# EFFECTIVENESS OF NEUROMUSCULAR TRAINING PROGRAM IN YOUNG ATHLETES SUFFERING FROM LOWER LATERAL ANKLE LIGAMENT INJURY

Soumendra Saha[1*], Deivendran Kalirathinam[2], Taran Singh[3], Srilekha Saha[1], Mohamed Saat Ismail[4], and Hairul Anwar Hashim[4]

[1]Exercise and Sport Science Unit, School of Health Sciences, Universiti Sains Malaysia, Malaysia
[2]Faculty of Health Sciences, Universiti Sultan Zainal Abidin, Malaysia
[3]Department of Orthopaedics, School of Medical Sciences, Universiti Sains Malaysia, Malaysia
[4]Exercise & Sport Science Program, School of Health Sciences, Universiti Sains Malaysia, Malaysia

*Email: drsoumen@usm.my
*(Received 8 March 2016; accepted 24 July 2016)*

**Abstract**

The perception and execution of musculoskeletal control and movement are mediated primarily by the central nervous system and involve the integration of three main subsystems: somatosensory, vestibular, and visual. Balance performance and its measurement are influenced by these sub-systems. This present study was carried out to investigate the effectiveness of neuromuscular-controlled training exercises, comprising BOSU-ball balance training and conventional physiotherapy exercise training protocols, in terms of stability, balance, and proprioception in athletes diagnosed with lateral ligament injury of the ankle joint. The Y Balance test was used as a reliable and valid tool for quantitative balance assessment. Thirteen players (aged between 19 to 26 years, Mean age = 23.2; SD = 2.46) suffering from grade II & grade III lateral ligament injury were recruited from the OPD of the department of Orthopaedics of the Hospital of Universiti Sains Malaysia. All participants were subjected to pre-intervention or baseline assessments consisting of a of Y-balance test and assessment of proprioception employing Biodex 4 Isokinetic Equipment. Participants were then introduced to 12 sessions of a neuromuscular controlled training program (30 min/day; 2 days/wk. for 6 wk.). Findings of the study revealed that six weeks of neuromuscular exercises training significantly improved balance, with certain significant aspects of proprioception observed among young athletes diagnosed with ankle lateral ligament injury.

*Keywords*: Athlete, ligament injury, BOSU ball, neuromuscular training, Y balance test

## Introduction

Lateral ankle sprain is an extremely common athletic injury. Regardless of clinical aetiology and scientific explanation, the high frequency of reported incidences of re-injury hinders the possibility of successful rehabilitation (Refshauge, Kilbreath & Raymond, 2000). In a review of the potential reasons of functional ankle instability, Hertel (2000) cited deficits in joint position-sense (Lentell et al., 1995), along with the possible reduction in muscle-strength (Konradsen, Olesen, and Hansen, 1998); delayed peroneal muscle-reaction time (Karlsson and Andreasson 1992); balance deficits; altered common peroneal nerve function; and decreased dorsiflexion range of motion (Leanderson, Wykman, and Eriksson, 1993). However, in-depth scrutiny of the contributory components for chronic ankle instability (CAI) in athletes may be viewed as significant inhibiting factor for increased vulnerability for re-injury after lateral ankle sprains (Hertel, 2000).

As Freeman and co-researchers (1976) suggested concerning CAI, an ankle injury may disrupt joint afferent fibres situated in the supporting ligaments. After injury to the neural and musculotendinous tissues, proprioceptive deficits are susceptible to occur, which in turn decrease joint position sense. Proprioception refers particularly to conscious (voluntary) and unconscious (reflexive) appreciation of joint position (Mountcastk, 1980; Michelson & Hutchins, 1995), while kinaesthesia is the impression of joint movement or acceleration (Mountcastk, 1980). The ability to distinguish movements in the foot and enable postural alterations in identifying movements is considered vitally important in producing counteractive movement in ankle. This phenomenon is associated with conscious proprioceptive interpretation, which is involved in overall control during sports activities (Michelson & Hutchins, 1995). The unconscious aspect is involved in joint stabilization during unexpected perturbations (Michelson & Hutchins, 1995), which may occur even before foot-contact is performed, resulting in inversion ankle sprains that may happen because of improper positioning of the foot, just before and at foot-contact (Wright, Neptune, van den Bogert, & Nigg, 2000; Tropp, Askling and Gillquist 1985). Such improper positioning may also occur due to loss of proprioceptive information from mechanoreceptors (Sammarco, 1977; Stormont, Morrey, An, & Cass, 1985; Tropp et al., 1985; Wright et al., 2000).

