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Effect of Sensory-Motor Training on Dynamic Balance in Patients with Patellofemoral Pain Syndrome Associated with Foot Pronation: A Randomized Controlled Trial

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Abstract

Objective: This research aimed to examine the impact of sensory-motor training (SMT) on dynamic balance in patients with patellofemoral pain syndrome associated with foot pronation.

Methods: Forty-eight male and female individuals diagnosed with patellofemoral pain syndrome, aged between 18 and 25 years, were randomly divided into two equal groups. The study group (n=24) underwent a regimen of sensory-motor training (SMT) and conventional exercise program, while the control group (n = 24), engaged solely in the conventional exercise program. All patients received three sessions per week for six weeks. Assessments before and following treatment were performed for the dynamic balance through the Y-Balance Test (YBT). Within and between-group comparisons of pre- and post-intervention outcome measures were assessed using paired t-tests and unpaired t-tests, respectively.

Results: The comparison within each group revealed notable enhancements in the dynamic balance following treatment, as opposed to before treatment. Additionally, the analysis between groups demonstrated significant statistical disparities favoring the study group over the control group.

Conclusions: Adding sensory-motor training into a conventional exercise program has demonstrated greater advantages on dynamic balance; compared to solely utilizing the conventional exercise program, due to notable enhancements in dynamic balance.

Keywords: Conventional exercise; Dynamic balance; Patellofemoral pain; Sensory Motor Training

Introduction

Patellofemoral Pain Syndrome (PFPS) is regarded as a common musculoskeletal condition affecting athletic or non- athletic population. It is described as anterior or retropateller pain inhabiting functional activities such as extended sitting, walking, stair climbing, running, and squatting **(Kasitinon et al., 2021).** Development of PFPS and patellofemoral malalignment has been linked to multiple factors either proximal factors like proximal hip & knee muscles weakness **(Fulkerson, 2002; and Souza & Powers, 2009)** or distal factors as abnormal foot posture or foot overpronation. Both affect patellofemoral joint kinematics **(Barton et al., 2010).**

Excessive foot pronation has been connected to PFPS in observational researches **(Barton et al., 2010).** In normal foot posture, at the initial heel strike, the subtalar joint (STJ) is in a supinated stance, which transitions to foot pronation and internal rotation of the tibia. By midstance, the foot achieves full contact with the ground, prompting the subtalar joint to supinate again, accompanied by external rotation of the tibia to facilitate knee extension. Conversely, in individuals with overpronated foot posture, the subtalar joint remains pronated during midstance, hindering external rotation of the tibia. In turn, the femur tends to rotate internally on the tibia to compensate for the loss of knee extension, leading to lateral tracking of the patella, and increasing patellofemoral stresses leading to painful movement of the knee joint accompanied by loss of knee function **(Barton et al., 2012).** Pronated foot positions are typically accompanied by weak and elongated intrinsic foot muscles, which could alter their length-tension relationship and impair their capacity to produce sufficient force **(Barton et al., 2010).** As a result, this can lead to poor sensory input, affecting postural control since maintaining an upright posture relies on feedback from the foot also, disturbing the normal alignment of the patellofemoral joint leading to limited knee functional capacity **(Janda, 1987).**

Treatment approaches for PFPS mainly include flexibility and strengthening exercises of the hip and knee muscles. Additionally, it may include taping, proprioception training, manual therapy, and foot orthotics **(Dursun et al., 2001; Crossley et al., 2002; Yip & Ng, 2006; Peeler & Anderson, 2007; and Iverson et al., 2008).** Sensory-motor training (SMT) has been considered in the rehabilitation of different musculoskeletal system disorders. These exercises aim to correct muscle imbalances and faulty movement patterns in the central nervous system by promoting neuromuscular functional adaptability, improving proprioception and coordination, so minimizing the injury risk. Additionally, SMT enhances plantar sensory feedback which activates intrinsic foot muscles, ultimately aiding in the correction of abnormal gait patterns linked to pronated feet **(Page, 2006).**

To the authors' knowledge, there wasn't much research demonstrating the effect of SMT program on dynamic balance in patients with PFPS associated with foot pronation, the present study's findings may contribute to closing this knowledge gap and enhancing our comprehension of this effect.

