Dynamic Limit of Stability and Ankle Joint Function Following Neuromuscular Training of Unstable Ankle Joints: A Randomized Controlled Trial

Dynamiczna granica stabilności i funkcji stawu skokowego po treningu nerwowo-mięśniowym niestabilnych stawów skokowych: Randomizowane badanie kontrolowane

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Abstract

Purpose. This study investigated and correlated between the dynamic limit of stability and functional level of the ankle joint in patients with unilateral chronic ankle instability after receiving neuromuscular training.
Material and Methods. Forty patients of both sexes were examined. They were assigned into two equal groups; experimental (Group A) and control (Group B). The Biodex Balance system was used for assessing the dynamic limit of stability and the ankle joint functional assessment tool (AJFAT) was used for assessing the functional level of the ankle joint before and after a 4-week period during which Group A received neuromuscular training.
Results. Mixed Design MANOVArevealed that the dynamic limit of stability test duration decreased and the AJFAT score increased significantly in Group A after training compared with before ($p < 0.05$). Similarly, the dynamic limit of stability test duration decreased and the AJFAT score increased significantly in Group A compared with Group B after training ($p < 0.05$). Pearson correlation showed significant strong negative correlation between the dynamic limit of stability test duration and AJFAT score in Group A ($p < 0.05$).
Conclusion. Improvement in dynamic stability and functional joint stability level was perceived with neuromuscular training. This improvement reflects the ability of training to enhance ankle joint sensorimotor capabilities.

Key words:

Neuromuscular training, Dynamic stability, Ankle joint function, Chronic ankle instability

Streszczenie

Cel. W badaniu zbadano i skorelowano dynamiczną granicę stabilności i poziom funkcjonalny stawu skokowego u pacjentów z jednostronną przewlekłą niestabilnością stawu skokowego po treningu nerwowo-mięśniowym. Materiał i metody. Przebadano czterdziestu pacjentów obojga płci. Uczestnicy zostali przydzieleni do dwóch równych grup: grupa eksperymentalna (grupa A) i grupa kontrolna (grupa B). Do oceny dynamicznej granicy stabilności wykorzystano system Biodex Balance, a do oceny poziomu funkcjonalnego stawu skokowego przed i po 4 tygodniach, w których Grupa A przeszła trening nerwowo-mięśniowy, wykorzystano narzędzie oceny funkcjonalnej stawu skokowego (AJFAT).
Wyniki. Projekt Mixed Design MANOVA wykazał, że dynamiczna granica czasu trwania testu stabilności zmniejszyła się, a wynik AJFAT wzrósł istotnie w grupie A po treningu w porównaniu z wynikiem przed treningiem ($p < 0,05$). Podobnie, dynamiczny limit czasu trwania testu stabilności zmniejszył się, a wynik AJFAT wzrósł istotnie w grupie A w porównaniu z grupą B po treningu ($p < 0,05$). Korelacja Pearsona wykazała istotną silną ujemną korelację między dynamiczną granicą czasu trwania testu stabilności a wynikiem AJFAT w grupie A ($p < 0,05$).
Wnioski. Poprawę stabilności dynamicznej i poziomu stabilności funkcjonalnej stawów zaobserwowano podczas treningu nerwowo-mięśniowego. Ta poprawa pokazuje, że trening może poprawić zdolności czuciowo-ruchowe stawu skokowego.

Słowa kluczowe:

trening nerwowo-mięśniowy, stabilność dynamiczna, funkcja stawu skokowego, przewlekła niestabilność stawu

Introduction

Chronic ankle instability (CAI) clinically refers to recurrent ankle sprain injuries. At least 30% of individuals who experience an ankle sprain will suffer from CAI[1]which is either mechanical or functional. Although there is no agreement on the factors that contribute to CAI development with so many controversies being reported [2], different factors were suggested. These factors include joint laxity, muscle weakness [3], impaired proprioception [4], impaired postural control [5], and/or impaired neuromuscular control [6]. Mechanical instability results from joint laxity while functional instability results from all other factors which may or may not be accompanied by joint laxity [7].