The perception of force is an innate human ability to assume and estimate pressure on load-bearing joints. Information is thereby transmitted to the spinal cord via afferent (sensory) pathways leading to a conscious awareness of joint movement, including position and force. Such awareness is vital for legitimate understanding with regard to the joint capacity in day-to-day sports and exercise activities, while fairly unconscious sense of proprioception modulates muscle function and initiates reflex adjustment. The efferent (motor) conditioned reaction to sensory impulses is however termed as neuromuscular control (Gollhofer & Kyrolainen, 1991).

Feed-forward neuromuscular control involves planning movements based on sensory information from past experiences (Lamell-Sharp, Swanik, & Tierney, 2002). The feedback process continuously regulates muscle activity through reflex pathways. Feed-forward mechanisms are responsible for preparatory muscle activity associated with before foot-contact is performed, while feedback processes are associated with reactive muscle activity, here related to post-contact impacts in the joint in producing counteractive movement in ankle. Because of the orientation and activation characteristics of the skeletal muscles, a diverse array of movement capabilities can be coordinated involving concentric, eccentric, and isometric contractions, while excessive joint motion is restricted. Dynamic restraint is thus achieved through preparatory and reflexive (mostly unconscious) neuromuscular control (Gollhofer & Kyrolainen ,1991; Dunn, Gillig, Ponsor, Weil, & Utz, 1986; Hertel & Olmsted-Kramer, 2007).

Training regimes consisting of strengthening, stretching, plyometric and balance techniques may facilitate enhancement of neuromuscular control (Hewett, Myer, & Ford, 2005), which tends to result in increased joint strength, thus having a defensive impact against damage (Dyhre-Poulse & Simon et al., 1991; Kandel and Schwartz et al., 1996). Increased joint strength enhances the perceptual ability to assume and estimate pressure on weight-bearing joints leading to heightened conscious awareness of joint movement; position and force. This enhancement in proprioceptive conscious awareness is absolutely essential in sport activities, which also helps in reduction in body sway while standing (Nashner, 1973). Ligamentous injury reduces this proprioceptive awareness, and hence increment in body sway result in impaired balancing ability (Garn & Newton 1988). Thus, poor balancing ability is reportedly associated with prolonged danger of ankle injuries among promising male and female athletes and in elite male competitors (Hewett, Paterno, & Myer, 2002; Myer, Ford, McLean, & Hewett, 2006; Willems et al., 2005; McGuine, Greene, Best, & Leverson, 2000).

Among all techniques which may result in enhancement of neuromuscular control, we intended to narrow our focus to the aspect of improvement in balancing ability to observe its impacts onto differential aspects of proprioception. In order to achieve this, we decided to utilize the BOSU balance training device, which is composed of a solid plastic base with an inflatable bladder, resembling a halved Swiss ball. It is designed for the athletic and recreationally active population. This equipment is unique in that it can be used with either the flat or bladder side on the ground, making it a versatile piece of balance training equipment. It may be assumed to induce varying difficulty levels depending on which side of the device is being used. Consequently, it has become a valid option for training in facilitating balance as well as enhancement in ankle joint strength. With such a background, researchers like Coughlan and Caulfield (2007) attempted to develop one exercise training protocol, using neuromuscular exercise training regimes in combination of use of BOSU balance trainer. In advent of growing interest among researchers to incorporate balance training regimes for injury prevention and rehabilitation, and with limited exploration of specific balance training, resultant impacts on ankle-lateral ligament rehabilitation have not yet been conclusive (Gribble, Hertel, & Denegar, 2007; Herrington, Hatcher, Hatcher, & McNicholas, 2009; Emery, Rose, McAllister, & Meeuwisse, 2007; McGuine & Keene, 2006; Blackburn, Hirth, & Guskiewicz, 2003).