Materials and Methods

Study design

This randomized controlled trial, with single-blinding, took place at the outpatient clinic and motion analysis laboratory of the Faculty of Physical Therapy, Delta University for Science and Technology, spanning from June 2022 to September 2023. Approval for the study was obtained from the research ethical Committee of the Faculty of Physical Therapy, Cairo University, under Project-ID: P.T.REC/012/003701. The research was registered on www.pactr.org, with Identifier: PACTR202301535060049. This study included forty-eight patients according to sample size calculation, diagnosed with PFPS. Patients were randomly and equally allocated to the study group (n = 24), which received sensory-motor training (SMT) and conventional exercise program, while the control group (n = 24), engaged solely in the conventional exercise program. The purpose and study methods were explained in detail to each patient. All patients signed an informed consent prior to participation.

Participants

Forty-eight male and female patients were included in this study, their age between 18 and 25 years old, with body mass index (BMI) ranged from 18.5 to 24.9 kg/m². They were diagnosed and referred with unilateral patellofemoral pain syndrome (PFPS), characterized by anterior or retropatellar knee pain lasting at least six weeks, along with a pronated foot posture indicated by a navicular drop test (NDT) greater than 10 mm. **(Brody, 1982).**

Patients were excluded from participation in the study if they didn't fulfill the inclusion criteria or if they suffered from previous knee injuries or surgeries in the last three months or even apparent deformities, had a history of foot orthoses in the previous 5 years, had a history of infection or systemic disease of the musculoskeletal system, and suffered from sensory disturbance **(Nadia et al., 2019).**

Randomization and blinding

Patients were randomly allocated to either of the two groups using a random generator (www.randomization.com). The assignment to a specific treatment option was disclosed to the patients upon confirmation of enrollment. Patients were kept unaware of their group assignment, ensuring blinding throughout the study. They remained uninformed about the exercises carried out by the other group.

Outcome measures

In this study, authors assessed the dynamic balance measured via Y-Balance Test (YBT), all testing procedures were performed prior to any intervention and after.

The Navicular Drop Test (NDT) was conducted to assess foot pronation and examine the medial longitudinal arch (MLA) **(Shultz et al., 2006).** It measures the variance (in millimeters) between the height of the navicular tuberosity at the subtalar joint in a neutral position and its height in a relaxed position. Elevated NDT values suggest both subtalar pronation and a lower MLA, while low NDT values indicate subtalar supination and a higher MLA **(Brody, 1982).** NDT is regarded as a reliable, valid, and straightforward method for assessing the height of the medial longitudinal arch **(Zuñiga-Escobar et al., 2018).**

Dynamic balance was evaluated using the Y-Balance Test (YBT). Each patient was asked to stand on the center of a drawn Y-shaped figure on the floor bare foot on the leg being measured while trying to perform maximum reach by the contralateral limb on the lines in the anterior, posterolateral, and posteromedial directions, then returned to the starting position, six familiarization trials, alternating among the three directions followed by three test trials for each direction, the average of these measurements was documented as the outcome for each direction. If the participant removed the support foot from the initial position or changed foot position to regain balance, the repetition was disregarded **(Moon & Jung, 2021).** Finally, a composite reach distance was computed as the sum of the reach distance in the 3 directions divided by 3 times the leg length and reported as an overall score of the test **(Wright et al., 2017).**

Interventions

All patients received a conventional exercise program which consists of strengthening exercises of hip abductors, hip lateral rotators, hip extensors, and quadriceps in addition to stretching exercises of hamstring, iliotibial band, and gastrocnemius.

Patients performed each exercise twice (2 sets) lifting a weight they could comfortably manage for 10 repetitions (10RM). This weight corresponded to 60% of their maximum capacity for 10 reps. They took short breaks (3 seconds) between each repetition and longer breaks (1 minute) between sets **(Ismail et al., 2013; and Colby, 2012).**

For hip abductors strengthening, the Patient lies on their side with the uninjured leg bent and the injured leg straight. The therapist steadies the patient's pelvis to prevent him from using other muscles. A weight is placed near the ankle of the injured leg. The patient lifts the injured leg out to the side, holds it for 6 seconds, lowers it back down, and relaxes. For hip lateral rotators strengthening, the Patient sits with his hips and knees bent at 90 degrees, using one hand for support. The therapist steadies the patient's thigh on the injured side. A weight is placed near the ankle of the injured leg. The patient rotates the injured leg inward, holds it for 6 seconds, brings it back to the starting position, and relaxes **(Nadia et al., 2019).**