Repetitive ankle sprains result mostly from impaired proprioception rather than mechanical instability and/or loss of muscle strength [8]. Damage of joint capsule and ligament receptors occurs resulting in impairment of proprioceptive afferent information "deafferentation" [8]. Proper proprioception is an essential constituent of neuromuscular control. With proper proprioception, one can timely anticipate and determine the speed and magnitude of perturbation and respond with proper muscle activation and joint motion [9].

Although extensive research work has been conducted over the past decades in an attempt to reduce the incidents of initial and recurrent ankle sprains, it is still unclear what rehabilitation protocol is most effective. Balance/postural training is the most commonly conducted rehabilitation protocol for ankle instability [9]. Yet, there is a great controversy regarding the effect of conducting balance training (e.g., single limb standing, standing on unstable surfaces) with much research work reporting positive therapeutic effects [10-14]while others declaring disagreement with these positive effects [15,16]. In the "Clinical Practice Guidelines" published recently, a panel of experts concluded that the evidence on conducting balance activities on unstable surfaces is weak (grade of recommendation "C") [17]. Even though if balance training is beneficial in reducing the incidents of ankle sprains, it is suggested to be due to improved muscle and ligament strength and stiffness not due to improved neuromuscular control [9].With repetitive ankle sprain being mostly due to impaired proprioception rather than loss of muscle strength as reported above [8], there is a need for involving neuromuscular control training in chronic instability rehabilitation. Knowing that impaired neuromuscular control caused by impaired ankle joint proprioception is involved in the high recurrence rate of ankle sprain [17, 18], it is anticipated that improving neuromuscular control may be effective in reducing this rate.

One distinguished form of neuromuscular control training has recently attracted attention, known as "Sensorimotor training (SMT)". SMT is a special form of proprioceptive and balance training that is utilized for management of chronic musculoskeletal pain syndromes. Many of these syndromes are characterized by muscle imbalance that causes movement impairment which in turn changes motor programming within the central nervous system (CNS). SMT involves progressive challenges to the sensorimotor system with the aim of restoring normal motor programs, muscle firing patterns and reflexive stability that are compromised in these syndromes [8]. It is based on the concept that instead of emphasizing the isolated strength of a group of muscles around a joint, normal CNS function is restored through motor-relearning [8, 9-21]. Maximal afferent information is ensured through increasing sensory input at three specific places in the body that are rich in proprioceptors (the foot, sacroiliac joint, and cervical spine) [19].Increasing proprioceptive input aims at stimulating subcortical pathways, facilitating automatic coordinated movement patterns [8], and improving postural control and motor response in dynamic situations [22, 23]. This is achieved through progression through static, dynamic and functional phases using simple rehabilitation tools [8].

Although dynamic balance is mainly affected in CAI, very limited studies examined it after SMT in such patients [24]. Even though, Filipa et al. [24] examined dynamic balance using the Star Excursion Balance Test not the Biodex Balance system, and tested a small sample size with the tested sample being healthy individuals and group allocation not being randomized. Thus, this study was conducted to examine the effect of SMT on dynamic balance and ankle joint function in patients with CAI. It was hypothesized that SMT will have positive effects on both the dynamic balance and ankle joint function level in patients with unstable ankle joints.

Material and Methods

Study design

Pre-test Post-test Control group design was adopted in this study in which patients were assessed for both dynamic stability and ankle joint functional level before and after the 4-week study period. The work described has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) with clinical trial registry (PACTR201809487841211).

Participants

Upon receiving the Institutional Review Board approval of the Faculty of Physical Therapy, Cairo University (Approval number: P.T.REC/012/002038).Forty male and female college students suffering from unilateral functional ankle instability participated in the study. The patients' age, weight and height ranged from 17 to 22 years, 52 to 79 kg and 150 to 186 cm respectively. All patients were diagnosed by the same therapist. Each patient had at least one significant lateral ankle sprain of either ankle, but not both, within the previous year, and one repeated injury or a "giving way" sensation in the affected ankle without being rehabilitated on. All patients had not any surgeries or fractures that require re-alignment in either limb of the lower extremity or acute injury to the musculoskeletal structures of other joints of the lower extremity in the previous three months. These criteria were specified by the International Ankle Consortium [25]. All patients had positive Single Leg Standing test. This is a valid test that is used to identify patients with chronic ankle instability that can benefit from rehabilitation that targets postural stability regain [26].

