 | -0.02 ± 0.07 | -0.6 ± 20.8 |
| | $EG_{HV}$ (19) | 0.44 ± 0.07 | 0.39 ± 0.08* | -0.05 ± 0.06 | -12.1 ± 14.3 |
| | $EG_{HI}$ (19) | 0.43 ± 0.09 | 0.34 ± 0.07* | -0.09 ± 0.09$^{A}$ | -19.1 ± 17.8$^{A}$ |
| CSE composite | CG (17) | 0.44 ± 0.08 | 0.41 ± 0.08 | -0.02 ± 0.06 | -4.1 ± 13.2 |
| | $EG_{HV}$ (19) | 0.46 ± 0.06 | 0.41 ± 0.08* | -0.05 ± 0.06 | -10.6 ± 13.1 |
| | $EG_{HI}$ (19) | 0.47 ± 0.08 | 0.39 ± 0.07* | -0.08 ± 0.06$^{A}$ | -15.5 ± 11.7$^{A}$ |
| *Unstable sitting test - Mean radial error (mm)* | | | | | |
| | CG (17) | 6.91 ± 1.64 | 6.45 ± 1.32* | -0.47 ± 0.76 | -5.5 ± 10.8 |
| | $EG_{HV}$ (20) | 6.84 ± 1.63 | 6.28 ± 1.55* | -0.56 ± 0.89 | -7.6 ± 11.3 |
| | $EG_{HI}$ (19) | 6.86 ± 1.51 | 6.26 ± 1.33* | -0.59 ± 0.80 | -7.8 ± 11.5 |
| *Sudden loading protocol - Maximal angular displacement at 110 ms (º)* | | | | | |
| Frontal direction | CG (17) | 5.36 ± 0.92 | 5.15 ± 0.89 | -0.21 ± 0.77 | -3.2 ± 14.2 |
| | $EG_{HV}$ (20) | 5.04 ± 0.76 | 4.91 ± 0.90 | -0.13 ± 0.84 | -1.8 ± 16.9 |
| | $EG_{HI}$ (18) | 5.00 ± 0.73 | 5.20 ± 1.19 | 0.20 ± 1.20 | 5.1 ± 23.3 |
| Lateral direction | CG (17) | 4.59 ± 0.94 | 4.50 ± 1.26 | -0.09 ± 1.14 | -0.7 ± 23.3 |
| | $EG_{HV}$ (20) | 4.40 ± 0.94 | 4.29 ± 1.06 | -0.11 ± 1.06 | -0.6 ± 27.4 |
| | $EG_{HI}$ (18) | 4.55 ± 1.22 | 4.81 ± 1.07 | 0.26 ± 1.00 | 9.8 ± 27.4 |
| Posterior direction | CG (16) | 9.86 ± 1.13 | 9.41 ± 1.43 | -0.46 ± 1.41 | -4.1 ± 13.6 |
| | $EG_{HV}$ (20) | 9.29 ± 1.20 | 8.79 ± 1.58 | -0.50 ± 1.84 | -4.3 ± 18.0 |
| | $EG_{HI}$ (17) | 9.67 ± 1.46 | 9.28 ± 1.34 | -0.39 ± 1.37 | -2.9 ± 14.5 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; $EG_{HV}$: experimental group which performed the higher volume program; $EG_{HI}$: experimental group which performed the higher intensity program; CSE: core stability exercise. For pelvic accelerations during the CSE, an average of the three most difficult variations of each exercise (i.e., the three highest accelerations) were calculated for each participant. *Significant pre-post differences p<.05. $^{A}$Significantly different with respect to the CG.*

***Table 3.*** Per-protocol analyses of the maximal holding time (s) observed in the core endurance tests before (Pre-test) and after (Post-test) the training period.

| | Sample (n) | Pre-test | Post-test | Δ | Δ (%) |
|---|---|---|---|---|---|
| Prone plank test | CG (17) | 161.5 ± 65.9 | 161.2 ± 54.2 | -0.3 ± 50.6 | 8.2 ± 43.6 |
| | $EG_{HV}$ (20) | 156.8 ± 48.5 | 186.3 ± 62.6* | 29.5 ± 38.6$^{A}$ | 20.5 ± 25.6 |
| | $EG_{HI}$ (19) | 164.2 ± 52.1 | 177.9 ± 63.4 | 13.7 ± 38.7 | 10.6 ± 26.0 |
| Dominant side bridge test | CG (17) | 93.6 ± 24.5 | 91.4 ± 22.0 | -2.3 ± 18.3 | 1.1 ± 23.6 |
| | $EG_{HV}$ (20) | 93.3 ± 22.3 | 102.1 ± 23.7* | 8.8 ± 16.2 | 11.5 ± 19.4 |
| | $EG_{HI}$ (19) | 94.3 ± 33.2 | 95.2 ± 27.8 | 1.4 ± 23.1 | 7.1 ± 25.0 |
| Biering-Sorensen test | CG (17) | 118.0 ± 43.0 | 115.4 ± 35.1 | -2.6 ± 34.4 | 5.3 ± 32.7 |
| | $EG_{HV}$ (20) | 120.1 ± 37.4 | 135.3 ± 37.0* | 15.2 ± 18.5 | 15.8 ± 22.6 |
| | $EG_{HI}$ (19) | 117.3 ± 31.1 | 132.7 ± 36.6* | 15.4 ± 27.2 | 15.5 ± 26.4 |
| Core endurance composite | CG (17) | 124.4 ± 35.0 | 122.7 ± 25.4 | -1.7 ± 21.2 | 2.5 ± 23.0 |
| | $EG_{HV}$ (20) | 123.4 ± 28.5 | 141.2 ± 29.8* | 17.8 ± 14.6$^{A}$ | 15.9 ± 14.0$^{A}$ |
| | $EG_{HI}$ (19) | 125.8 ± 30.2 | 135.9 ± 35.6* | 10.2 ± 21.1 | 9.4 ± 17.8 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; $EG_{HV}$: experimental group which performed the higher volume program; $EG_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences p<.05. $^{A}$Significantly different with respect to the CG.*

**Table 4.** Per-protocol analyses of the whole-body dynamic balance outcomes before (Pre-test) and after (Post-test) the training period.

| | Sample (n) | Pre-test | Post-test | Δ | Δ (%) |
|---|---|---|---|---|---|
| *Y-Balance test - Distance reached normalized to the leg length (%)* | | | | | |
| Anterior direction | CG (17) | 59.4 ± 6.6 | 60.6 ± 6.1* | 1.2 ± 1.6 | 2.1 ± 2.6 |
| | $EG_{HV}$ (20) | 61.1 ± 4.8 | 63.0 ± 4.2* | 1.9 ± 3.6 | 3.3 ± 6.5 |
| | $EG_{HI}$ (19) | 60.0 ± 6.3 | 61.3 ± 5.2 | 1.3 ± 4.0 | 3.2 ± 7.0 |
| Posterolateral direction | CG (17) | 102.7 ± 7.6 | 104.5 ± 6.3 | 1.8 ± 3.7 | 1.9 ± 3.9 |
| | $EG_{HV}$ (20) | 108.8 ± 3.9 | 110.5 ± 4.1* | 1.7 ± 2.5 | 1.6 ± 2.3 |
| | $EG_{HI}$ (19) | 104.5 ± 8.4 | 105.6 ± 6.7 | 1.1 ± 3.5 | 1.2 ± 3.3 |
| Posteromedial direction | CG (17) | 108.7 ± 7.1 | 111.0 ± 5.8* | 2.3 ± 2.8 | 2.2 ± 2.8 |
| | $EG_{HV}$ (20) | 110.9 ± 5.6 | 113.6 ± 5.2* | 2.7 ± 3.4 | 2.5 ± 3.2 |
| | $EG_{HI}$ (19) | 107.7 ± 7.3 | 109.4 ± 6.6* | 1.7 ± 3.0 | 1.7 ± 2.8 |
| Y-Balance composite | CG (17) | 90.3 ± 6.8 | 92.0 ± 5.8* | 1.8 ± 2.0 | 2.1 ± 2.0 |
| | $EG_{HV}$ (20) | 93.6 ± 3.9 | 95.7 ± 3.8* | 2.1 ± 2.1 | 2.1 ± 2.1 |
| | $EG_{HI}$ (19) | 90.7 ± 6.9 | 92.1 ± 5.6* | 1.3 ± 2.7 | 1.3 ± 2.7 |
| *Triple hop test - Distance reached normalized to the leg length (N times leg length)* | | | | | |
| | CG (14) | 4.99 ± 0.63 | 4.91 ± 0.63 | -0.1 ± 0.3 | -1.6 ± 5.2 |
| | $EG_{HV}$ (18) | 4.96 ± 0.68 | 4.97 ± 0.66 | 0.0 ± 0.2 | 0.3 ± 4.6 |
| | $EG_{HI}$ (19) | 4.90 ± 0.48 | 4.87 ± 0.46 | 0.0 ± 0.3 | -0.3 ± 6.6 |
| *Tandem stance balance test - Mean radial error (mm)* | | | | | |
| | CG (17) | 9.87 ± 1.96 | 9.28 ± 1.48 | -0.6 ± 1.6 | -4.5 ± 15.1 |
| | $EG_{HV}$ (19) | 10.60 ± 2.21 | 9.81 ± 2.15 | -0.8 ± 2.4 | -5.0 ± 21.8 |
| | $EG_{HI}$ (18) | 9.40 ± 0.97 | 9.07 ± 1.36 | -0.3 ± 1.5 | -2.7 ± 16.6 |
| *Single-leg stance balance test - Mean radial error (mm)* | | | | | |
| | CG (17) | 11.19 ± 1.43 | 10.43 ± 1.33* | -0.8 ± 1.1 | -6.4 ± 9.5 |
| | $EG_{HV}$ (19) | 11.46 ± 2.37 | 11.00 ± 2.09 | -0.5 ± 1.4 | -3.2 ± 11.3 |
| | $EG_{HI}$ (18) | 10.72 ± 1.86 | 9.89 ± 1.08* | -0.8 ± 1.6 | -6.0 ± 14.9 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; $EG_{HV}$: experimental group which performed the higher volume program; $EG_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences p<.05.*