For hip extensors strengthening, the patient lies face down on their stomach with their upper body slightly propped up (half-prone position). They straighten their knee completely, extending the entire injured leg behind them. The therapist steadies the patient's pelvis to prevent them from using other muscles. A weight is placed near the ankle of the injured leg. The patient lifts the injured leg straight back up in the air, holds it for 6 seconds, lowers it back down, and relaxes **(Nadia et al., 2018).**

For quadriceps strengthening, the patient lies on his back with their knees straight (supine position). The therapist places a rolled towel under the knee of the injured leg for comfort. The therapist steadies the patient to prevent him from using other muscles. A weight is placed near the ankle of the injured leg. The patient straightens his knee as much as possible, lifts his heel off the table, holds it for 6 seconds, lowers their leg back down, and relaxes **(Hamada et al., 2017).**

For gastrocnemius stretching, the patient lies on their back (supine position). The therapist stands beside the injured leg. With one hand, the therapist steadies the patient's leg for support. The therapist uses his other hand to gently cup the patient's heel. The therapist slowly pulls the foot toward dorsiflexion. The therapist holds this gentle stretch for 30 seconds. He repeats this stretch three times, with short 10-second breaks in between each repetition. For hamstring stretching, the patient lies on his back with a straight knee (supine position). The therapist lifts the patient's injured leg and rests it comfortably over his shoulder. To keep the patient stable, the therapist uses a strap to secure the other leg along its front side (anterior thigh). The therapist holds this stretch for 30 seconds. They repeat this stretch three times, with short 10-second breaks in between each repetition. For iliotibial band stretching, the patient lies on his side with the uninjured leg underneath him. The therapist uses one hand to stabilize the patient's pelvis to prevent him from arching their back. With the other hand, the therapist gently pulls the injured leg across the uninjured leg. The therapist holds this stretch for 30 seconds. He repeats this stretch three times, with short 10-second breaks in between each repetition **(Colby, 2012).**

Furthermore, patients in the study group received SMT, which comprised 18 distinct exercises that progressed over six weeks. Adjustments in posture, support base, and center of gravity were established within a closed kinetic chain state while barefoot. Patients applied single-leg stance, tandem stance, and forward lean during weeks one (stable surface) and two (unstable surface) respectively, for 3 sets of 30 seconds. The next phase exercises were carried out on a stable surface (week three), and then an unstable surface (week four). Exercises include throwing a ball in different directions, kicking the leg in different directions, and upper limb PNF pattern with elastic resistance each action was performed ten times in three sets. The third phase included squatting, lunging, and jumping on a stable surface (week five), and then an unstable surface (week six). Each action was held for 30 seconds in three sets with a 30-second pause allowed following each movement **(Moon & Jung, 2021).**

Statistical analysis

All statistical analyses were conducted using Statistical Package for Social Sciences (SPSS) software (version 21 for Windows). Initially, the data underwent tests for normality using the Kolmogorov-Smirnov test and for homogeneity of variance using Levene's test. The results indicated that the data were normally distributed (P>0.05), and the assumption of homogeneity of variance was not violated (P>0.05). Descriptive statistics, including mean and standard deviation, were calculated for all variables. Within-group and between-group comparisons of pre-interventional and post-interventional outcome measures were conducted using paired and unpaired t-tests, respectively. Demographic data between groups were compared using the Chi-square test for categorical variables [number (%)] and unpaired t-tests for continuous data.

Results

Sixty patients were assessed for eligibility. However, 48 patients were eligible. They were randomized to receive interventions and completed the treatment protocol and post-intervention analysis without any dropouts (Figure 1).

The demographic information of patients in both groups is presented in Table (1). There were no notable variations between the two groups regarding demographic factors such as body mass index (BMI), age, and gender distribution.

Table (1): Demographic data of the study and control groups

Patients group	Age (years) Mean ± SD	BMI (kg/m^2) Mean ± SD	GENDER COUNT (%)
Study (n=24)	21.58 ± 1.61	22.94 ± 1.45	Men =14 (58.3%) Women= 10 (41.7%)
Control (n=24)	21.04 ± 1.6	22.24 ± 1.81	Men =13 (54.2%) Women=11 (45.8%)
Statistics	t- value 1.168	t- value 1.479	Chi-square 0.085
P value	0.2490	0.1461	0.771