Randomization

Upon arrival to the institutional "Balance Assessment Laboratory", all inclusion criteria were verified by the same therapist for all patients. A brief orientation session about the study, its purposes and the tasks to be accomplished was provided to each patient and personal data were taken. Patients were randomly assigned to either group through drawing one of 40 folded papers of the tested group, placed in a container; half of which had a note "experimental group" and the other half had a note of "control group" by a blinded and an independent researcher. Informed consents were taken before participation.

Outcome measures

Dynamic limit of stability

A Biodex Balance System (Biodex Medical Systems Inc, Shirley, NY, USA was used to assess dynamic stability. This system with its multiaxial platform that permits surface tilt of up to 20 degrees creates a dynamic situation that is similar to actual functional activities that cause instability [27]. The reliability of the Biodex Balance system was documented with an intraclass correlation coefficient (ICC) of 0.65-0.85 [28].
For dynamic balance assessment, patients stood on the device platform, bare footed, dressed in untaught short pants and T-shirts. They were instructed to stand in natural stance trying to keep balance while the platform is being released (becoming unstable). Initially, they were allowed to support themselves using the device handrails. Once they became able to master their stability, they were instructed to stand unsupported. Each patient was asked to center the body on the platform by shifting feet positions trying to keep the cursor (displayed on the device screen grid) centered. Upon mastering this stable position, the platform was stabilized and the feet positions on the platform were identified and the feet coordinates were recorded. Foot coordinates were measured from the center of the back of the heel. The foot angle was determined by finding a line on the platform that is parallel to the line that bisects the foot (a line that connects the center of the heel with the second toe). Three trials were initially conducted before actual testing, for familiarization. The dynamic limit of stability test duration was the recorded variable. To assess the test duration, eight boxes were displayed on the device screen around a central box. One box was displayed at once in a random place. The patient was asked to move the platform trying to point the cursor at the box upon its appearance then return back to the central box. The time taken to point at the eight boxes and return back to the central box after pointing at each box was recorded. A decrease in the test duration indicates increased stability. For all patients, the ankle joint functional level was assessed first followed by dynamic balance assessment.

Ankle joint functional assessment tool (AJFAT)

The ankle joint functional assessment tool (AJFAT) was used for assessing the ankle joint functional level. It is an excellent tool for discriminating between stable and functionally unstable ankles. It has high test-retest reliability as well as precision. The intraclass correlation coefficient equals 0.94 and the standard error of measurement equals 1.5 points [29].
Regarding ankle joint function assessment, each patient was asked to fill-in the AJFAT. One answer to each of the 12 questions of the AJFAT that best suited the ankle status at time of assessment was chosen. Each question has five answers; each answer was assigned a point value ranging from 0-4. The overall AJFAT score was recorded.A high AJFAT score indicates high ankle joint functional level.

Intervention

Participants were randomly assigned into two equal age-, weight-, and height-matched groups. Group A (Experimental) had SMT for four weeks while Group B (Control) had not any form of training.
Rocker and wobble boards were used for neuromuscular training. Both are designed to facilitate balance, automatic postural reactions and reflexive righting movements through providing unstable sensory-stimulating surfaces [30].
Regarding the neuromuscular training that was conducted for Group A, it involved three respective stages; static, dynamic and functional. Within each stage, patients progress through exercises that elicit automatic reflexive muscular stabilization. This challenges patients to maintain postural control in different positions that require proper neuromuscular control [8, 31]. Training was conducted six times per week for four weeks. Each session lasted for about 30 minutes. Patients were trained under the supervision of the same therapist to ensure accurate training performance. A detailed description of the training program is provided by Page [8].