With such a background, the present study observes the effectiveness of neuromuscular controlled training using a BOSU-ball balance trainer on the level of proprioception based on both active and passive repositioning indices evidenced among the athletes, diagnosed with lateral ligament injury of ankle joint.

## Methods

*Participants*

With assumed Cohen's *d* 2.36 and Effect Size *r* .76, sample size was calculated for multiple linear regression analyses using G Power 3.1.9 software (Faul, Erdfelder, Buchner, & Lang, 2013). The power of the study was set at 0.80 with a 95% confidence interval and the effect size was set at 0.76, which revealed that when total number of predictors was fixed at 2, only 13 participants were considered adequate to carry out the study. Thus, 13 participants (ranging between 19 to 26 years, with mean age = 23.2; SD = 2.46), diagnosed as suffering from grade II & grade III lateral ligament injury were recruited from the OPD of the Department of Orthopaedics, Hospital Universiti Sains Malaysia. We intended to recruit larger sample size, but owing to stringent inclusion criteria, within the period of January 2015 to August 2015 we only reached a total of 18 participants. Of these, five participants were excluded as they were unable to follow the rigorous experimental protocol.

*Design overview*

A single-blinded controlled trial was carried out to determine whether the level of balance and proprioception ability improves after participation in a composite training program, developed using neuromuscular controlled exercise regimes including BOSU-ball training (Coughlan & Caulfield, 2007).

*Procedure*

Ethical permission for this experimental study was obtained from the Human Research Ethics Committee (study protocol code: USM/JEPeM/14100373 assigned with the stipulated period experimentation from December 2014 to November 2015). From a pool of injured athletes diagnosed at the OPD of the Orthopaedics Department suffering from ankle-lateral ligament injury (within the range of Grades II & III), young competitive athletes were identified and opaque sealed letter of invitation to join in this experimental study was sent to them. As the athletes agreed upon to take part in this study, they understood the study protocol, along with concerns about time-engagements; constraints; potential risks; and the possibility of adverse consequences. Once they agreed and signed the informed consent form, all participants at were initially subjected to pre-intervention or baseline assessments, consisting of a Y-balance test and assessment of proprioception employing Biodex 4 Isokinetic Equipment. An AY-balance test instrument was used to assess dynamic postural control of the participants; the Biodex 4 Isokinetic dynamometer was used to identify the level of proprioception in the participants. These two types of assessments were required, as when lateral ankle sprain occurs structural damage not only occurs to the ligamentous tissue, but also to the musculotendinous tissue around the ankle complex. The Y balance test device consists of a stance plate to which three pieces of PVC pipes are attached in the anterior, posterior and postero-lateral reach directions. The posterior pipers are positioned 135 degrees from the anterior pipe with 45 degrees between the posterior pipes. Each pipe is marked in 5 millimeter increments for measurement. The participant was required to push a target-box along the pipe. Reach height was standardized and the target remained over the tape measure after performance of the test, making the determination of reach distance more precise (Plisky et al., 2009). While working on the intra-rater reliability for a Y-balance test, Plisky, Gorman, Butler and co-researchers (2009) reported differential extents of reliability scores for anterior reach (0.91), posteromedial reach (0.85), and posterolateral reach (0.90) as well as for composite scores of 0.91. Inter-rater reliability between the two testers was observed to range from 0.99 to 1.0, with anterior 1.0, posteromedial 0.99, posterolateral 0.99 and composite score of 0.99.

