Role of Core-Based Exercises in Improving Proprioception among Individuals with Neurological Disorders: A Systematic Literature Review and Meta-Analysis

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INTRODUCTION

Neurological disorders are the world’s second leading cause of death, and are responsible for >9 million fatalities annually [1,2]. These conditions, which are predicted to affect half of all women and one-third of all men at some stage in their lives [3], stem from structural anomalies within the brain [4,5]. Neurological disorders are diseases that negatively affect the nervous system, including the brain, spinal cord, cranial nerves, peripheral nerves, and neuromuscular junctions [6], such as dementia, stroke, Parkinson’s disease, and multiple sclerosis [7,8]. These diseases are characterized by symptoms, like decreased motor function [2], impaired gait [9] and balance, and proprioception [10].

Proprioception is a critical sensory system that transmits signals from mechanical receptors in joints, muscles, ligaments, and tendons to the central nervous system. This system provides feedback that is essential for discerning the position and movement of various body segments [11], thereby playing a pivotal role in the maintenance of postural stability [12]. Proprioception encompasses two primary sensations: joint position sensation, that is the static awareness of the spatial orientation of body segments, and joint motion sensation, which is the dynamic detection of joint movements [13]. Both sensations are integral to balance and ambulation [14,15]. Impairments in proprioception can result from damage to

PURPOSE: This study aimed to validate the effect of core-based exercise on proprioception in individuals with neurological disorders through a systematic review and meta-analysis.

METHODS: A systematic literature search was conducted using databases such as PubMed, Web of Science, and Scopus for studies published up to October 10, 2023. The search yielded 1,945 articles, with seven studies ultimately included for in-depth analysis. Meta-analysis was performed using Review Manager 5.4 software. Standardized mean differences (SMDs) were calculated using Hedges’ g value using both random-effects and fixed-effects models.

RESULTS: The meta-analysis revealed that core-based exercise significantly improved joint position sense (SMD=-1.33; 95% confidence interval [CI]=-2.09 to -0.57; $P=0.001$) and kinesthesia (SMD=-0.33; 95% CI=-0.62 to -0.05; $P=0.00$) in individuals with neurological disorders. In a sub-analysis by the type of neurological disease, core-based exercises were beneficial only for stroke patients (SMD=-1.05; 95% CI=-2.07 to -0.03; $P=0.58$; $P<0.05$), but not for those with Parkinson’s disease or chorea. An analysis by the type of core exercise showed that core stability exercises had a significant benefit (SMD=-0.55; 95% CI=-0.97 to -0.14; $P=0.00$; $P<0.001$), whereas yoga exercises did not demonstrate a significant effect.

CONCLUSIONS: In this study, core-based exercises positively improved proprioception in patients with neurological disorders, and were particularly effective in stroke patients. Among various types of core exercises, only core stability exercises had a positive effect on proprioception in patients with neurological disorders.

Key words: Core-based exercise, Core stability exercise, Neurological disorder, Proprioception, Joint position sense, Kinesthetic sense, Stroke

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various brain regions, including the thalamus, frontal lobe, and parietal cortex, where frontal lobe damage notably increases the risk of functional impairments, such as gait disturbances and falls [16,17]. Remarkably, proprioception is deemed more vital than visual feedback in balance maintenance [18,19], a finding consistent across all age brackets [20]. Additionally, decreased proprioception can increase arthritis incidence, due to poor joint control and constant loading on the joints [21], which can lead to abnormal gait patterns [22] and ultimately to rapid cognitive decline [23]. Thus, proprioception is crucial not only for physical balance but also for the prevention of cognitive deterioration [24].

To effectively improve proprioception, it is important to maintain body stability, and typical exercise interventions include resistance training [25], core stability exercises [26], prone bridge exercises [27], and instability training [28]. The core muscles, which are the muscles commonly targeted in these exercise interventions (e.g., the transversus abdominis, external and internal obliques, paravertebralis, glutes, diaphragm, and pelvic floor muscles) [29], are important in athletic contexts. They provide proximal stability for distal mobility [30], and make an important contribution to body stability by utilizing the lumbar obliques during whole-body exercises [31]. Evidence suggests that proprioception is enhanced by the activation of core muscles [28]. Core exercises provide unstable conditions that can stimulate proprioception by providing feedback for maintaining balance and sensing body position [32]. Instability induces rapid changes in muscle-tendon unit length, tension, and neuromuscular activity, which contribute to the ability to detect proprioception and respond reflexive activity accordingly [33]. Pilates exercises utilizing core muscles have been shown to enhance proprioception in healthy adults [34], while core stability training on unstable surfaces has been effective in improving proprioception in athletes with chronic ankle instability [35]. Furthermore, core stability exercises are more effective than resistance exercises in improving proprioception [36]. Additionally, core exercises are also effective in improving dynamic balance and gait ability, which are closely related to proprioception in patients with neurological diseases [37-39].