Sample size calculation

Due to lack of previous studies on the effect of SMT on dynamic stability with the consequent inability to calculate the effect size, a pilot study was conducted for a sample of 10 patients. The statistical analysis test (2x2 Mixed Design MANOVA) conducted on this sample size revealed a Pillai value of 0.715 that was used to detect the effect size using G*power program (G*power 3.0.10). Power analysis revealed that 12 patients were sufficient to produce a power level of 96% with a detected effect size of 1.58. With the fear of losing patients during the 4-week study duration, we examined all available patients during the whole study period. Forty patients completed the whole study duration. Power analysis was conducted again on the whole 40 patients to determine the actual power level of the study. It revealed that a sample size of 17 patients was needed to produce the actual power of the study which was 97% with a calculated effect size of 1.23.

Results

A total of 45 patients were examined, three of which didn't meet the inclusion criteria and two declined to participate. Hence, forty patients were examined. These forty patients were randomly assigned to two groups (20 in Group A and 20 in Group B). All forty patients completed the 4-week study duration and their data were used for analysis (figure 1).

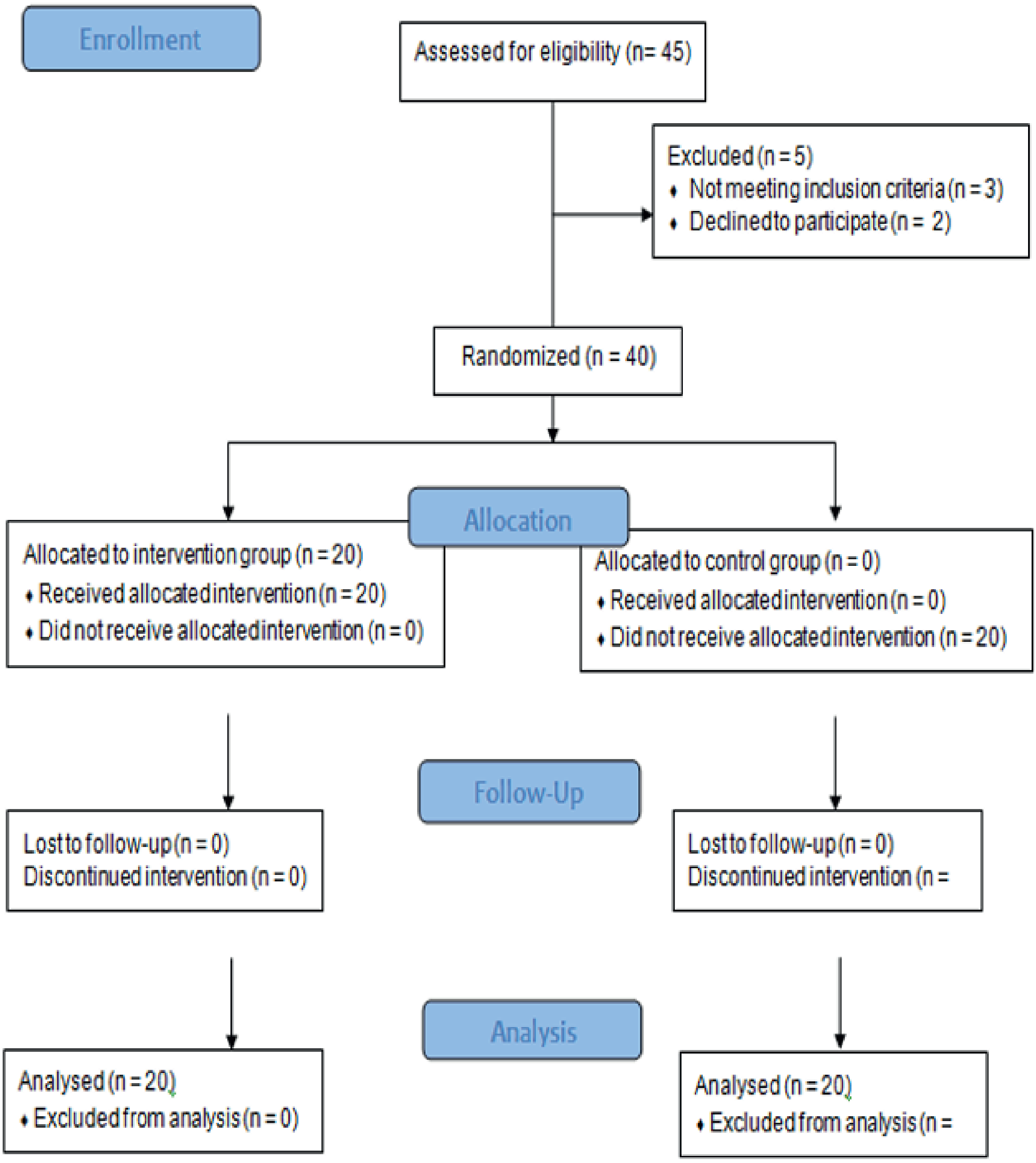

Figure 1. CONSORT flow chart of patient enrollment

Regarding the patients' demographic data, the mean ± standard deviation values for the age, weight and height were 19.15 ± 1.66 vs 19.6 ± 1.5 years, 65.3 ± 9.52 vs 68.5 ± 6.87 kg, and 170.4 ± 8.29 vs 170.1 ± 8.83 cm for Group A Vs Group B. Unpaired t-tests showed no significant difference in between ($p > 0.05$).

Initially, data were screened for normality and homogeneity of variance assumptions. Once both assumptions were assured not to be violated, Mixed Design MANOVA was conducted. The alpha level was set at 0.05.