## DISCUSSION

ANOVAs results revealed that the CSE programs were useful to improve lumbopelvic postural control during the CSE and the holding time in the core endurance tests. However, the lack of significant differences between both CSE programs suggests that the volume and the smartphone-based intensity set for these short programs (6 weeks, 2 sessions/week) were not enough to differentially promote core stability and/or endurance adaptations in young physically active males. Nevertheless, considering the pairwise comparison results, the main hypothesis of this study cannot clearly be rejected. This is, based on the stimulus specificity, the higher intensity CSE program seemed to produce greater improvements in lumbopelvic postural control during the CSE execution, while the higher volume CSE program seemed to have a larger impact on the holding time during the core endurance tests. In this sense, only the $EG_{HI}$ showed significant lumbopelvic acceleration reductions in the CSE (Δ% for composite score: $EG_{HI}$=-15.5; $EG_{HV}$=-10.6; CG=-4.1) compared to the CG, and only the $EG_{HV}$ showed significant endurance increases (Δ% for composite score: $EG_{HV}$=15.9; $EG_{HI}$=9.4; CG=2.5) with respect to the CG, which reveals specific adaptations depending on the stimulus provided for each CSE program. Although these results contribute to the characterization of the dose-response relationship of CSE programs, future studies with larger samples and longer training durations should explore which CSE intensities and volumes are most appropriate to produce differential core stability and endurance adaptations in this and in other populations.

Despite the improvements in lumbopelvic postural control during the CSE (especially in the $EG_{HI}$), none of the CSE programs had a noticeable impact on trunk postural control during unstable sitting nor on trunk response to sudden perturbations. Therefore, trunk postural control demands imposed on the participants while maintaining lying and quadruped positions during the CSE execution induced core adaptations only revealed through specific CSE measurements. These results support the need for specificity when measuring and training core stability in young physically active males.[9,20] Similarly, both CSE programs did not obtain a significant impact on whole-body dynamic balance, which calls into question the effectiveness of using conventional isometric CSE (performed in lying and/or quadruped positions) to enhance balance in young individuals without postural control deficits. Although some studies found that CSE programs had a positive effect on different balance outcomes in similar populations,[10-12] the training programs were longer (e.g., 8-12 weeks, 3 sessions per week, 60-minute session duration…)[11,12] or they combined CSE executed in lying positions with general exercises performed in more functional positions (e.g., walking lunge, frontal and lateral stance balance, shoulder contact…).[10] In addition, although other studies have also found pre-post balance improvements in similar CSE interventions,[21,22] they did not obtain changes compared to the CG. Therefore, further research is needed to determine to what extent the impact of performing conventional lying CSE can be generalizable to balance measures obtained in more functional conditions.

As explained above, there are some limitations that could bias the result interpretation, mainly the sample characteristics and the short program duration. In addition, although this experimental study aimed to compare the effects of performing higher intensity *vs.* longer duration CSE, it would be interesting to match the training volume of both programs to compare the effects of performing CSE at intensities above and below the acceleration thresholds established by Heredia-Elvar et al.[6]

## CONCLUSION

In summary, while the higher intensity CSE program had a greater impact on lumbopelvic control during the execution of the CSE, the higher volume CSE program produced larger effects on the core endurance tests. However, both short-term CSE programs did not have a significant impact on trunk postural control on an unstable seat, on trunk response to sudden perturbations, or on whole-body dynamic balance. Overall, although further research is needed to properly characterize the dose-response relationship of CSE programs in different populations, the training load control performed in this study through the smartphone-accelerometry allowed to describe the specificity of the effects caused by two CSE programs in young physically active males.

### Contributors

All authors listed have made a substantial, direct and intellectual contribution to the work and approved it for publication.

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### Competing interests

The authors declare that they have no competing interests.