Thereafter, the participants were introduced to assessments of proprioception. Both active and passive joint position sense were assessed using the Biodex 4 isokinetic dynamometer. Each of the participants sat on the associated chair of the BIODEX 4 device in a supine position, with the calf of the tested leg resting on a 40-cm-high platform. The bare foot of the participant was supposed to be aligned with the axis of the dynamometer and attached to the foot plate by a very small wrap to reduce cutaneous receptor input. The talocrural joint was maintained at 15 degrees of plantar flexion. The lower leg was kept secured to the platform by hook and loop straps. Two positions were tested at 15 degrees of inversion and maximal active inversion minus 5 degrees. Participants were kept blindfolded throughout the examination. Tankevicius, Lankaite and Krisciunas (2013) reported the reliability scores of the Isokinetic assessment protocols, as .87–.96 ICC (intra class correlation values) with 95% confidence interval level.

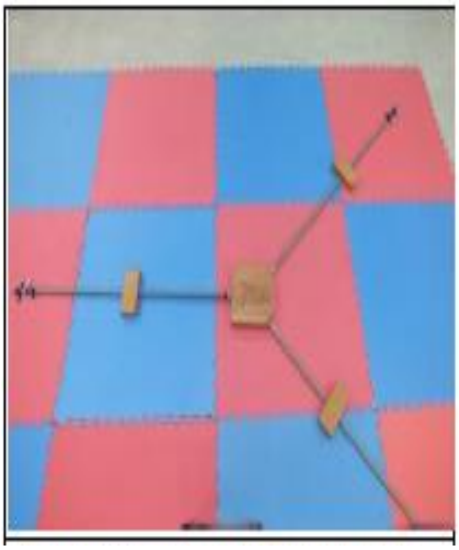

**Figure 1:** Y-balance test device.

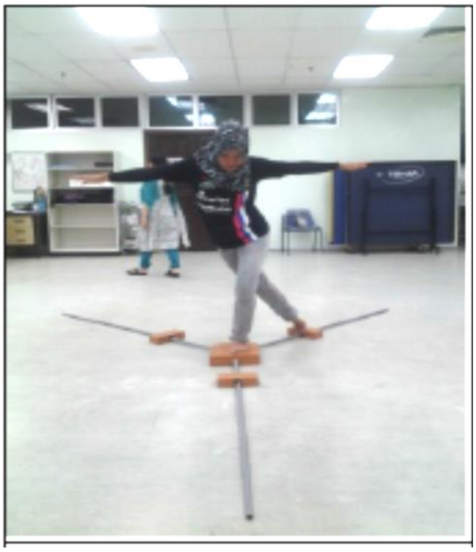

**Figure 2:** Assessment of balancing ability using Y-balance test device.

Thereafter the participants were introduced with neuromuscular controlled training program, which was imparted to them following a standardised protocol (Coughlan & Caulfield, 2007) of30 min/day; 2 days/week for a duration of 6 weeks. Thus, the intervention continued for 12 sessions altogether. The neuromuscular training program was carried out involving 4 sets of exercises. Each set was conducted for 3 sessions; overall, 12 sessions of trainings were imparted. Level 1 program involved bilateral stance exercises, with no change in the base of support, including squats, heel raises, and toe raises, as well as with an introduction to dynamic exercise on the unstable surface of the BOSU ball. Levels 2 and 3 of this exercise protocol (refer to table 1) are comprised of single-leg exercises on stable surfaces, which are aimed at developing neuromuscular control of the limb in a controlled situation. Lastly, level 4 and 5 involved more complex single-leg exercises on both stable and unstable surfaces. Participants were instructed to stabilize, with their knees flexed upon landing, at each phase of the particular exercise for one second before completing the next movement in the exercise (refer to Table I).