The subsequent multiple pairwise comparison tests, conducted with Bonferroni adjustment, revealed that the dynamic limit of stability test duration decreased significantly and the AJFAT score increased significantly in Group A compared with Group B post-training ($p < 0.05$). Similarly, the dynamic limit of stability test duration decreased significantly and the AJFAT score increased significantly post-training compared with pre-training in Group A ($p < 0.05$). No other significant differences were found (tables 1).

Pearson correlation showed significant strong negative correlation between the dynamic limit of stability test duration and AJFAT score in Group A ($r = -0.647$, $p = 0.000$) with a regression equation of dynamic limit of stability test duration = 4.69 −0.086 (AJFAT score). No significant correlation was found for Group B ($r = -0.048$, $p = 0.389$) (figures 2&3).

Table 1. Descriptive and Inferential Statistics of the Dependent Variables in The Experimental and Control Groups Pre and Post the Four-Week Study Period

Dependent variables				
	Mean ± SD			
	Experimental group		Control group	
	Pre	Post	Pre	Post
Dynamic limit of stability test duration (sec)	3.32 ± 0.96	2.05 ± 0.61	3.32 ± 0.63	3.36 ± 0.71
AJFAT† score	17.2 ± 3.14	29.65 ± 5.57	16.33 ± 2.09	15.78 ± 1.99
	Pre testing vs. Post testing (p values and effect size estimates)			
	Experimental group		Control group	
Dynamic limit of stability test duration (sec)	p-value = 0.0001* Cohen's d = 1.581		p-value = 0.737 Cohen's d = −0.072	
AJFAT† score	p-value = 0.0001* Cohen's d = −2.754		p-value = 0.506 Cohen's d = 273	
	Experimental vs. Control (p values and effect size estimates)			
	Dynamic limit of stability test duration (sec)		AJFAT† score	
Pre treatment	p-value = 0.997 Cohen's d = 0.0012		p-value = 0.329 Cohen's d = 0.325	
Post treatment	p-value = 0.0001* Cohen's d = −1.99		p-value = 0.0001* Cohen's d = 3.317	

*Data are expressed as mean ± SD, * Significant at alpha level < 0.05.*
† AJFAT: Ankle Joint Functional Assessment Tool