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## SUPPLEMENTARY MATERIAL

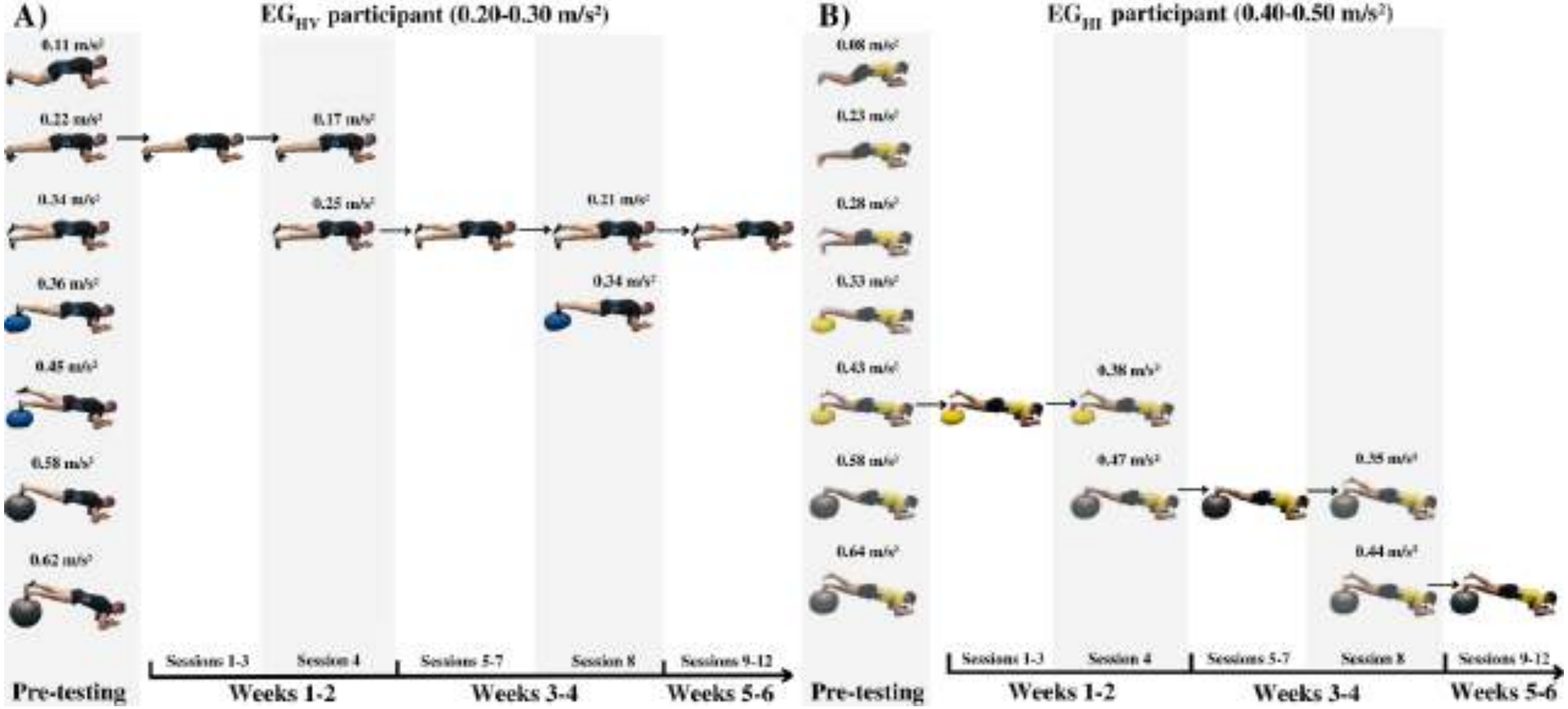


**Figure S1.** Example of the exercise intensity readjustment during the training process for two participants. The grey shaded areas represent the acceleration assessment periods. The pre-test refers to the 2nd week of baseline assessment in which all the exercise variations were performed by the participants. From all the variations, the one that was within the corresponding acceleration range of each group (i.e., 0.20-0.30 m/s$^2$ for EG$_{HV}$ and 0.40-0.50 m/s$^2$ for EG$_{HI}$) in the pre-test was selected for weeks 1 and 2 of the training period. In the 4th and 8th session, an exercise intensity readjustment was performed using the smartphone-accelerometer. In these sessions, the participants performed 2 repetitions (out of 4 for each core stability exercise) using the variation that they had been performing the last three sessions, and 2 repetitions using the variation that obtained the next higher lumbopelvic acceleration during the pre-test. Of both variations, the one that fell within the corresponding acceleration range of each group was selected as the new exercise variation for the next two weeks of training.

**Table S1.** Percentage of participants of both experimental groups who progressed 0, 1 or 2 intensity levels in each exercise (i.e., changing to a more difficult exercise variation) during the exercise program.

| | **EG$_{HV}$ (n=20)** | **EG$_{HI}$ (n=19)** |
|---|---|---|
| *Front bridge* | | |
| No progression | 5.3 | 11.1 |
| Increased 1 level | 42.1 | 27.8 |
| Increased 2 levels | 52.6 | 61.1 |
| *Back bridge* | | |
| No progression | 21.1 | 5.6 |
| Increased 1 level | 36.8 | 66.7 |
| Increased 2 levels | 42.1 | 27.8 |
| *Dominant side bridge* | | |
| No progression | 10.5 | 16.7 |
| Increased 1 level | 52.6 | 38.9 |
| Increased 2 levels | 36.8 | 44.4 |
| *Bird-dog* | | |
| No progression | 15.8 | 11.1 |
| Increased 1 level | 47.4 | 55.6 |
| Increased 2 levels | 36.8 | 33.3 |

*EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program.*

**Table S2.** Exercise variations in which participants from each core stability exercise program trained.

| | **EG$_{HV}$ (n=20)** | **EG$_{HI}$ (n=19)** |
|---|---|---|
| *Frontal bridge* | | |
| Weeks 1-2 | 2.4 ± 0.9 | 4.3 ± 1.1 |
| Weeks 3-4 | 3.4 ± 0.9 | 5.6 ± 1.1 |
| Weeks 5-6 | 4.3 ± 1.3 | 6.4 ± 1.0 |
| *Back bridge* | | |
| Weeks 1-2 | 2.3 ± 1.5 | 4.1 ± 1.3 |
| Weeks 3-4 | 2.9 ± 1.1 | 4.4 ± 1.5 |
| Weeks 5-6 | 3.5 ± 1.3 | 5.1 ± 1.5 |
| *Dominant side bridge* | | |
| Weeks 1-2 | 1.8 ± 0.7 | 3.1 ± 1.1 |
| Weeks 3-4 | 2.4 ± 0.7 | 3.9 ± 1.2 |
| Weeks 5-6 | 3.0 ± 0.8 | 4.5 ± 1.4 |
| *Left side bridge* | | |
| Weeks 1-2 | 1.8 ± 0.7 | 3.1 ± 1.1 |
| Weeks 3-4 | 2.2 ± 0.7 | 3.9 ± 1.1 |
| Weeks 5-6 | 2.8 ± 0.8 | 4.3 ± 1.4 |
| *Bird-dog* | | |
| Weeks 1-2 | 2.8 ± 1.0 | 5.4 ± 1.3 |
| Weeks 3-4 | 3.5 ± 1.0 | 6.8 ± 1.3 |
| Weeks 5-6 | 4.2 ± 1.1 | 6.7 ± 1.1 |

*EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program.*

**Table S3.** Intention-to-treat analyses of the core stability outcomes before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| *Core stability exercise accelerometry tests – Lumbopelvic acceleration ($m/s^2$)* | | | | | |
| Front bridge | CG (21) | 0.46 ± 0.09 | 0.45 ± 0.08 | -0.01 ± 0.06 | -0.3 ± 15.8 |
| | EG$_{HV}$ (22) | 0.49 ± 0.09 | 0.43 ± 0.11* | -0.06 ± 0.07$^{A}$ | -12.7 ± 14.1$^{A}$ |
| | EG$_{HI}$ (20) | 0.46 ± 0.10 | 0.41 ± 0.09* | -0.05 ± 0.07$^{A}$ | -10.6 ± 13.1$^{A}$ |
| Back bridge | CG (21) | 0.46 ± 0.11 | 0.42 ± 0.12 | -0.04 ± 0.09 | -7.1 ± 15.6 |
| | EG$_{HV}$ (22) | 0.50 ± 0.06 | 0.46 ± 0.07* | -0.04 ± 0.09 | -6.8 ± 15.3 |
| | EG$_{HI}$ (20) | 0.51 ± 0.10 | 0.43 ± 0.08* | -0.08 ± 0.08 | -14.4 ± 14.0 |
| Dominant side bridge | CG (21) | 0.49 ± 0.12 | 0.45 ± 0.09 | -0.03 ± 0.11 | -4.6 ± 16.5 |
| | EG$_{HV}$ (22) | 0.47 ± 0.09 | 0.45 ± 0.12 | -0.02 ± 0.09 | -4.3 ± 19.9 |
| | EG$_{HI}$ (20) | 0.49 ± 0.11 | 0.43 ± 0.11* | -0.06 ± 0.08 | -11.7 ± 14.8 |
| Bird-dog | CG (21) | 0.42 ± 0.11 | 0.41 ± 0.09 | -0.01 ± 0.06 | 0.1 ± 17.9 |
| | EG$_{HV}$ (22) | 0.46 ± 0.07 | 0.41 ± 0.08 | -0.04 ± 0.06 | -9.6 ± 13.6$^{A}$ |
| | EG$_{HI}$ (20) | 0.43 ± 0.09 | 0.35 ± 0.07 | -0.08 ± 0.09$^{A}$ | -17.2 ± 17.7$^{A}$ |
| CSE composite | CG (21) | 0.46 ± 0.08 | 0.43 ± 0.08 | -0.02 ± 0.06 | -4.2 ± 11.4 |
| | EG$_{HV}$ (22) | 0.48 ± 0.05 | 0.44 ± 0.08* | -0.04 ± 0.06 | -8.9 ± 12.2 |
| | EG$_{HI}$ (20) | 0.48 ± 0.08 | 0.41 ± 0.07* | -0.07 ± 0.06$^{A}$ | -13.9 ± 11.3$^{A}$ |
| *Unstable sitting test – Mean radial error (mm)* | | | | | |
| | CG (19) | 7.14 ± 1.72 | 6.72 ± 1.53* | -0.42 ± 0.73 | -5.0 ± 10.3 |
| | EG$_{HV}$ (22) | 6.95 ± 1.60 | 6.44 ± 1.57* | -0.51 ± 0.87 | -6.9 ± 11.0 |
| | EG$_{HI}$ (19) | 6.86 ± 1.51 | 6.26 ± 1.33* | -0.59 ± 0.80 | -7.8 ± 11.5 |
| *Sudden loading protocol - Maximal angular displacement at 110 ms (º)* | | | | | |
| Frontal direction | CG (17) | 5.36 ± 0.92 | 5.15 ± 0.89 | -0.21 ± 0.77 | -3.2 ± 14.2 |
| | EG$_{HV}$ (20) | 5.04 ± 0.76 | 4.91 ± 0.90 | -0.13 ± 0.84 | -1.8 ± 16.9 |
| | EG$_{HI}$ (18) | 5.00 ± 0.73 | 5.20 ± 1.19 | 0.20 ± 1.20 | 5.1 ± 23.3 |
| Lateral direction | CG (17) | 4.59 ± 0.94 | 4.50 ± 1.26 | -0.09 ± 1.14 | -0.7 ± 23.3 |
| | EG$_{HV}$ (20) | 4.40 ± 0.94 | 4.29 ± 1.06 | -0.11 ± 1.06 | -0.6 ± 27.4 |
| | EG$_{HI}$ (18) | 4.55 ± 1.22 | 4.81 ± 1.07 | 0.26 ± 1.00 | 9.8 ± 27.4 |
| Posterior direction | CG (16) | 9.86 ± 1.13 | 9.41 ± 1.43 | -0.46 ± 1.41 | -4.1 ± 13.6 |
| | EG$_{HV}$ (20) | 9.29 ± 1.20 | 8.79 ± 1.58 | -0.50 ± 1.84 | -4.3 ± 18.0 |
| | EG$_{HI}$ (17) | 9.67 ± 1.46 | 9.28 ± 1.34 | -0.39 ± 1.37 | -2.9 ± 14.5 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program; CSE: core stability exercise. For pelvic accelerations during the CSE, an average of the three most difficult variations of each exercise (i.e., the three highest accelerations) were calculated for each participant. *Significant pre-post differences $p<.05$. $^{A}$Significantly different with respect to the CG.*