*P< 0.05

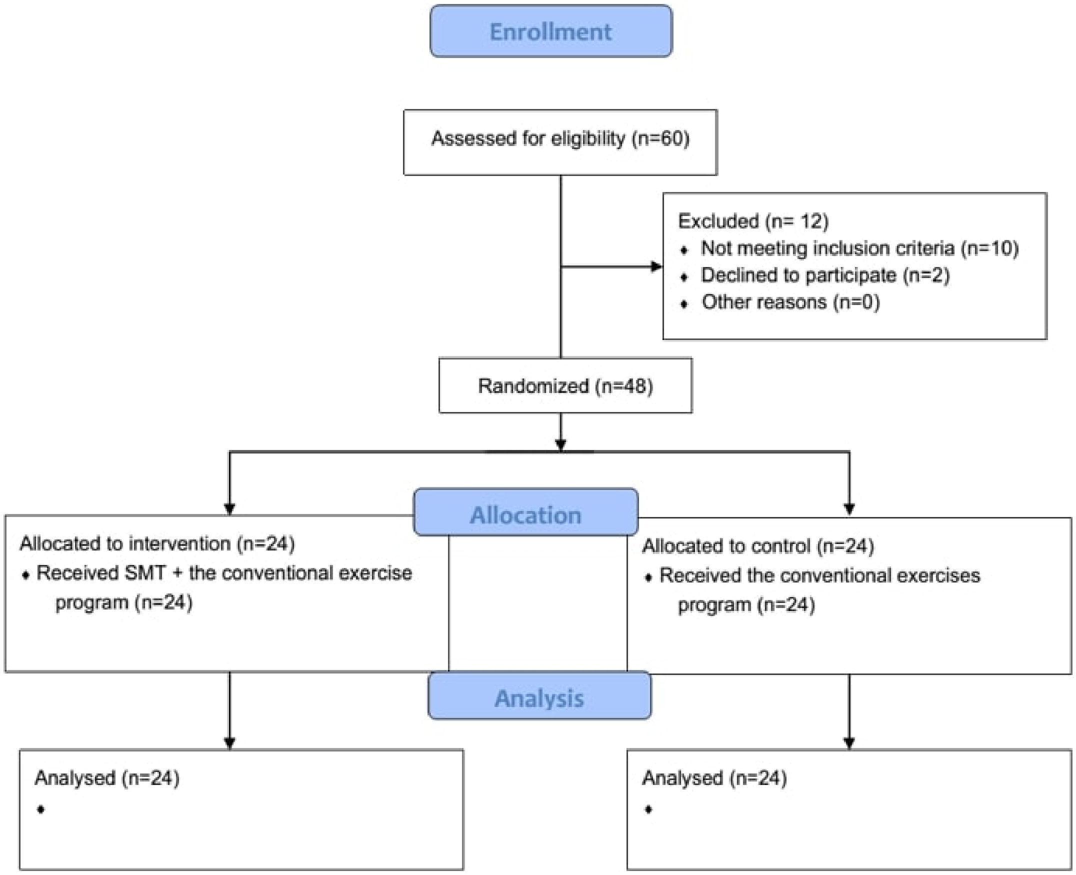

Figure 1. Flow diagram of the study conduction.

Dynamic balance

In the study group, the mean dynamic balance for composite reach distance pre- and post-treatment was 85.75 ± 4.79 and 94.92 ± 4.20, respectively, while in the control group, it was 82.95 ± 5.595 and 91.199 ± 5.92, respectively (Figure 2; and Table 2). Prior to treatment, there was no notable distinction in dynamic balance between the groups (P= 0.091). However, post-treatment, dynamic balance scores significantly favored the SMT group (P= 0.033). Furthermore, within each patient group, there was a significant improvement in dynamic balance post-treatment (P < 0.001).