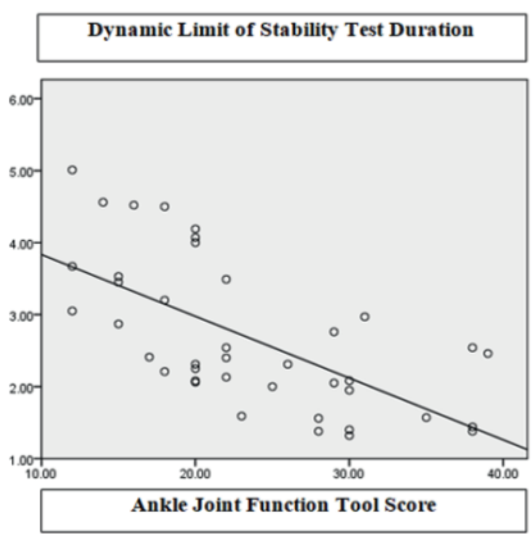

Figure 2. Correlation between dynamic limit of stability test duration and ankle joint function tool score in the experimental group

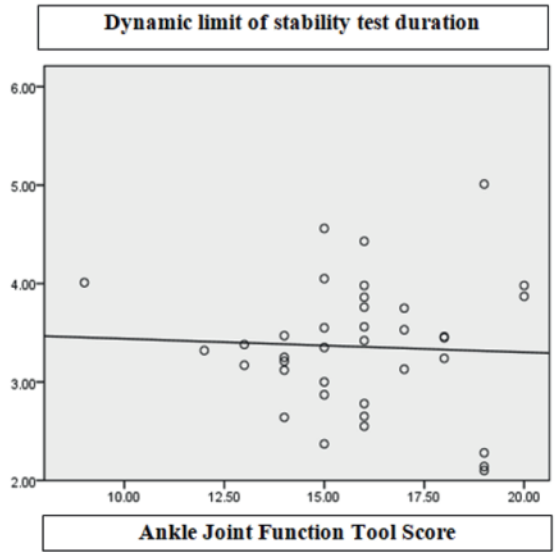

Figure 3. Correlation between dynamic limit of stability test duration and ankle joint function tool score in the control group

Discussion

The significant decrease in the dynamic limit of stability test duration and significant increase in the AJFAT score recorded in Group A after four weeks of SMT compared with before together with the similar findings recorded for Group A compared with Group B after the 4-week period as well as the significant strong negative correlation between the dynamic limit of stability test duration and the AJFAT score in Group A indicate improvement in the dynamic and functional joint stability levels. Improvement is anticipated to have occurred by virtue of SMT that plays an important role at the sensory (proprioceptive), and motor (motor control) levels with emphasis on motor re-learning (programming).

It has long been believed that chronic musculoskeletal pain, as that present in CAI, is mediated centrally within the CNS where motor programming is changed. The altered programming is caused by movement impairment that results from muscle imbalance [32]. Janda [32] believed that this movement impairment could be corrected through normalizing the peripheral proprioception, correcting muscle imbalance and enhancing correct motor programming.

When injury first occurs with the concomitant damage of the mechanoreceptors of the lateral structures of the ankle joint and the consequent reduction in proprioceptive input, central affection occurs (altered supraspinal motor control mechanisms) [33]. The altered proprioceptive input results in reduced strength of the ankle muscles [3], or arthrogenic muscle inhibition [34]. In addition, the damaged proprioceptors may cause delay in conduction of the afferent signals and consequent delay in the efferent signals causing delay in the corrective muscle contractions required to address perturbation [35]. The insufficient and delayed activation of the supporting ankle muscles could result in inadequate joint motion control causing repetitive episodes of instability [34].

With SMT, joint proprioception is improved [36]. SMT increases proprioceptive input at three sites of the body that are rich in proprioceptors (foot, sacroiliac joint, and cervical spine). This aims at stimulating subcortical pathways and facilitating automatic coordinated movement patterns. The increased inflow of proprioceptive information reaches the three specialized and somatotopically organized areas of the motor cortex which are connected to the motor neurons present in the spinal cord [37]. These areas are involved with encoding the muscles that should be activated, quantifying the amount of force to be produced, identifying the direction of motion, organizing and preparing motor commands, and programming the sequence of movements that are produced by groups of muscles [38].