**Table S4.** Intention-to-treat of the maximal holding time (s) observed in the core endurance tests before (Pre-test) and after (Post-test) the training period.

| | Sample (n) | Pre-test | Post-test | Δ | Δ (%) |
|---|---|---|---|---|---|
| Prone plank test | CG (20) | 159.5 ± 62.2 | 159.3 ± 51.9 | -0.3 ± 46.5 | 7.0 ± 40.2 |
| | EG$_{HV}$ (21) | 154.6 ± 48.3 | 182.7 ± 63.1* | 28.1 ± 38.2$^{A}$ | 19.5 ± 25.3 |
| | EG$_{HI}$ (19) | 164.2 ± 52.1 | 177.9 ± 63.4 | 13.7 ± 38.7 | 15.5 ± 26.4 |
| Dominant side bridge test | CG (20) | 94.2 ± 22.6 | 92.2 ± 20.3 | -2.0 ± 16.9 | 0.9 ± 21.7 |
| | EG$_{HV}$ (21) | 92.1 ± 22.4 | 100.4 ± 24.3* | 8.3 ± 15.9 | 10.9 ± 19.1 |
| | EG$_{HI}$ (19) | 95.8 ± 33.2 | 97.3 ± 27.8 | 1.4 ± 23.1 | 7.1 ± 25.0 |
| Biering-Sorensen test | CG (20) | 122.2 ± 41.1 | 120.0 ± 34.4 | -2.2 ± 31.6 | 4.5 ± 30.1 |
| | EG$_{HV}$ (21) | 120.0 ± 36.4 | 134.4 ± 36.3* | 14.4 ± 18.3$^{A}$ | 15.1 ± 22.3 |
| | EG$_{HI}$ (19) | 117.3 ± 31.1 | 132.7 ± 36.6* | 15.4 ± 27.2 | 15.5 ± 26.4 |
| Core endurance composite | CG (20) | 115.0 ± 28.6 | 116.8 ± 21.2 | 1.9 ± 16.9 | 4.6 ± 19.2 |
| | EG$_{HV}$ (21) | 113.4 ± 24.7 | 128.0 ± 25.3* | 14.6 ± 13.6$^{A}$ | 14.3 ± 14.1 |
| | EG$_{HI}$ (19) | 117.9 ± 28.5 | 125.8 ± 31.8 | 7.9 ± 17.9 | 8.1 ± 16.1 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences $p<.05$. $^{A}$Significantly different with respect to the CG.*

**Table S5.** Intention-to-treat analyses of the whole-body dynamic balance outcomes before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| *Y-Balance test - Distance reached normalized to the leg length (%)* | | | | | |
| Anterior direction | CG (18) | 59.8 ± 6.6 | 60.9 ± 6.1* | 1.1 ± 1.6 | 2.0 ± 2.8 |
| | $EG_{HV}$ (21) | 60.8 ± 5.0 | 62.6 ± 4.5* | 1.8 ± 3.6 | 3.2 ± 6.3 |
| | $EG_{HI}$ (19) | 60.0 ± 6.3 | 61.3 ± 5.2 | 1.3 ± 4.0 | 2.5 ± 7.0 |
| Posterolateral direction | CG (18) | 102.2 ± 7.7 | 103.9 ± 6.6 | 1.7 ± 3.6 | 1.8 ± 3.8 |
| | $EG_{HV}$ (21) | 108.2 ± 4.7 | 109.8 ± 5.1 | 1.6 ± 2.4 | 1.5 ± 2.3 |
| | $EG_{HI}$ (19) | 104.5 ± 8.4 | 105.6 ± 6.7 | 1.1 ± 3.5 | 1.2 ± 3.3 |
| Posteromedial direction | CG (18) | 108.5 ± 6.9 | 110.7 ± 5.8* | 2.2 ± 2.8 | 2.1 ± 2.8 |
| | $EG_{HV}$ (21) | 110.4 ± 5.9 | 113.0 ± 5.9* | 2.6 ± 3.3 | 2.4 ± 3.2 |
| | $EG_{HI}$ (19) | 107.7 ± 7.3 | 109.4 ± 6.6* | 1.7 ± 3.0 | 1.7 ± 2.8 |
| Composite | CG (18) | 90.2 ± 6.6 | 91.8 ± 5.7* | 1.7 ± 2.0 | 1.9 ± 2.4 |
| | $EG_{HV}$ (21) | 93.1 ± 4.4 | 95.1 ± 4.6* | 2.0 ± 2.1 | 2.1 ± 2.3 |
| | $EG_{HI}$ (19) | 90.7 ± 6.9 | 92.1 ± 5.6* | 1.3 ± 2.7 | 1.6 ± 3.0 |
| *Triple hop test - Distance reached normalized to the leg length (N times leg length)* | | | | | |
| | CG (20) | 5.03 ± 0.58 | 5.00 ± 0.58 | 0.0 ± 0.2 | -0.5 ± 5.0 |
| | $EG_{HV}$ (21) | 4.89 ± 0.68 | 4.89 ± 0.67 | 0.0 ± 0.2 | 0.0 ± 4.3 |
| | $EG_{HI}$ (19) | 4.90 ± 0.48 | 4.87 ± 0.46 | 0.0 ± 0.3 | -0.3 ± 6.6 |
| *Tandem stance balance test - Mean radial error (mm)* | | | | | |
| | CG (18) | 10.05 ± 2.05 | 9.49 ± 1.69 | -0.6 ± 1.5 | -4.2 ± 14.7 |
| | $EG_{HV}$ (21) | 10.66 ± 2.12 | 9.94 ± 2.10 | -0.7 ± 2.3 | -4.6 ± 20.7 |
| | $EG_{HI}$ (19) | 9.46 ± 0.98 | 9.21 ± 1.46 | -0.2 ± 1.5 | -2.0 ± 16.4 |
| *Single-leg stance balance test - Mean radial error (mm)* | | | | | |
| | CG (18) | 11.38 ± 1.60 | 10.65 ± 1.61* | -0.7 ± 1.0 | -6.1 ± 9.3 |
| | $EG_{HV}$ (21) | 11.51 ± 2.27 | 11.09 ± 2.03 | -0.4 ± 1.3 | -2.9 ± 10.8 |
| | $EG_{HI}$ (19) | 10.94 ± 2.03 | 10.15 ± 1.54 | -0.8 ± 1.5 | -5.7 ± 14.5 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; $EG_{HV}$: experimental group which performed the higher volume program; $EG_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences $p<.05$.*