**Table 1:** Protocol for neuromuscular control training program.

| Level | A | B | C | D |
|---|---|---|---|---|
| 1 | DLS with lumbar control 2X10 (e.g., 10 repetition/set for 2 sets) Toe raises 2 X 20 (e.g., 20 repetition/set for 2 sets) DL heel raises 2 X20(e.g., 20 repetition/set for 2 sets) | DLS on BOSU 2 X10 (e.g., 10 repetition/set for 2 sets) | DL compressions on BOSU 2 X20 (e.g., 20 repetition/set for 2 sets) | Forward/backward hop on BOSU 2 X20 (e.g., 20 repetition/set for 2 sets) |
| 2 | DL skiing exercises on BOSU 2X10 (side to Side Squats) (e.g., 10 repetition/set for 2 sets) | DL box jumps onto Reebok step 2 X15 (e.g., 15 repetition/set for 2 sets) (stabilize on landings) | SL step down on Reebok step 2 X 10 (e.g., 10 repetition/set for 2 sets) | SL lunges forward 2 X 10 (e.g., 10 repetition/set for 2 sets) |
| 3 | SLS 2 X 10(e.g., 10 repetition/set for 2 sets) | As in B2 above but increase reebok step height | As in C2 above but increase Reebok step height | SL hopping forwards 2 x10 SL hopping sideways 2 X10 (e.g., 10 repetition/set for 2 sets for both) |

| | | | | |
|---|---|---|---|---|
| 4 | SLS 2 X10 (e.g., 10 repetition/set for 2 sets) and hold squat position for 10secons after 10 squats | DL bunny hop onto BOSU 2 X10 (e.g., 10 repetition/set for 2 sets) DL lateral bunny hop onto BOSU 2 X10 (e.g., 20 repetition/set for 2 sets) | SL step up on BOSU 2 X10 (e.g., 10 repetition/set for 2 sets) SL step down on BOSU 2 X10 (e.g., 20 repetition/set for 2 sets) | Lateral SL hops onto BOSU 2 X10 (e.g., 10 repetition/set for 2 sets) |
| 5 | SLS on BOSU 2 X10 (e.g., 20 repetition/set for 2 sets) | High knee lifts on BOSU 2X 20(e.g., 20 repetition/set for 2 sets) | Lunge from Reebok step onto BOSU 2 X10 (e.g., 20 repetition/set for 2 sets) | As in D4 above but increase distance of jump onto BOSU |

SL= single leg; DL=double leg; SLS= single-leg squat: DLS=double-leg squat. Coughlan & Caulfield (2007).