Based on these previous studies, it can be inferred that core muscles are positively correlated with proprioception, and that core exercises may potentially have positive effects on the body’s ability to balance and eventually walk by improving proprioception. However, it is important to analyze how core training affects proprioception in individuals with neurological disorders, as there are limited studies that examined the effects of core training on proprioception. The present study is the first to examine the effectiveness of core-based exercises in improving proprioception in individuals with neurological disorders. This study aimed to analyze the effects of core-based exercises on proprioception in individuals with neurological diseases using a systematic review and meta-analysis. We hypothesized that core-based exercises will improve proprioception in individuals with neurological diseases.

**METHODS**

This review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [40]. The protocol for this review has been previously described in PROSPERO (CRD42023476685).

1. **Search strategy**

The following electronic databases were searched from their inception to October 10, 2023: PubMed/Medline (https://pubmed.ncbi.nlm.nih.gov), Web of Science (https://www.webofscience.com), and Scopus (https://www.scopus.com). No year restrictions were applied to our search strategy. The reference lists of the selected trials and previously published and cited reviews were also examined.

The search strategy involved combining Medical Subject Headings (MeSH) terms with free-text terms related to the study objectives tailored towards the specific features of each database. The search strategy was organized around four categories: Participants, Intervention, Outcome, and Type of Study, which were connected using the Boolean operator ‘AND.’ Within each category, the search terms were linked using the Boolean operator ‘OR.’ The following search terms were used: (trunk training OR core training OR trunk stability exercise OR core stability exercise OR Pilates OR Yoga OR proprioceptive training OR core strength training) AND (proprioception OR joint position OR joint reposition OR position detection OR joint position reproduction OR kinesthesia OR active movement extent discrimination assessment OR threshold to detection of passive motion) AND (neurological disorder OR neurological pathology OR multiple sclerosis OR Parkinson’s disease OR Huntington’s disease OR cerebellar ataxia OR Alzheimer’s disease OR stroke OR Mild Cognitive Impairment OR dementia) AND (randomized controlled trial OR controlled clinical trial OR randomized OR randomly).

Manual searches of the reference lists of the included articles were conducted to identify eligible studies that were not identified in the systematic literature search. All the study information retrieved from each
database was imported into EndNote software (X9; Clarivate Analytics, New York, NY, USA), and duplicate records were removed. Two of the three reviewers, H-C. Lee and J-H. Lee, independently screened the titles and abstracts of the retrieved studies, based on predefined inclusion and exclusion criteria. All studies deemed potentially relevant were assessed in the full text, and those that did not meet the study objectives were excluded.

2. Inclusion criteria

Criteria were developed according to the PICOS principles, and the inclusion criteria were as follows: (1) Participants: patients with neurological disorders, such as multiple sclerosis, Parkinson’s disease, Huntington’s disease, Alzheimer’s disease, dementia, stroke, and mild cognitive impairment; (2) Intervention: core exercise or other activities targeting the core muscles, such as the pilates, yoga, and proprioceptive training; (3) C (comparators): observation or general treatment without core muscle exercises; (4) O (outcome): proprioception, Romberg test. The Romberg test conducted with the eyes closed helps discover proprioceptive impairment by reducing the influence of a patient’s vision; and (5) S (study design): randomized controlled trials (RCTs). To effectively evaluate the impact of the intervention, mitigate the risk of bias in the study, and analyze reliable data.

3. Exclusion criteria

The exclusion criteria for this systematic review and meta-analysis were as follows: (1) non-RCT publications (this includes conference abstracts only, systematic reviews, meta-analyses, cross-sectional studies, case-control studies, cohort studies, case reports, case series, and letters to the editor). Studies that were not designed as RCTs were excluded; (2) duplicate publications: articles identified as duplicates were removed to ensure that each study was counted only once in the analysis; (3) studies with insufficient data: studies lacking adequate data for a thorough analysis were excluded; (4) language limitations: studies not published in English language were excluded to ensure the feasibility of a detailed review and analysis; (5) non-compliant studies: studies that failed to meet the specified inclusion criteria were not considered in this review; and (6) intervention compliance: studies were excluded if both the exercise and control groups performed exercises that aligned with the inclusion criteria; this is to distinctly compare the impact of core exercises against non-core or general treatments. These criteria were meticulously applied to distill the body of literature into those most relevant and capable of providing insights into the effects of core-based exercises on proprioception in individuals with neurological disorders.