**Table S6.** Per-protocol analyses of lumbopelvic acceleration ($m/s^2$) during all front bridge variations before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| **A** | CG (17) | 0.10 ± 0.06 | 0.10 ± 0.05 | 0.00 ± 0.03 | 5.4 ± 29.8 |
| | $EG_{HV}$ (19) | 0.10 ± 0.03 | 0.09 ± 0.03 | -0.01 ± 0.03 | -6.7 ± 35.4 |
| | $EG_{HI}$ (19) | 0.09 ± 0.02 | 0.09 ± 0.03 | 0.00 ± 0.03 | -3.1 ± 28.1 |
| **B** | CG (17) | 0.24 ± 0.12 | 0.23 ± 0.10 | 0.00 ± 0.05 | 5.2 ± 22.6 |
| | $EG_{HV}$ (19) | 0.24 ± 0.10 | 0.20 ± 0.08* | -0.04 ± 0.08 | -12.8 ± 27.2$^{A}$ |
| | $EG_{HI}$ (19) | 0.22 ± 0.12 | 0.20 ± 0.08 | -0.02 ± 0.07 | 1.3 ± 29.9 |
| **C** | CG (17) | 0.38 ± 0.11 | 0.36 ± 0.10 | -0.01 ± 0.07 | -0.7 ± 20.3 |
| | $EG_{HV}$ (19) | 0.37 ± 0.14 | 0.33 ± 0.09 | -0.04 ± 0.10 | -5.3 ± 22.1 |
| | $EG_{HI}$ (19) | 0.40 ± 0.13 | 0.36 ± 0.10* | -0.04 ± 0.07 | -8.2 ± 19.7 |
| **D** | CG (17) | 0.31 ± 0.16 | 0.32 ± 0.14 | 0.00 ± 0.10 | 7.6 ± 31.2 |
| | $EG_{HV}$ (19) | 0.33 ± 0.11 | 0.27 ± 0.11* | -0.06 ± 0.09$^{A}$ | -17.1 ± 22.1$^{A}$ |
| | $EG_{HI}$ (19) | 0.28 ± 0.10 | 0.26 ± 0.10 | -0.02 ± 0.08 | -3.8 ± 28.4 |
| **E** | CG (17) | 0.42 ± 0.11 | 0.43 ± 0.11 | 0.01 ± 0.08 | 5.0 ± 19.3 |
| | $EG_{HV}$ (19) | 0.43 ± 0.11 | 0.38 ± 0.11* | -0.05 ± 0.08$^{A}$ | -12.3 ± 17.7$^{A}$ |
| | $EG_{HI}$ (19) | 0.45 ± 0.13 | 0.40 ± 0.11* | -0.05 ± 0.08$^{A}$ | -8.1 ± 15.2$^{A}$ |
| **F** | CG (17) | 0.41 ± 0.12 | 0.40 ± 0.11 | -0.01 ± 0.09 | 0.4 ± 27.8 |
| | $EG_{HV}$ (18) | 0.44 ± 0.12 | 0.36 ± 0.12* | -0.09 ± 0.09$^{A}$ | -17.9 ± 18.0$^{A}$ |
| | $EG_{HI}$ (18) | 0.38 ± 0.10 | 0.34 ± 0.10* | -0.04 ± 0.07 | -10.5 ± 16.6 |
| **G** | CG (16) | 0.41 ± 0.12 | 0.40 ± 0.11 | -0.01 ± 0.09 | 0.4 ± 27.8 |
| | $EG_{HV}$ (18) | 0.44 ± 0.12 | 0.36 ± 0.12* | -0.09 ± 0.09 | -17.9 ± 18.0 |
| | $EG_{HI}$ (19) | 0.38 ± 0.10 | 0.34 ± 0.10* | -0.04 ±0 .07 | -10.5 ± 16.6 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group;* $EG_{HV}$*: experimental group which performed the higher volume program;* $EG_{HI}$*: experimental group which performed the higher intensity program. *Significant pre-post differences p<.05.* $^{A}$*Significantly different with respect to the CG.*

**Table S7.** Per-protocol analyses of lumbopelvic acceleration (m/s$^2$) during all back bridge variations before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| **A** | CG (17) | 0.14±0.06 | 0.13±0.08 | -0.01±0.04 | -6.2±26.2 |
| | EG$_{HV}$ (19) | 0.16±0.05 | 0.15±0.06 | -0.01±0.06 | -1.8±31.5 |
| | EG$_{HI}$ (19) | 0.14±0.05 | 0.15±0.06 | 0.01±0.06 | 6.3±32.2 |
| **B** | CG (17) | 0.42±0.14 | 0.37±0.14* | -0.04±0.05 | -10.4±10.8 |
| | EG$_{HV}$ (19) | 0.45±0.15 | 0.39±0.12* | -0.06±0.11 | -10.8±22.2 |
| | EG$_{HI}$ (19) | 0.44±0.17 | 0.39±0.12 | -0.06±0.12 | -8.4±21.7 |
| **C** | CG (17) | 0.20±0.07 | 0.21±0.09 | 0.01±0.09 | 8.4±46.3 |
| | EG$_{HV}$ (19) | 0.24±0.07 | 0.20±0.07* | -0.04±0.07 | -13.4±24.8 |
| | EG$_{HI}$ (19) | 0.23±0.10 | 0.22±0.08 | 0.00±0.06 | 2.2±25.9 |
| **D** | CG (16) | 0.41±0.17 | 0.37±0.16 | -0.04±0.10 | -8.0±21.7 |
| | EG$_{HV}$ (19) | 0.45±0.16 | 0.38±0.11* | -0.07±0.15* | -11.9±26.0 |
| | EG$_{HI}$ (19) | 0.44±0.15 | 0.40±0.12 | -0.03±0.10 | -3.8±23.1 |
| **E** | CG (14) | 0.39±0.11 | 0.35±0.12 | -0.04±0.12 | -6.5±29.4 |
| | EG$_{HV}$ (17) | 0.44±0.15 | 0.34±0.09* | -0.10±0.16 | -17.5±26.0 |
| | EG$_{HI}$ (17) | 0.46±0.13 | 0.33±0.09* | -0.12±0.14 | -23.9±20.8 |
| **F** | CG (15) | 0.53±0.12 | 0.51±0.13 | -0.02±0.09 | -2.4±16.7 |
| | EG$_{HV}$ (17) | 0.55±0.10 | 0.52±0.10 | -0.03±0.10 | -3.8±22.0 |
| | EG$_{HI}$ (16) | 0.55±0.08 | 0.46±0.08* | -0.09±0.09$^{A}$ | -16.4±14.7$^{A}$ |
| **G** | CG (6) | 0.61±0.29 | 0.42±0.12 | -0.19±0.22 | -24.6±23.5 |
| | EG$_{HV}$ (7) | 0.56±0.20 | 0.45±0.08 | -0.11±0.18 | -15.7±17.3 |
| | EG$_{HI}$ (7) | 0.64±0.33 | 0.51±0.13 | -0.12±0.25 | -12.5±22.3 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences $p<.05$. $^{A}$Significantly different with respect to the CG.*

**Table S8.** Per-protocol analyses of lumbopelvic acceleration (m/s$^2$) during all dominant side bridge variations before (Pre-test) and after (Post-test) the training period.

| | Sample (n) | Pre-test | Post-test | Δ | Δ (%) |
|---|---|---|---|---|---|
| **A** | CG (17) | 0.21 ± 0.10 | 0.18 ± 0.07 | -0.03 ± 0.07 | -6.4 ± 32.1 |
| | EG$_{HV}$ (19) | 0.16 ± 0.04 | 0.16 ± 0.04 | 0.00 ± 0.04 | 2.6 ± 22.7 |
| | EG$_{HI}$ (19) | 0.19 ± 0.07 | 0.16 ± 0.05 | -0.03 ± 0.07 | -11.0 ± 23.5 |
| **B** | CG (17) | 0.35 ± 0.14 | 0.32 ± 0.11* | -0.03 ± 0.11 | -4.1 ± 25.3 |
| | EG$_{HV}$ (19) | 0.29 ± 0.13 | 0.30 ± 0.08 | 0.00 ± 0.10 | 8.6 ± 33.2 |
| | EG$_{HI}$ (19) | 0.33 ± 0.10 | 0.29 ± 0.07* | -0.04 ± 0.09 | -9.9 ± 21.1$^{B}$ |
| **C** | CG (17) | 0.39 ± 0.12 | 0.40 ± 0.10 | 0.01 ± 0.12 | 8.2 ± 29.5 |
| | EG$_{HV}$ (19) | 0.36 ± 0.11 | 0.39 ± 0.12 | 0.03 ± 0.10 | 10.7 ± 31.2 |
| | EG$_{HI}$ (19) | 0.43 ± 0.10 | 0.39 ± 0.10 | -0.03 ± 0.08$^{B}$ | -7.2 ± 14.9$^{B}$ |
| **D** | CG (17) | 0.42 ± 0.11 | 0.41 ± 0.10 | -0.01 ± 0.10 | 1.2 ± 25.1 |
| | EG$_{HV}$ (19) | 0.37 ± 0.08 | 0.38 ± 0.12 | 0.01 ± 0.09 | 2.0 ± 24.3 |
| | EG$_{HI}$ (19) | 0.41 ± 0.10 | 0.37 ± 0.10* | -0.04 ± 0.09 | -9.2 ± 19.1 |
| **E** | CG (17) | 0.48 ± 0.11 | 0.47 ± 0.10 | -0.01 ± 0.13* | 0.6 ± 23.5 |
| | EG$_{HV}$ (19) | 0.47 ± 0.08 | 0.44 ± 0.13 | -0.02 ± 0.09 | -6.2 ± 20.0 |
| | EG$_{HI}$ (19) | 0.49 ± 0.11 | 0.44 ± 0.11* | -0.05 ± 0.06 | -9.9 ± 11.4 |
| **F** | CG (6) | 0.62 ± 0.13 | 0.48 ± 0.10 | -0.14 ± 0.19 | -19.5 ± 24.7 |
| | EG$_{HV}$ (11) | 0.51 ± 0.09 | 0.47 ± 0.19 | -0.04 ± 0.15 | -9.6 ± 28.4 |
| | EG$_{HI}$ (11) | 0.48 ± 0.13 | 0.40 ± 0.12 | -0.07 ± 0.12 | -14.0 ± 21.2 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences $p<.05$. $^{A}$Significantly different with respect to the CG; $^{B}$Significantly different with respect to the EG$_{HV}$.*