Interpretation of proprioceptive information by higher brain centers improves nervous system's ability to generate fast and optimal muscle firing patterns and stimulates central mechanisms responsible for dynamic joint stability [31]. In that study conducted by Gruber et al. [31], a complex activation pattern in the ankle muscles was found after four weeks of SMT. Significant increases in the contractile impulses and rate of force development during maximum isometric plantar flexion together with early recruitment of large motor units were also found after the four-week training period. These increases were postulated to be related to neural adaptation as similar effects were found with supramaximal nerve stimulation.

In the same context, retraining the altered afferent pathways with the consequent improvement of proprioception using SMT is suggested to enhance joint position sense in patients with functional ankle instability [36].Enhancing joint position sense helps restore the neuromuscular control of the ankle joint which is crucial for regaining dynamic joint stability and returning back to pre-injury functional levels [4].

SMT permits improvement of kinaesthetic awareness on both stable and unstable surfaces. In SMT, patients are trained to adopt and maintain correct foot, lumbopelvic and cervical positions during the three stages of training (static, dynamic and functional) together with performing active range of motion exercises in different positions. Kinaesthetic awareness of proper segment positions activates the "deep stabilization" system. Mastering proper segment positions in static and dynamic situations helps in generating new patterns of motion. This improves balance and reaction times in daily living activities [30].

Motor control is further enhanced by improved muscle agonist/antagonist balance. Proper muscle balance is one of the key factors of proper dynamic joint stability [39]. Normally, concentric eversion is required to counteract the violent inversion that occurs during ankle sprain injury. If the evertors are not strong enough to counteract the inversion moment, injury of the lateral ligaments could occur as their tensile strength are exceeded [3]. A concentric eversion/eccentric inversion ratio is used to reflect the functional capacity for providing dynamic ankle joint stability. SMT was found to increase the isokinetic eversion/inversion strength ratio in patients with functional ankle instability [36], thus reducing muscle imbalance. Co-contraction and motor control were trained through closed-chain exercises. Patients were instructed to consciously manipulate their ankle position during various exercises while keeping balance. To incorporate visual and vestibular inputs, patients were trained with eyes opened then closed, while sitting then standing, on firm then soft surfaces, and on stable then unstable surfaces.

As mentioned earlier, SMT emphasizes restoration of the central nervous system function through motor-relearning rather than treating isolated structures. Two stages of motor relearning are being stressed on; voluntary control of movement that becomes automatic upon learning followed by an unconscious "feedforward" mechanism. Once voluntary control of movement is learnt, the new coordinated movement pattern becomes programmed in the subcortical region, becoming automatic and much quicker. Herein, the "feedforward" mechanism occurs unconsciously which is essential for preparing the body before movement initiation through activation of the stabilizing joint muscles [32].

Successful rehabilitation programs were previously proposed to incorporate activities that address the three levels of motor control (spinal cord, brain stem and cerebral cortex levels). Since SMT incorporates these three levels of motor control, it could be considered a successful program. SMT involves activities that focus on sudden changes in joint position with reflexive stimulation of neuromuscular control (reflex joint stabilization responses at the spinal cord level). In addition, it involves balance and postural activities conducted with and without visual input (motor control at the brain stem level). Finally, SMT involves joint repositioning activities, specially performed at joint end ranges (motor control at the cerebral cortex level). Training at the cerebral cortex level enhances the conversion of conscious motor programming to unconscious one. As one repeats these activities, the cerebral cortex becomes able to determine the most appropriate motor pattern to a given task, considering the proprioceptive information gained in previous attempts during training [40].

Conclusion

To sum it up and as we hypothesized, SMT could be considered beneficial in improving dynamic joint stability and functional level of the ankle joint in patients with chronic ankle instability. Hence, with improved stability the incidence of recurrent sprains is anticipated to be reduced. Attention should be taken that the findings of our study could be generalized to patients with functional ankle instability. Further studies are needed to examine the long term effect of SMT on dynamic joint stability and recording the frequency of ankle sprain re-injury after SMT.

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