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Comparison of modified hybrid strength training and neuromuscular electrical stimulation on joint position sense in healthy untrained individuals: A randomized controlled trial

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ABSTRACT

Background: Low physical activity reduces muscle strength and proprioception, increasing injury risk. Neuromuscular electrical stimulation (NMES) and hybrid training aim to enhance proprioception by strengthening muscles. This study compared the effects of a modified hybrid strength training program and Russian protocol NMES on knee joint position sense (JPS) in healthy, untrained men.

Methods: Sixteen untrained males were randomly allocated to either the hybrid training group or the NMES group. Both groups exercised three times a week for four weeks. An isokinetic dynamometer was used to measure JPS at 30° and 60° on both dominant and non-dominant legs before and after the intervention.

Results: Both interventions significantly improved JPS across all tested angles. In the hybrid group, improvements were observed in the dominant leg at 30° ($p = 0.028$) and 60° ($p = 0.009$), and in the non-dominant leg at 30° ($p = 0.033$) and 60° ($p = 0.008$). The NMES group showed similar improvements at 30° and 60° in both legs ($p < 0.05$). No significant differences were found between groups.

Conclusion: Modified hybrid strength training and Russian protocol NMES both enhanced knee JPS in healthy, untrained men, with neither proving superior. Larger trials are needed to confirm comparative effectiveness and explore clinical applications.

Keywords: hybrid training system, joint position sense, neuromuscular electrical stimulation, proprioception.
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INTRODUCTION

Knee injuries are a common concern in musculoskeletal health, particularly among youth and young adults. Incidence rises during childhood and adolescence, peaks between 15 and 29 years, and declines thereafter. Data from 2017–2018 report an annual incidence of 83.9 per 100,000 in males and 60.1 per 100,000 in females.[1] Moreover, 15–17% of inactive adults experience injuries related to sporadic physical activity, likely due to reduced neuromuscular fitness, which increases injury risk.[2] Deficits in proprioception further exacerbate knee injuries, as impaired joint position sense (JPS) diminishes neuromuscular control and heightens susceptibility to dynamic injury.[3]

Proprioception is essential for stability and coordination in daily activities and sports, enabling automatic adjustment of movement patterns in response to joint position and external forces.[4] It relies on sensory input from receptors in the skin, muscles, ligaments, and tendons, which help regulate posture and stability during complex movements.[5,6] Intact proprioceptive feedback is critical for knee movement control and stabilization, as impaired JPS increases re-injury risk, particularly in individuals with prior knee trauma.[7] Enhancing proprioception may protect the joint by improving the body's response to mechanical stress.[8]

Proprioception is commonly assessed using the JPS test, which measures how accurately individuals replicate a specific joint angle under active or passive conditions and within the same or contralateral limb. Angular error—the difference between the target and reproduced angles—quantifies proprioceptive accuracy.[9] Advances such as electro-goniometers and image-based motion capture have improved measurement precision.

Proprioceptive training has shown benefits across populations. For example, Pánics et al. reported improved JPS in athletes after balance and coordination exercises.[10] Similarly, another study found that isokinetic quadriceps and hamstring strengthening enhanced balance and proprioception in patients with osteoarthritis.[11] Neuromuscular electrical stimulation (NMES) has also been shown to improve proprioceptive accuracy, potentially by increasing sensory input from skin and joint receptors.[12,13]

Despite evidence supporting NMES and exercise for proprioception, studies in healthy, untrained individuals are limited. Hybrid training, which combines NMES with voluntary resistance exercises, has demonstrated strength gains of 20–40% in untrained adults.[14,15] This approach uses Russian wave electrical stimulation to elicit antagonist muscle contractions, promoting physiologically aligned recruitment while reducing dependence on external resistance equipment.[16] Given the limited comparative data, this study aimed to evaluate the effectiveness of hybrid training versus traditional NMES in enhancing knee joint proprioception in healthy adults.

METHODS

This randomized controlled trial received ethical approval from the Health Research Ethics Committee (number 0522/KEPK/XI/2022) and was conducted at the Medical Rehabilitation Unit from November to December 2022.

Inclusion criteria were healthy, untrained males aged 18–40 years with low to moderate physical activity levels, as measured by the International Physical Activity Questionnaire-short form (IPAQ-SF), normal musculoskeletal function, and willingness to provide informed consent. Exclusion criteria included any exercise contraindications, such as acute knee joint inflammation or pain during active movement, contraindications to neuromuscular electrical stimulation, recent knee injuries, or lower limb strength training within the past six months. Participants were withdrawn if they chose to discontinue, failed to follow the training protocol, reported joint or muscle pain with a Visual Analog Scale score >2 during unweighted movement, experienced inflammation or delayed muscle soreness preventing two consecutive sessions, or developed an allergic reaction to electrical pads. Group assignment was performed using simple randomization with a sealed-envelope lottery.