**Table S9.** Per-protocol analyses of lumbopelvic acceleration ($m/s^2$) during all bird-dog variations before (Pre-test) and after (Post-test) the training period.

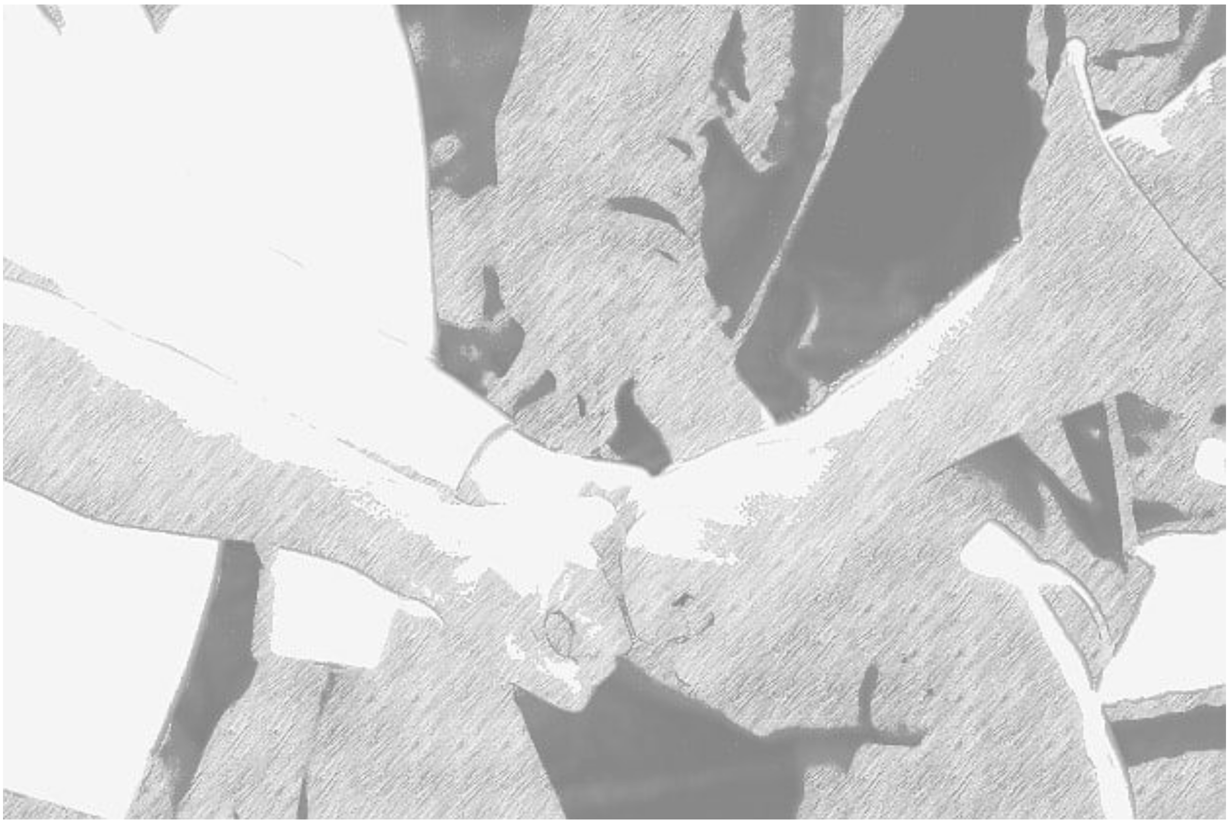
| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| **A** | CG (17) | 0.13 ± 0.05 | 0.12 ± 0.06 | 0.00 ± 0.02 | -3.5 ± 15.9 |
| | EG$_{HV}$ (19) | 0.15 ± 0.05 | 0.14 ± 0.06 | -0.01 ± 0.03 | -7.2 ± 18.6 |
| | EG$_{HI}$ (18) | 0.15 ± 0.06 | 0.13 ± 0.03* | -0.02 ± 0.04 | -8.2 ± 18.9 |
| **B** | CG (17) | 0.16 ± 0.06 | 0.16 ± 0.06 | 0.00 ± 0.03 | 3.7 ± 21.2 |
| | EG$_{HV}$ (19) | 0.18 ± 0.04 | 0.17 ± 0.05 | -0.01 ± 0.04 | -4.0 ± 28.7 |
| | EG$_{HI}$ (19) | 0.17 ± 0.06 | 0.16 ± 0.04 | -0.01 ± 0.04 | -3.8 ± 18.3 |
| **C** | CG (17) | 0.22 ± 0.08 | 0.24 ± 0.08 | 0.02 ± 0.07 | 13.6 ± 36.3 |
| | EG$_{HV}$ (19) | 0.28 ± 0.10 | 0.23 ± 0.09* | -0.05 ± 0.10$^{A}$ | -13.6 ± 38.2$^{A}$ |
| | EG$_{HI}$ (19) | 0.24 ± 0.08 | 0.19 ± 0.06* | -0.05 ± 0.05$^{A}$ | -17.2 ± 19.1$^{A}$ |
| **D** | CG (17) | 0.21 ± 0.09 | 0.19 ± 0.06 | -0.02 ± 0.06 | -2.9 ± 37.6 |
| | EG$_{HV}$ (19) | 0.25 ± 0.07 | 0.21 ± 0.08* | -0.04 ± 0.06 | -15.9 ± 21.4 |
| | EG$_{HI}$ (19) | 0.25 ± 0.11 | 0.19 ± 0.07* | -0.06 ± 0.10 | -15.2 ± 30.2 |
| **E** | CG (17) | 0.39 ± 0.11 | 0.37 ± 0.09 | -0.02 ± 0.08 | -0.9 ± 24.7 |
| | EG$_{HV}$ (19) | 0.46 ± 0.09 | 0.40 ± 0.11* | -0.06 ± 0.07 | -12.7 ± 15.5 |
| | EG$_{HI}$ (19) | 0.40 ± 0.12 | 0.34 ± 0.10* | -0.06 ± 0.10 | -11.7 ± 25.4 |
| **F** | CG (17) | 0.34 ± 0.12 | 0.32 ± 0.12 | -0.02 ± 0.06 | -5.2 ± 19.1 |
| | EG$_{HV}$ (18) | 0.37 ± 0.09 | 0.34 ± 0.10* | -0.04 ± 0.06 | -8.9 ± 16.2 |
| | EG$_{HI}$ (19) | 0.37 ± 0.11 | 0.30 ± 0.07* | -0.07 ± 0.09 | -14.8 ± 20.4 |
| **G** | CG (16) | 0.48 ± 0.16 | 0.48 ± 0.11 | 0.00 ± 0.10 | 16.2 ± 67.1 |
| | EG$_{HV}$ (15) | 0.52 ± 0.09 | 0.46 ± 0.08* | -0.07 ± 0.11 | -10.9 ± 19.6 |
| | EG$_{HI}$ (16) | 0.55 ± 0.13 | 0.41 ± 0.10* | -0.14 ± 0.16$^{A}$ | -21.4 ± 24.9$^{A}$ |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences $p<.05$. $^{A}$Significantly different with respect to the CG.*