4. Quality assessment and data extraction

The risk of bias in the included studies was assessed independently by two authors, H-C. L. and J-H. L. using the Cochrane Risk of Bias Tool for RCTs [41]. The results were then compared, and a third reviewer, M-S. H., decided in cases of disagreement. The tool was divided into seven specific domains: (1) random sequence generation (selection bias); (2) allocation concealment (selection bias); (3) blinding of participants and personnel (performance bias); (4) blinding of outcome assessment (detection bias); (5) incomplete outcome data (attrition bias); (6) selective reporting (reporting bias); and (7) other sources of bias. Assessment in each domain was conducted by rendering a judgment choosing from three available options for that domain: ‘low risk of bias,’ ‘high risk of bias,’ and ‘unclear risk of bias.’

5. Statistical analysis

A meta-analysis was conducted using the Review Manager (RevMan version 5.4; Cochrane Collaboration, London, UK, 2020). For each study, the treatment endpoint absolute scores (mean and standard deviation: M ± SD) of intervention (core-based exercise) and control (observation or general treatment that patients were previously undergoing for symptom relief without core muscle exercises) groups were analyzed. In studies investigating the effects of yoga exercises that provided medians and quartiles [42], formulas were used to transform these values into means and standard deviations [43]. Subsequently, the standardized mean difference (SMD) values were extracted. The SMD was calculated using the inverse of variance as the weighting factor to compute the overall effect and 95% confidence intervals (CIs). It is important to note that the SMD method does not correct for differences in scale direction. In cases where some scales indicated better performance with decreasing values, the mean values were multiplied by -1 to ensure that all scales had the same direction [41]. We classified the magnitude of SMD according to the Cohen’s rules of thumb on magnitudes of effect sizes: small (SMD = 0.2-0.5), medium (SMD = 0.5-0.8), and large (SMD > 0.8) [44,45].

Heterogeneity of the results was reported as I², followed by a percentage: I² between 0-40% corresponds to low heterogeneity, 30-60% corresponds to moderate heterogeneity, 50-90% corresponds to substantial heterogeneity, and 75-100% corresponds to considerable heterogeneity [41]. In cases where there was little or no heterogeneity between the studies (I² < 50%), a fixed-effects model was used for analysis. However, when
heterogeneity was significant ($I^2 > 50\%$), a random-effects model was used for the analysis. A significance level of $p < .05$ indicated a statistically significant difference. Studies with < 10 trials were not considered adequate for a funnel plot [46]; therefore, we did not present a funnel plot in this meta-analysis.

**RESULTS**

A total of 1,945 publications were identified using the search strategy shown in Fig. 1. Of these, 57 were excluded because of duplication, and an additional three articles were added by manually searching the reference lists of the included studies. After screening the titles and abstracts, 1,891 articles were excluded. This initial screening process reduced the number of potentially eligible studies to 53, which were then downloaded for detailed full-text review. After an in-depth examination of the full texts, 46 studies were excluded for not meeting specified inclusion and exclusion criteria: 14 studies did not incorporate a core-based intervention, six were not related to patients with neurological disorders; 22 failed to measure proprioception, and four lacked a control group that did not engage in training, excluding those receiving conventional treatment. Consequently, seven studies were included in this systematic review (Fig. 1).

1. **Participants’ characteristics**

The RCTs included 235 participants (121 in the exercise group, and 114 in the control group). The average age of the participants ranged between 41-83 years. This study included both males and females. Three studies included individuals with Parkinson’s disease [47], two with stroke [48], and two with Schizophrenia or related psychotic disorder [49,50].

2. **Interventions’ characteristics**

The included core-based exercises were core stability exercise ($n = 3$), yoga exercises ($n = 3$), and weight-shift training ($n = 1$). The movements included in truncal and cervical stabilization exercises are similar to those in core stability exercises; therefore, we classified this exercise as a core stability exercise. The intervention durations were 4 ($n = 1$), 8 ($n = 4$), and...
12 (n = 2) weeks. The number of sessions per week ranged between 1-5, with participation in exercise occurring once a week (n = 2), twice a week (n = 2), three times a week (n = 1), four times a week (n = 1), and five times a week (n = 1). Details of the included studies are presented in Table 1.