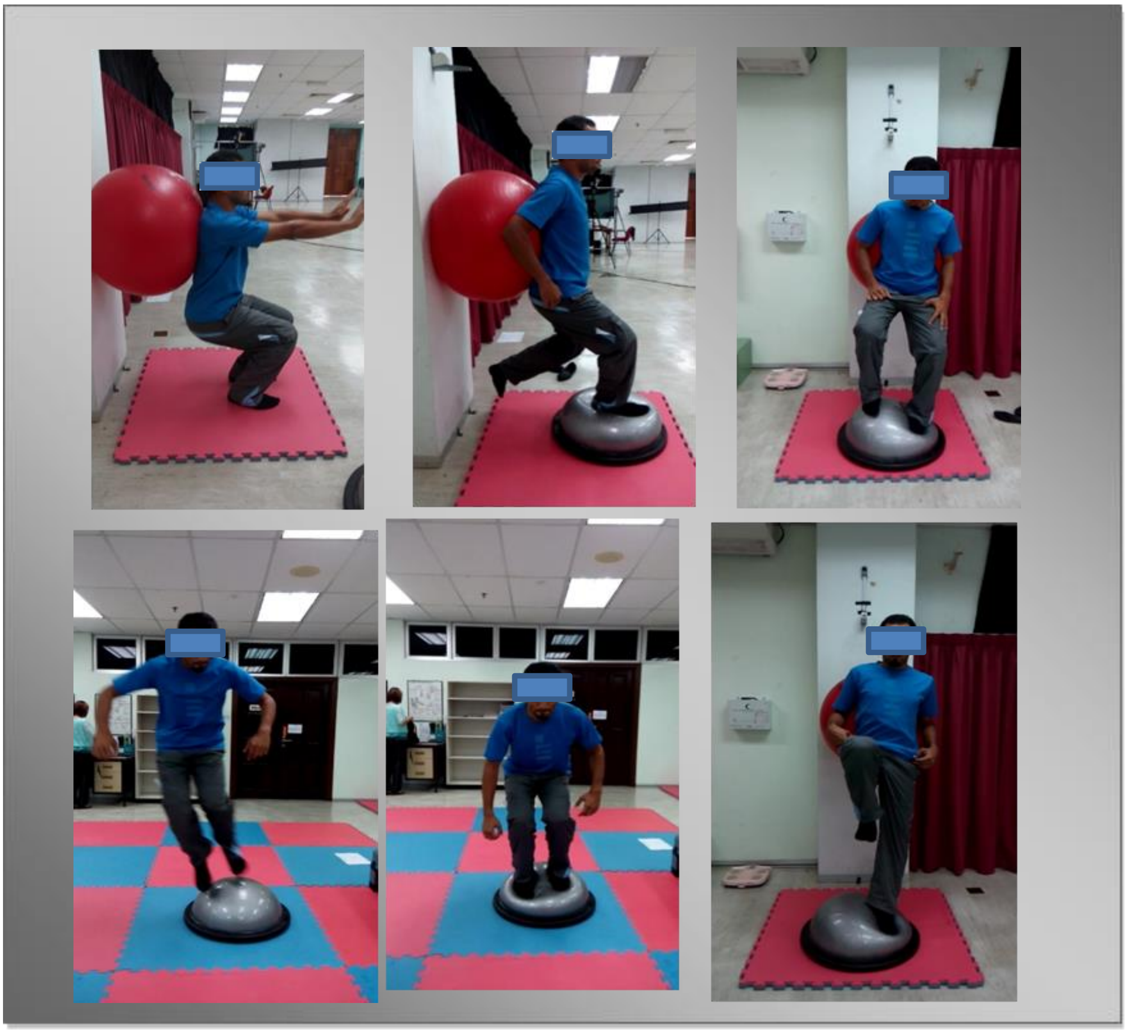

**Figure 3:** Neuromuscular training exercises (with and without BOSU balance trainer).

The data were analysed using the SPSS 22.0. For the smaller actual sample size, we opted for non-parametric evaluations (Kruskal-Wallis; Willcoxon's Signed rank tests). Descriptive statistical analyses were carried out and multiple linear regression tests were also performed to identify predictive contribution of independent confounding variables.

## Results

Descriptive tables were conceived to summarize outcomes of analyses of central tendency and extent of variability of the data and mean differences found in data obtained from the participants during the pre-intervention and post-intervention assessment phases. A Kruskal-Wallis test was performed to identify difference between the groups and Wilcoxon signed-rank test was carried out. The outcomes are represented in Tables 2 and 3.

**Table 2:** Means and Mean Differences in the Level of Proprioception observed among the participants when the extent of error committed during active repositioning activities were assessed.

| Measures | Proprioception (in Extent of errors committed) | | |
|---|---|---|---|
| | Pre-intervention | Post-intervention | Mean Difference |
| Errors committed in Active Repositioning Movement (15 degrees) | 5.41±.74 | 2.63±.81 | .005** |
| Errors committed in Active Repositioning Movement (5 degrees) | 2.03±.45 | 1.11±..27 | .007** |

**Table 3:** Means and Mean Differences in the Level of Proprioception observed among the participants when the extent of error committed during passive repositioning activities were assessed.

| Measures | Proprioception (in Extent of errors committed) | | |
|---|---|---|---|
| | Pre-intervention | Post-intervention | Mean Difference |
| Errors committed in Passive Repositioning Movement (15degrees) | 7.14±1.08 | 3.02±1.11 | .012** |
| Errors committed in Passive Repositioning Movement (5degrees) | 4.03±1.15 | 2.69±.53 | .047* |

**Table 4:** Summary of multiple linear regression analysis when impact of training on active repositioning observed among the participants was assessed.

| Model ***a*** Dependent Variable – Improvement in proprioception (Active repositioning) | Unstandardized Coefficients | | Standardized Coefficients | | | Correlations Coefficients | | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | t | Sig. | Zero-order | Partial | Part | Tolerance | VIF |
| (Intercept) | .149 | .021 | | 7.134 | .000 | | | | | |
| Pre-intervention level Posterolateral performance in Y-balance test employing the uninvolved ankle | .064 | .007 | .667 | 9.451 | .000 | .449 | .568 | .561 | .706 | 1.416 |
| Pre-intervention level Posteromedial performance in Y-balance test employing the involved ankle | -.013 | .004 | -.214 | - 3.060 | .003 | -.061 | -.218 | -.182 | .721 | 1.387 |

a(F (2, 11) = 24.77, P < 0.005)) Model Adj.R2 = 74.5%.