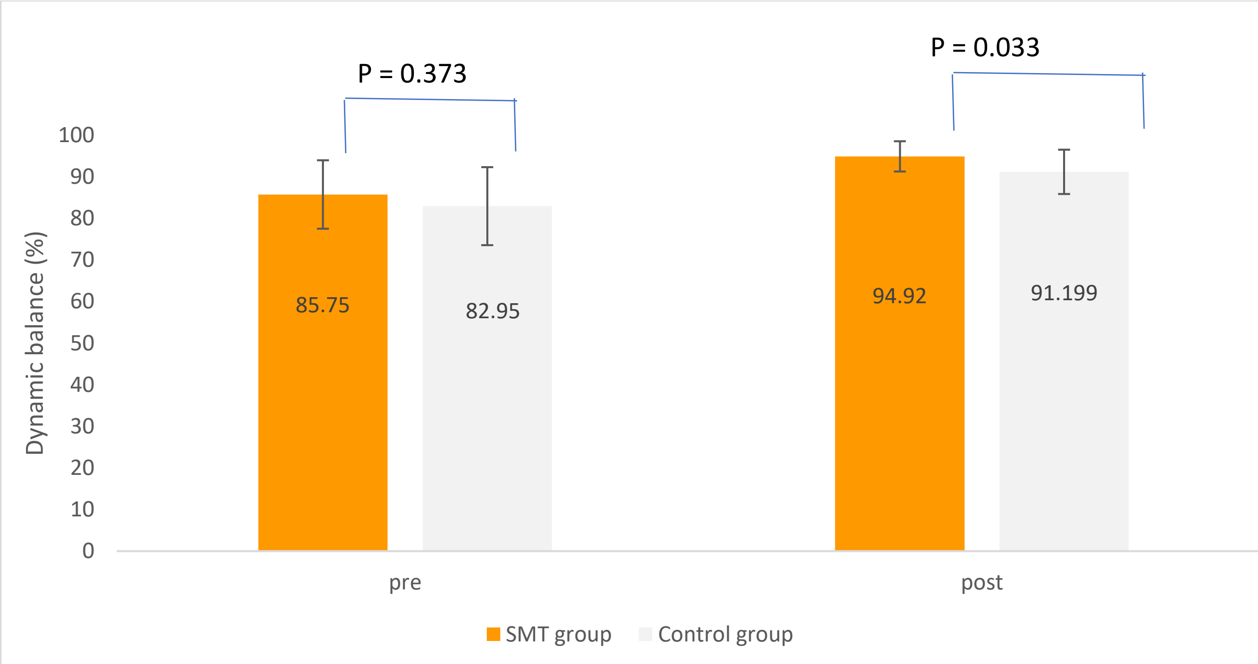

Fig. (2): The dynamic balance post-treatment comparison between the experimental and control patients.

Table (2): The effect of the interventions on dynamic balance between and within groups' pre versus post-treatment evaluations

Patient group	Dynamic balance (composite reach distance) Pre-intervention Mean ± SD	Dynamic balance (composite reach distance) Post-intervention Mean ± SD	P-value
Study (n=24)	85.75 ± 4.79	94.92 ± 4.20	<0.001*
Control (n=24)	82.95 ± 5.595	91.199 ± 5.92	<0.001*
P value	0.091	0.033*	-

*P<0.05.

Discussion

The objective of this research was to examine the impacts of SMT on dynamic balance in patients with PFPS associated with pronated foot. The findings from the present study demonstrated a notable distinction between the two groups for mean dynamic balance in favor of the SMT group.

Comparing the two groups, our findings indicated a highly notable disparity in the mean composite score of the Y-balance test (YBT) for dynamic balance, favoring the SMT group. This is likely because SMT can address muscle imbalances and motor programming at the central nervous system (CNS) level, allowing for neuromuscular function adaptation and injury reduction. Furthermore, SMT enhances proprioception and intramuscular coordination **(Luza et al., 2020).**

The findings were agreed by previously conducted studies **(Steinberg et al., 2020; Ahmadi et al., 2020; and Ahmadi et al., 2021).** It was agreed by a study conducted on 32 PFPS patients who received SMT for 12 weeks and it was found that SMT could improve the sensory integrative system, resulting in enhancement in both attention and cognitive functions. This also led to improved dynamic balance and overall stability **(Steinberg et al., 2020).** Further, in a study conducted on ninety-eight young dancers diagnosed with PFPS managed with an SMT program for 12 weeks, it was noted that there was a notable enhancement in dynamic balance and proprioception and this credit went to SMT which showed a high YBT score **(Ahmadi et al., 2020).** Further, in a randomized clinical trial conducted on 32 patients diagnosed with PFPS who were treated with SMT for 12 weeks, it was concluded that SMT improved knee proprioceptive capabilities and overall postural control reflecting its clinical value in those patients **(Ahmadi et al., 2021).**

Conclusion

The findings of this research indicate that incorporating SMT into a conventional exercise program offers greater advantages in enhancing dynamic balance for PFPS patients than relying solely on a conventional exercise program which may contribute to better prognosis and reduce the recurrence rate.

Author contributions

MIE: Developing idea, conducting practical section, data extraction, writing – original draft.
MSA, DSA: Developing idea, follow progress, data analysis, and manuscript review & editing.
MAB: Developing idea, laboratory supervision, and manuscript review & editing.

Conflict of interest

The authors assert that this study was carried out with no conflicts of interest.

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