**Table S10.** Per-protocol analyses of the whole-body dynamic balance outcomes in both preferred and non-preferred legs before (Pre-test) and after (Post-test) the training period.

| | **Sample (n)** | **Pre-test** | **Post-test** | **Δ** | **Δ (%)** |
|---|---|---|---|---|---|
| *Y-Balance test - Distance reached normalized to the leg length (%) – Preferred leg* | | | | | |
| Anterior direction | CG (17) | 60.1 ± 8.0 | 60.7 ± 7.2 | 0.6 ± 2.8 | 1.2 ± 4.8 |
| | EG$_{HV}$ (20) | 60.2 ± 5.6 | 62.2 ± 4.7* | 2.0 ± 3.9 | 3.6 ± 7.0 |
| | EG$_{HI}$ (19) | 60.1 ± 6.4 | 61.0 ± 5.3 | 1.0 ± 3.6 | 1.9 ± 6.1 |
| Posterolateral direction | CG (17) | 103.7 ± 8.8 | 105.4 ± 7.7 | 1.7 ± 3.7 | 1.8 ± 3.9 |
| | EG$_{HV}$ (20) | 108.8 ± 4.1 | 110.2 ± 5.0 | 1.4 ± 3.5 | 1.3 ± 3.2 |
| | EG$_{HI}$ (19) | 104.8 ± 8.9 | 105.7 ± 7.4 | 0.9 ± 4.9 | 1.0 ± 4.6 |
| Posteromedial direction | CG (17) | 108.5 ± 7.7 | 111.0 ± 7.1* | 2.5 ± 3.0 | 2.4 ± 2.9 |
| | EG$_{HV}$ (20) | 111.3 ± 6.3 | 113.5 ± 5.8* | 2.3 ± 3.7 | 2.1 ± 3.4 |
| | EG$_{HI}$ (19) | 106.8 ± 8.1 | 109.6 ± 6.8* | 2.9 ± 3.9 | 2.9 ± 3.9 |
| Y-Balance composite | CG (17) | 90.8 ± 7.9 | 92.4 ± 7.0* | 1.6 ± 1.9 | 1.9 ± 2.6 |
| | EG$_{HV}$ (20) | 93.4 ± 4.3 | 95.3 ± 4.5* | 1.9 ± 2.7 | 2.0 ± 2.9 |
| | EG$_{HI}$ (19) | 90.6 ± 7.0 | 92.1 ± 5.7* | 1.6 ± 2.9 | 1.9 ± 3.3 |
| *Y-Balance test - Distance reached normalized to the leg length (%) – Non-preferred leg* | | | | | |
| Anterior direction | CG (17) | 58.7 ± 5.8 | 60.5 ± 5.4* | 1.8 ± 1.4 | 3.1 ± 2.6 |
| | EG$_{HV}$ (20) | 62.0 ± 4.7 | 63.8 ± 4.6* | 1.8 ± 3.7 | 3.1 ± 6.5 |
| | EG$_{HI}$ (19) | 59.9 ± 6.8 | 61.5 ± 5.4 | 1.6 ± 4.9 | 3.2 ± 9.1 |
| Posterolateral direction | CG (17) | 101.8 ± 7.7 | 103.7 ± 6.0 | 1.9 ± 4.5 | 2.1 ± 4.7 |
| | EG$_{HV}$ (20) | 108.8 ± 4.3 | 110.8 ± 3.9* | 2.0 ± 3.5 | 1.9 ± 3.3 |
| | EG$_{HI}$ (19) | 104.2 ± 8.2 | 105.4 ± 6.5 | 1.2 ± 2.6 | 1.3 ± 2.6 |
| Posteromedial direction | CG (17) | 108.8 ± 6.8 | 110.9 ± 5.5* | 2.1 ± 3.2 | 2.0 ± 3.2 |
| | EG$_{HV}$ (20) | 110.6 ± 5.4 | 113.7 ± 5.1* | 3.1 ± 4.1$^{B}$ | 2.9 ± 3.9 |
| | EG$_{HI}$ (19) | 108.6 ± 7.3 | 109.1 ± 6.8 | 0.6 ± 3.5 | 0.6 ± 3.3 |
| Y-Balance composite | CG (17) | 89.8 ± 6.5 | 91.7 ± 5.2* | 1.9 ± 2.2 | 2.3 ± 2.6 |
| | EG$_{HV}$ (20) | 93.8 ± 3.9 | 96.1 ± 3.6* | 2.3 ± 1.9 | 2.5 ± 2.1 |
| | EG$_{HI}$ (19) | 90.9 ± 7.0 | 92.0 ± 5.7 | 1.1 ± 2.7 | 1.4 ± 3.1 |
| *Triple hop test - Distance reached normalized to the leg length (m)* | | | | | |
| Preferred leg | CG (16) | 5.03 ± 0.64 | 5.05 ± 0.66 | 0.0 ± 0.3 | 0.6 ± 7.0 |
| | EG$_{HV}$ (19) | 4.85 ± 0.67 | 4.86 ± 0.70 | 0.0 ± 0.3 | 0.4 ± 6.7 |
| | EGHI (19) | 4.84 ± 0.47 | 4.85 ± 0.46 | 0.0 ± 0.3 | 0.3 ± 6.8 |
| Non-preferred leg | CG (14) | 4.94 ± 0.63 | 4.82 ± 0.60 | -0.1 ± 0.4 | -2.1 ± 7.0 |
| | EG$_{HV}$ (20) | 5.05 ± 0.69 | 5.05 ± 0.63 | 0.0 ± 0.2 | 0.2 ± 4.9 |
| | EGHI (19) | 4.95 ± 0.56 | 4.89 ± 0.50 | -0.1 ± 0.4 | -0.7 ± 8.4 |
| *Single-leg stance balance test - Mean radial error (mm)* | | | | | |
| Preferred leg | CG (17) | 11.29 ± 1.51 | 10.37 ± 1.66* | -0.9 ± 1.4 | -7.7 ± 12.4 |
| | EG$_{HV}$ (19) | 11.33 ± 2.52 | 10.59 ± 2.07 | -0.7 ± 1.6 | -5.4 ± 13.1 |
| | EG$_{HI}$ (19) | 10.61 ± 2.15 | 9.95 ± 1.40 | -0.7 ± 1.8 | -2.5 ± 25.2 |
| Non preferred leg | CG (17) | 11.10 ± 1.71 | 10.48 ± 1.34 | -0.6 ± 1.4 | -4.3 ± 14.0 |
| | EG$_{HV}$ (19) | 11.58 ± 2.47 | 11.40 ± 2.55 | -0.2 ± 2.0 | -0.5 ± 16.1 |
| | EG$_{HI}$ (18) | 10.94 ± 2.14 | 10.00 ± 1.24* | -0.9 ± 1.8 | -6.7 ± 14.9 |

*Data are presented as Mean ± SD. Δ: absolute delta of change; Δ (%): relative delta of change; SD: standard deviation; CG: control group; EG$_{HV}$: experimental group which performed the higher volume program; EG$_{HI}$: experimental group which performed the higher intensity program. *Significant pre-post differences $p<.05$. $^{B}$Significantly different with respect to the EG$_{HI}$.*



# AGRADECIMIENTOS

Todavía recuerdo esa tarde de domingo corriendo por la banda izquierda, una de esas míticas tardes de fútbol. Esa fue la primera vez que sentí un pinchazo en la espalda, algo que fue esporádico y puntual, pero quizás el primer recuerdo que tengo de un dolor de espalda que me acompaña desde hace años, y que seguramente sea una de las razones por las que haya hecho esta tesis doctoral. Haciendo una analogía a la bici de montaña, creo que esta "aventura" ha sido como una buena ruta, de subidas intensas, bajadas técnicas y divertidas, *repechitos* explosivos, caídas y vuelta a levantarse… Pero como siempre en este tipo de rutas, el disfrutar del camino y de la compañía, es clave. Y en este sentido, como una vez me dijo un amigo: "Si quieres llegar rápido ve sólo, pero si quieres llegar lejos, ve acompañado", y vaya que si he tenido un buen acompañamiento durante este camino…

En primer lugar, me gustaría empezar agradeciendo a mi familia, que me han acompañado desde el inicio. A mis padres, gracias por darme alas y enseñarme a volar. Por dejarme equivocarme en el camino, pero siempre estar al lado para guiarme. Por haber dado todo lo que tenéis por nosotros, por darnos una educación y unos valores que nos han ayudado a construir quienes somos hoy en día. Gracias a mi hermano, *Dit*, por hacer tan bien de hermano mayor, por toda la paciencia que has tenido siempre conmigo (menos explicándome fisiología en primero de carrera), y por en cierta manera, introducirme en el mundo de la investigación. Gracias por estar siempre ahí, por compartir tantos momentos y aficiones (en especial la montaña, y cómo no, la gastronomía), por esa sinceridad en nuestras conversaciones, y por ser tan buen ejemplo para mí. Gracias a mis tíos, Joselu, por tantas charlas de historia de las que no soy capaz de recordar ni la mitad, y Jose Miguel, por ser una persona de diez y descubrirme tantísimas cosas, entre ellas el ciclismo, aunque sigo siendo una globera que vuelve a casa con la pierna manchada de grasa. Por último, gracias a mis abuelos, que aunque no estéis ya aquí, llevo conmigo todo lo que compartí y aprendí de y con vosotros.