Participants in the Hybrid Modification Group performed knee extension exercises three times per week, with at least 48 hours between sessions. Each session consisted of 10 sets of 10 repetitions with 1-minute rests between sets, during which the antagonist hamstring was stimulated at 80% of the participant's maximum comfortable intensity, determined at the start of the exercise. Participants in the

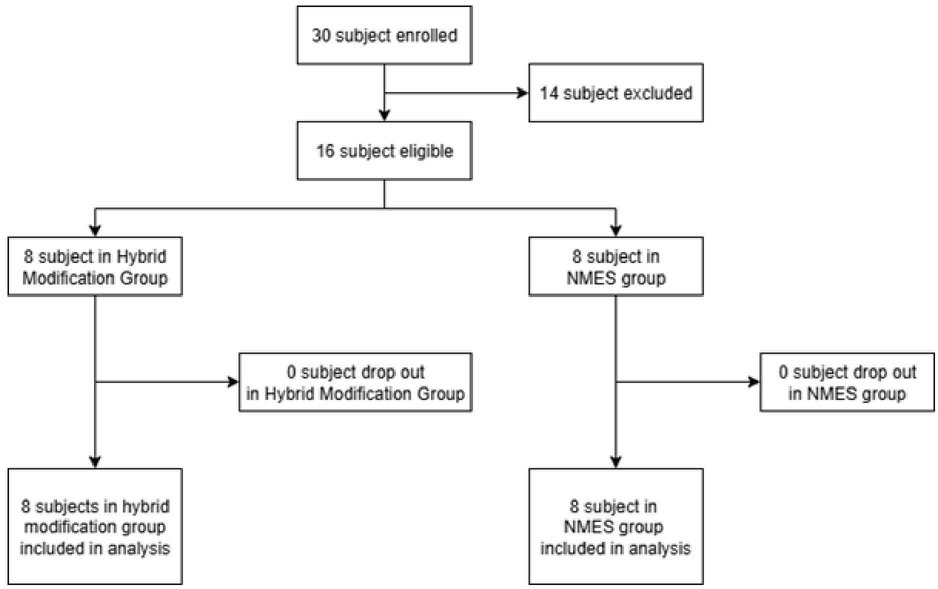

Figure 1. Flow chart of the study

Table 1. **Characteristic of subjects**

Variable	Hybrid Modification Group (n = 8) Mean ± SD	Neuromuscular Electrical Stimulation Group (n = 8) Mean ± SD	*P*-value
Age (years)	30.38 ± 2.07	30.88 ± 2.71	0.683a
Body weight (kg)	73.00 ± 6.28	74.13 ± 9.89	0.790a
Height (m)	1.72 ± 0.05	1.70 ± 0.07	0.402a
Body Mass Index (kg/m2)	24.67 ± 2.34	25.69 ± 2.30	0.395a
IPAQ-SF			
Low	3 (37.5%)	2 (25.0%)	0.264b
Moderate	5 (62.5%)	6 (75.0%)	

IPAQ-SF, international physical activity questionnaire-short form; Kg, killogram; kg/m2, killogram per meter squared; m, meter; n, number of subject; SD, standard deviation
aContinuous variables were compared using the independent *t*-test, bCategorical variables were analyzed using the Mann–Whitney test.

Table 2. **Comparison of joint position sense (JPS) in hybrid modification group before and after intervention**

Variable	Before intervention (*Mean ± SD*)	After intervention (*Mean ± SD*)	*P-value*a	Cohen's *d*	95% *CI*
JPS 30o dominant leg (o)	25.23 ± 4.80	30.00 ± 1.73	0.028	0.98 (large)	[-8.86, -0.69]
JPS 30o non-dominant leg (o)	27.48 ± 3.09	30.28 ± 1.71	0.033	0.94 (large)	[-5.30, -0.30]
JPS 60o dominant leg (o)	49.93 ± 4.93	58.98 ± 3.04	0.009	1.26 (large)	[-15.06, -3.04]
JPS 60o non-dominant leg (o)	51.25 ± 5.15	58.73 ± 2.16	0.008	1.28 (large)	[-12.34, -2.61]

CI, confidence interval; SD, standard deviation.
aPaired *t*-tests were used to compare pre- and post-intervention values.