3. Effects of core–based exercise on proprioception

When analyzing the overall observed results (Fig. 2), core-based exercises were found to have a significant effect on proprioception compared with a control group (SMD = -0.45; 95% CI = -0.72, -0.19; I² = 41%; p < .001, fixed-effect model). Among the studies assessing joint position sense, core-based exercises were found to have a significant impact compared to the control group (SMD = -1.33; 95% CI = -2.09, -0.57; I² = 0%; p < .001). For studies assessing kinesthesia related to the perception of direction, position, and magnitude of bodily movements, core-based exercises were found to have a significant effect in comparison with the control group (SMD = -0.33; 95% CI = -0.62, -0.05; I² = 0%; p < .05).

4. Effects of core–based exercise depending on the type of neurological disorder

The analyses confirmed that core-based exercises increased proprioception in stroke (SMD = -1.05; 95% CI = -2.07, -0.03; I² = 51%; p < .001) and Parkinson’s disease (SMD = -0.35; 95% CI = -0.90, 0.20; I² = 35%; p = 0.21) and psychiatric disease (SMD = -0.35; 95% CI = -0.90, 0.20; I² = 51%; p = 0.22) (Fig. 3).

5. Effects of core exercise types

Effects of the type of core-based exercise on proprioception were confirmed for core stability exercise (SMD = -0.55; 95% CI = -0.97, -0.14; I² = 0%; p < .01). However, no statistical significance was observed for yoga exercise (SMD = -0.26; 95% CI = -0.62, 0.10; I² = 33%; p = 0.15). As there was only one study on weight-shift training, we did not perform a meta-analysis (Fig. 4).

6. Quality assessment

The assessment of bias in the seven studies using the Cochrane’s risk of bias evaluation criteria yielded the following results (Fig. 5). All the seven studies were deemed to have a low risk of bias during generation of the random allocation sequence. In terms of allocation concealment, all but two studies were evaluated as low risk. Two exceptions were rated as ‘unclear’ because of insufficient details regarding the allocation sequence and methodology. For blinding of the participants, among the four studies that mentioned this aspect, the risk was assessed as low.
remaining three studies, which did not specifically address participant blinding, were assessed as ‘unclear’ for this criterion. Regarding the blinding of outcome assessment, five studies explicitly stated that outcome assessors were blinded and thus, rated as low risk. Studies that did not mention the blinding of the outcome assessors were considered ‘unclear’ in terms of risk. With respect to the completeness of the outcome data, one study was identified as having high risk, owing to significant dropout rates affecting outcome reporting. Two studies were categorized as ‘unclear’ because of insufficient information on this aspect, whereas the remaining were considered low risk studies. In terms of selective reporting, one study was found to have a high risk of bias, as it failed to report information on dropouts and attrition rates. Two studies were assessed as ‘unclear’, owing to inadequate reporting, whereas the remaining studies were considered as having a low risk of bias.

**DISCUSSION**

We conducted a systematic review and meta-analysis based on the hypothesis that core-based exercises would enhance proprioception in individuals with neurological disorders. The findings revealed that core-
based exercises significantly improved both joint position sense and kinesthesia, which are critical proprioceptive senses, in individuals with neurological disorders. These results support our initial hypothesis and underscore the significance of core exercises in enhancing proprioception in this population. The following is a discussion of these findings:

1. Effects of core–based exercises on proprioception

Proprioception is a sensory system that relays signals from joints, muscles, ligaments, and tendons of the extremities with mechanical receptors to the central nervous system for feedback and provides information regarding the position and movement of body segments [11]. Proprioception plays a key role in maintaining postural stability [12]. It is divided into joint position sensation, which is a static sensation that is the basis for interpreting the position of body segments in space, and joint motion sensation, which is a sensation that detects joint movements and is involved in dynamics [13]. Joint positional sense can be assessed by accurately reproducing joint positions [51], although kinesthetic sense can be assessed by performing the Romberg test without visual intervention [52].

In this study, we found that core-based exercises significantly improved proprioception and kinesthesia in patients with neuropathy. Core exercises have been shown to improve joint position sensitivity [26], and are effective in improving kinesthesia [53]. These results are thought to be due to increased muscle activity through core-based exercises, which stimulate musculoskeletal and joint receptors and improve the accuracy
of sensory integration processes, leading to enhanced joint repositioning and improved kinesthesia [54].