Es verdad que han sido varias las paradas previas hasta llegar a la ciudad de las palmeras. De la etapa del grado en la fría Siberia-Gasteiz, me gustaría dar las gracias especialmente a Itziar, por ese descubrimiento compartido del mundo de la actividad física y la salud en aquellas prácticas en Miranda de Ebro. Siguiendo ese largo camino desde más allá del muro hasta desembarco del rey, pasé también por Lausanne, en aquel erasmus que siguió aumentando mis ganas de viajar y conocer otros sitios, que después me llevaron hasta Bruselas, Barcelona y Brisbane. Gracias a todas las personas que conocí durante esos años, que me hicieron seguir creciendo y vivir experiencias increíbles; a big thanks to Gail Hunter, for all the adventures and years of friendship. Gracias también a mis provincianas, compartiendo momentos y creando recuerdos desde que somos unas *mueticas*, especialmente a Naiara, quien comparte a *Murphy* conmigo y ha aguantado mis indecisiones e inquietudes durante tanto tiempo.

Cabe destacar una de esas paradas como un punto de inflexión en el camino, y es que durante el máster en Barcelona descubrí eso de la investigación, y que además, había grupos que trabajaban en ejercicio físico y dolor lumbar. Es ahí donde me recomiendan que, si quiero aprender sobre este tema, me vaya a Elche con un tal Fran Vera. De esa manera acabo en tierra de los Lannister, cuando todavía era 100% del norte y toleraba el frío (esto no es ironía). Es verdad que, aunque no empecé con buen pie (pero esto en sentido literal, maldito peroné), recuerdo que lo que más me sorprendió al llegar al Centro de Investigación del Deporte fue el tremendo equipo humano que lo conforma, y que desde entonces sigue siendo una suerte poder compartir el día a día con todos ellos… Hay una frase que dice que la magia no la hacen los lugares, sino las personas, y no podría ser más acertada en este caso... Gracias a Eduardo Cervelló, por haber construido con tanto cariño un sitio así, a Manolo, por esas arduas labores de gestión que nos facilitan a todos el resto de tareas, a Carlos Montero, por esas visitas a la centralita, a Raúl Reina, por las cenas con un buen vinito acompañando la mesa, a Fito, por todos los consejos desinteresados (y los chistes malos), a Rafa, por ese sarcasmo tan sutil, a Francis, por ese desempeño para el buen desarrollo del programa de doctorado, a Manolo Peláez, por la ruta en bici que tenemos pendiente. También gracias a Altair, por infinitas revisiones de textos aunque siempre te dijera "creo que esta versión va a ser la última", y pocas veces lo era… Gracias a todo el *team tapeo*: a Diego, que espero que hayas cogido algo de cariño al final a los metas, a Txiki, que además de ser alguien que siempre está ahí, nos entendemos entre cepas de Monastrell o Garnacha, a Carla, por venderme tan bien su tierra y convencerme con su comida (bendita patatera), a Isa, por esas tardes en el roco/gym divagando en mil conversaciones, a Arturo, por nuestros míticos *"What a week, huh?"* aunque estuviéramos a lunes, y por ser tan buen modelo de tesis…(cuando quieras hacemos otra ronda de puentes). Gracias a Sarabia, por hacer magia con sus *techno-consejos* que salvan horas de trabajo, a Noemí, por compartir esa gran afición por la comida (aunque también por las lesiones), a Xoxe, Peña y Java, por esos incontables cafés y raticos en el CID (por cierto Java, todavía tienes pendiente volver al roco). Gracias a Tomás, por ayudarme cuando no funcionaba/encontraba algún aparatejo del laboratorio, a Agustín, por ayudarme a entender mejor los metas y sufrirlo conmigo, a Alicia, por haber compartido nuestros inicios en la docencia universitaria, que no fueron fáciles, pero que cuánto hemos aprendido… Y a Saioa, por acompañarme en el último tramo de esta etapa. Y por supuesto, gracias a los MVP del CID, Dori y Juan Pedro, siempre presentes para echar un cable en lo que sea… Juan Pedro, ya hasta me he aprendido ese trabalenguas en valenciano… Plou poc, però…

Esta es parte de lo que ha sido mi segunda casa, o más bien la primera, ya no lo sé. Pero dentro de ella si ha habido un sitio en el que he pasado más tiempo, ha sido sin duda en el laboratorio de biomecánica y salud. Cuántos *cositos* para investigar, que en aquel inicio no conocía la mayoría, pero eso no duró demasiado… maldito Alberto con sus pruebas de protocolos en el isocinético… Aquí he tenido la suerte de compartir muchos momentos, muchas horas de mediciones y no sé cuántos *"buah, buah, tenemos que hacer…"* Todo ello con un gran equipo: gracias a Jose Luis, por toda esa labor tecnológica que nos facilita todos los registros y nos quita muchos quebraderos de cabeza, a Casto, por compartir horas de mediciones y discusiones de cualquier tema que pudiera surgir, y por transmitir ese disfrute por la naturaleza, a Alejandro, por darme la oportunidad de colaborar en distintos trabajos y echarme una mano siempre que hiciera falta, a Iñaki, que pese a ser más de Bilbo que la mismísima ría es tan majo que parece navarro, a Diego, por esos momentazos en nuestros viajes a Navarra y Almería, a Belén, por esas tardes de baile, a Fran, David, Alberto, Pedro, Javi, Aarón, Carmen, Maripili, Ayala, Sergio, Víctor y Juanra. Gracias a todos por haberme enseñado tanto, por ayudarme a dar mis primeros pasos en esta área, por hacer crecer mi motivación para seguir aprendiendo, y sobre todo, por ser un equipo dispuesto a echar una mano sin que sea necesario pedirlo.

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Durante el doctorado, también he tenido la oportunidad de hacer estancias fuera, lo que me ha permitido conocer otro tipo de trabajos, de metodologías, y seguir formándome en el ámbito académico con gente increíble. Merci à tout l'équipe du Lc65+ à Lausanne, particulièrement à Yves Henchoz. Merci de m'avoir donnée l'opportunité de pouvoir apprendre dans un étude longitudinal si complexe, de que je puisse en faire partie pendant mon séjour, et pour le temps que tu as passé pour m'expliquer beaucoup de choses que j'ai apprises là-bas. Gracias también a todo el equipo de biomecánica del CAR en Chile: a Mauricio, Christopher, Alejandro, Hugo… y a todas las personas que conocí durante mi estancia allí, que hicieron que casi lograra "chilenizarme" en el poco tiempo que estuve. Aquí tengo que agradecer especialmente al profesor Aedo, por hacerme sentir como en casa, por darme la oportunidad de aprender y participar en tantas cosas que en mi cabeza no paraban de surgir ideas en las que investigar. Gracias por motivar todavía más mi inquietud hacia nuevos aprendizajes en el área del deporte, pero también en la vida, y por enseñarme conceptos tan importantes como el "partir la semana" mientras establecía una relación de amor-odio con el *Vicon*. También gracias a mi *werita* Consu, desde ese inicio compartiendo esas largas jornadas en el restaurante "español" menos español de todo Brisbane, hasta enseñarme tu tierra a través de ceviches y empanadas acompañados de unos buenos *Carmenère*.

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