Neuromuscular Electrical Stimulation (NMES) Group received Russian protocol stimulation of the quadriceps femoris for 10 sets of 10 repetitions with 1-minute rests. In both groups, NMES was delivered at a carrier frequency of 5000 Hz modulated at 20 Hz (2.4 ms on, 47.6 ms off) and administered at 80% of the maximum tolerable intensity, determined by gradually increasing the amplitude until discomfort was reported, then reduced to 80% of that level. All interventions were supervised by physicians.

Joint position sense (JPS) was assessed before and after the intervention at 30° and 60° using an isokinetic dynamometer (Cybex NORM™) on both knees. The test was performed actively, with three repetitions at each angle averaged for analysis, and conducted three days after the final intervention session in the following sequence: 30° right, 30° left, 60° right, and 60° left.

JPS data were examined within and between groups using SPSS version 26. Normality was determined using the Shapiro-Wilk test. Between-group comparisons used independent *t*-tests for normally distributed data and Mann-Whitney *U* tests for non-normal data, whereas within-group changes used paired *t*-tests or Wilcoxon signed-rank tests. We estimated confidence intervals and effect sizes (Cohen's *d*), and *p*-values <0.05 were considered statistically significant.

Table 3. Comparison of joint position sense (JPS) in the neuromuscular electrical stimulation group before and after intervention

Variable	Before intervention (*Mean ± SD*)	After intervention (*Mean ± SD*)	*P-valuea*	Cohen's *d*	95% *CI*
JPS 30o dominant leg (o)	24.13 ± 3.90	28.80 ± 3.60	0.032	0.95 (large)	[-8.80,-0.55]
JPS 30o non-dominant leg (o)	25.88 ± 4.01	29.78 ± 3.59	0.034	0.93 (large)	[-7.42,-0.38]
JPS 60o dominant leg (o)	48.38 ± 6.01	56.58 ± 3.52	0.002	1.73 (large)	[-12.16,-4.24]
JPS 60o non-dominant leg (o)	51.35 ± 4.87	57.65 ± 2.67	0.006	1.38 (large)	[-10.12,-2.48]

CI, confidence interval; SD, standard deviation.

aPaired *t*-tests were used to compare pre- and post-intervention values.

Table 4. Comparison of joint position sense (JPS) change between groups

Variable	HM Group (Mean ± SD)	NMES Group (Mean ± SD)	P-valuea	Cohen's d	95% CI
ΔJPS 30o dominant leg (o)	4.78 ± 4.89	4.68 ± 4.94	0.968	0.20 (medium)	[-5.37, 5.17]
ΔJPS 30o non-dominant leg (o)	2.80 ± 2.99	3.90 ± 4.21	0.557	0.29 (medium)	[-2.82, 5.02]
ΔJPS 60o dominant leg (o)	9.05 ± 7.19	8.20 ± 4.74	0.784	0.14 (small)	[-7.38, 5.68]
ΔJPS 60o non-dominant leg (o)	7.48 ± 5.82	6.30 ± 4.56	0.660	0.23 (medium)	[-6.78, 4.43]

CI, confidence interval; HM, hybrid modification; NMES, neuromuscular electrical stimulation; SD, standard deviation.

Δ, delta (difference); aBetween-group comparisons were performed using independent *t*-tests.

RESULTS

Thirty individuals were screened, and sixteen met the inclusion criteria, with no exclusions or dropouts. The final cohort comprised sixteen right-foot-dominant males (**Figure 1**), divided equally into the Hybrid Modification Group (n = 8), which received hybrid training, and the NMES Group (n = 8), which received Russian protocol NMES, both three times per week for four weeks. All participants completed the study. Baseline characteristics are presented in **Table 1**.

Both groups showed significant improvements in knee joint position sense (JPS) at 30° and 60° in both legs. The Hybrid Modification Group exhibited significant gains across all measured angles, with a similar pattern observed in the NMES Group. However, between-group comparisons revealed no statistically significant differences in the magnitude of change (**Tables 2–4**).

DISCUSSION

This study demonstrated that both modified hybrid strength training and neuromuscular electrical stimulation (NMES) significantly improved knee joint position sense (JPS) at 30° and 60° in both the dominant and non-dominant legs, yet no statistically significant difference was found between the groups. These results indicate that while each method is effective for enhancing proprioception in healthy, untrained men, neither intervention proved superior. Similar improvements in JPS following strengthening or NMES-based interventions have been reported in previous studies, suggesting that enhanced muscle activation and sensory input contribute to better proprioceptive control regardless of the modality applied.

Accordingly, the present findings support the role of both voluntary strengthening and electrical stimulation as viable strategies for improving knee proprioception, while underscoring the need for larger studies to determine whether one approach offers additional benefits over the other.