2. Effects of different types of neurological conditions on core-based exercise

Neurological diseases include dementia, stroke, multiple sclerosis, Parkinson’s disease, schizophrenia etc. [7,8]; however, in the present study, only patients with stroke, Parkinson’s disease, and psychiatric conditions were included in the analysis, and only patients with stroke showed significant effects. In a previous study, core exercises effectively improved proprioception in patients with stroke [48]. In patients with stroke having reduced trunk position sense, which is involved in balance and walking ability, core exercises may have increased the sensitivity of proprioceptive information from soft tissues, such as muscles, tendons, ligaments, and joint capsules in the body. Voluntary contractions through core exercises may activate the proximal spine more during sensing of changes in muscle length and conscious perception of limb movement [55], which may have increased the sensitivity of proprioceptive information.

However, the effects of core-based exercises in patients with Parkinson’s disease and schizophrenia could not be confirmed in this study. These results contradict the findings of a study that showed that core-based exercises improved proprioception in patients with Parkinson’s disease [56] and a study that found that core exercises improved proprioception in patients with schizophrenia [49]. This was supported by Cuğ et al. in 2018 [57], who reported that 30 minutes of training per exercise at a frequency of three times per week for at least four weeks was required to improve proprioception. Two of the three intervention studies in this review that included patients with Parkinson’s disease [42,58] and two intervention studies in psychiatric patients [49,50] did not meet the exercise frequency of three times per week. Therefore, the frequency of exercise interventions used in the individual studies included in this meta-analysis may have been insufficient to improve proprioception. Further analysis of the duration of exercise intervention is warranted.

3. Effects of different types of core-based exercises on proprioception

The core-based exercises analyzed in this study included core stability exercises and yoga. Among these, only core stability exercises significantly improved proprioception in patients with neurological disorders. The results of this study support those of previous studies that have shown that four weeks of core stability exercises effectively improved proprioception [36], which is consistent with the findings that core stability exercises improve the hip and intertrunk muscles [52], and that the increase in these muscles stimulates muscle spindles and joint receptors, leading to improved proprioception [54]. Furthermore, it is suggested that core stability exercises enhance awareness of force and effort by maintaining a consistent amount of force to sustain a posture for a predetermined duration. Through training that prioritizes the activation of one muscle over another within a coordinated muscle group, proprioception is improved [59].

Yoga exercises can activate core muscles to strengthen core capabilities [60], and a study that analyzed core muscle activation patterns during the performance of 11 commonly used yoga postures reported that yoga exercises can effectively activate core muscles [61]. It has also been reported that yoga exercises are effective in improving proprioception [62]; however, this study did not show any such effect of yoga exercises. A meta-analysis that analyzed the effect of yoga exercises in patients with stroke did not show any improvement in motor function [63], which may be due to the small number of included studies. This study also included a limited number of studies, which may explain the lack of effectiveness of yoga exercises. If more RCTs are conducted and analyzed in the future, the effects and mechanisms of core-based exercises on neurological diseases may be better explained.

This systematic review and meta-analysis has several limitations. First, the number of studies and sample sizes of core-based exercises that have improved proprioception in individuals with neurological diseases were relatively limited, which may have affected the final meta-analysis results. Second, this study only included studies published in English language, which may have overlooked important studies published in other languages. Third, there was an inevitably high degree of heterogeneity, owing to the diversity of methods used to measure proprioception. Fourth, the small and limited data included in this study may have affected the subgroup analyses that explored the sources of heterogeneity. Fifth, as the number of included studies analyzed in this study was less than 10, a funnel plot was not conducted.

CONCLUSIONS

This meta-analysis evaluated the effect of core-based exercises on proprioception in individuals with neurological disorders. Our findings revealed that core-based exercises significantly enhanced proprioception in this population, specifically in terms of joint position and kinesthetic sensation. Notably, these exercises are particularly effective in patients
with stroke, highlighting the unique benefits of core stability exercises. Therefore, the critical role of core exercises in improving proprioception in individuals with neurological conditions was substantiated.

**Recommendations**

The positive influence of core-based exercises on proprioception in individuals with neurological disorders identified in this meta-analysis suggests potential benefits for preventing balance and gait impairments. To build on these findings, future studies should focus on conducting high-quality meta-analyses characterized by reduced heterogeneity and increasing the number of RCTs. Such studies are essential to deepen our understanding of the precise mechanisms by which core muscle exercises influence proprioception in neurological disorders.

**CONFLICT OF INTEREST**

The authors declare that there is no conflict of interest.

**AUTHOR CONTRIBUTIONS**

Conceptualization: HC Lee, MS Ha; Funding acquisition: MS Ha; Methodology: HC Lee, JH Lee; Project administration: MS Ha; Visualization: HC Lee; Writing-original draft: HC Lee; Writing-review and editing: JH Lee, MS Ha.

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