Previous research has reported that isokinetic training, including leg curls and knee extension exercises at an angular speed of 60°/s, three times per week for six weeks, improved JPS in young male subjects with patellofemoral pain syndrome.[17] Dynamic stability of the knee joint relies heavily on the surrounding muscles, particularly the hamstrings.[18] The quadriceps and hamstring muscles help maintain knee joint stability during both static and dynamic activities. A decrease in muscle strength, endurance, and fatigue can reduce proprioceptive sensitivity and control. Increased quadriceps and hamstring strength and work capacity are associated with dynamic knee stabilization.[17] Strengthening these muscles contributes to improved knee function, especially in individuals with knee weakness, by enhancing the hamstring-to-quadriceps ratio and reducing the risk of anterolateral tibial subluxation.[18]

Significant improvements were observed in the Russian NMES group, consistent with studies showing that low-intensity quadriceps strengthening, with or without blood flow restriction, enhances knee JPS in patients with knee osteoarthritis.[19] These gains are linked to increased muscle strength, which stimulates proprioceptive receptors, particularly muscle spindles. Proprioception is regulated peripherally and centrally: at the peripheral level, exercise induces adaptations in intrafusal fibers, shortens stretch reflex latency, and increases reflex amplitude, enhancing mechanoreceptor sensitivity. At the central level, exercise strengthens proprioceptive input via the gamma motor system, increases cortical projections, and promotes neuroplastic changes, including stronger synaptic connections and neural pathway reorganization.[20]

These results also align with studies comparing concentric and eccentric knee training, which found that JPS improvements depend more on training intensity than type.[21] Knee proprioception is critical for joint stability, precise muscle activation, and neuromuscular control, supporting functional movement.[22] Joint position sense (JPS) reflects dynamic proprioception, and angles of 30° and 60° maximally activate muscle spindles, making them optimal for assessment.[20,23,24]

The findings did not support the initial hypothesis anticipating greater improvements in the hybrid strengthening group. Several factors may explain this outcome. First, hybrid training combines eccentric quadriceps and hamstring exercises, which can cause muscle damage, myofibrillar disruption, inflammation, and delayed onset muscle soreness (DOMS), temporarily reducing strength, joint mobility, and proprioception.[25-27] To minimize fatigue effects, JPS measurements were taken on days 3–4 post-exercise. Second, proprioceptive improvements occur at central and peripheral levels, but this study did not assess muscle morphology, stretch reflex latency, or motor unit activity; thus, it is unclear whether one intervention had superior effects.[20] Third, participants did not warm up before JPS testing, which may have affected accuracy.[28] Finally, concurrent physical activities emphasizing joint awareness (e.g., Tai Chi, gymnastics, swimming, running) could have influenced outcomes.[20,29]

This study has several limitations. The sample consisted solely of young, healthy, untrained males, limiting generalizability to females, older adults, trained individuals, or clinical populations. The four-week intervention prevents conclusions about the long-term sustainability of JPS improvements. Mechanistic assessments, such as electromyography or biochemical markers, were not conducted, and functional outcomes related to proprioception—balance, coordination, or injury prevention—were not evaluated. Potential effects on prolonged muscle fatigue or microtrauma were also unexamined. The small sample size (n = 8 per group) limits statistical power and external validity. Future studies should include larger, more diverse populations, incorporate mechanistic and functional measures, extend intervention duration, assess safety, and explore applicability to clinical populations. Until then, clinical implications should be interpreted cautiously.

CONCLUSION

This study found that both modified hybrid strength training and Russian protocol neuromuscular electrical stimulation (NMES) significantly enhanced knee joint position sense (JPS) at 30° and 60° in the dominant and non-dominant legs of healthy, untrained men. There were no significant differences between the two therapies, implying that neither strategy was superior. These findings indicate that both techniques are effective at improving proprioception, but more study with bigger and more diverse populations is required to prove their comparative effectiveness and long-term applicability.

ETHICAL CLEARANCE

The Health Research Ethics Committee of Dr. Soetomo General Academic Hospital in Surabaya, Indonesia, approved the study (Approval No. 0522/KEPK/XI/2022).

CONFLICT OF INTEREST

The authors have declared no conflicts of interest.

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AUTHOR CONTRIBUTION

ASH, DT, and NKW conceptualized the study design and defined the intellectual content. All authors contributed to the literature search, data acquisition, and both clinical and experimental studies. Data analysis and statistical analyses were performed by ASH, DT, and NKW. All authors participated in manuscript preparation, editing, and review, with DT serving as the guarantor of the study.

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