Findings of the prediction analysis represented by the Model ***a*** (Table 4), however, suggested that the dependent measure of improvement in proprioception (Active repositioning activity), as evident in that participants were apt to be predicted by pre-existing posterolateral performance ability in the Y-balance test employing the uninvolved ankle, and the posteromedial performance ability in the Y-balance test displayed by the athletes employing their involved ankle-joint movements.

**Table 5:** Summary of multiple linear regression analysis. Ankle stability from all impacts of training on passive repositioning observed among the participants was assessed.

| Model ***b*** Dependent Variable – Improvement in proprioception (Passive repositioning) | Unstandardized Coefficients | | Standardized Coefficients | | | Correlations Coefficients | | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | t | Sig. | Zero-order | Partial | Part | Tolerance | VIF |
| (Intercept) | .121 | .021 | | 5.71 | .000 | | | | | |
| Pre-intervention level Posterolateral performance in Y-balance test employing the uninvolved ankle | .955 | .041 | .955 | 23.307 | .000 | .803 | .994 | .731 | .586 | 1.706 |
| Pre-intervention level Posteromedial performance in Y-balance test employing the involved ankle | .576 | .037 | .576 | 15.559 | .000 | .594 | .986 | .488 | .719 | 1.391 |

$^{b}$(F (3, 10) = 22.11, P < 0.000)) Model Adj.$R^2$ = 68.3%.

The findings shown in Table 5 of the prediction analysis represented by the Model ***b***, however, suggest that the dependent measure of improvement in proprioception (Passive repositioning activity), evident in the participants were aptly predicted by the pre-intervention level ability of posterolateral performance in Y-balance test employing the uninvolved ankle, and the posteromedial performance ability in Y-balance test displayed by the athletes employing their involved ankle-joint movements.

## Discussion

A summary of the descriptive statistics shows that the data obtained did not have huge discrepancies, and hence were not highly skewed. Normality transformations (log transformations & squared transformations) were carried out wherever required and finally descriptive outcomes are represented in the Tables 2 and 3. Tables 2 and 3 also represented the mean differences for the variables such as errors committed in both Active and Passive Repositioning Movement (in both 15 degrees & 5 Degrees). Outcomes of Tables 2 & 3 show that pre-intervention data pertaining to proprioception, obtained by employing Biodex 4 Isokinetic Dynamometer, were not grossly inconsistent and hence a huge dispersion was not observed. The post-intervention data also revealed that, outcomes of specific parameters pertaining to analyses of proprioception were also free from higher extent of dispersion from normality.

Impact of the intervention introduced was evidenced, since the post-intervention outcomes revealed that the errors committed in perception of active repositioning movement task (both in 15 degrees and in 5 degrees) got reduced (refer to Table 2). The observed improvement in the ability to perceive movement repositioning accurately enough could have been possible by virtue of increased neural activities in the ligaments and in the musculotendinous tissues in the ankle joint. Perhaps the introduction of neuromuscular controlled exercises enhanced joint position sense in the ankle of the athletes, and as this sense is an integral component of proprioception, the sense of proper positioning of the ankle joint was also enhanced (Wright et al., 2000; Tropp et al.,1985).

Identical improvement in joint position sense was also evident, when athletes were engaged in passive repositioning task, performed both in 15 and 5 degree rotations (refer to Table 3). This passive repositioning task involves conscious recall of previous position of the foot and range of movement is required for repositioning of the foot up to the optimal extent. Thus, the observed improvement in passive repositioning ability may be attributed to both conscious and unconscious appreciation of joint position, and improvement in kinaesthesia as well, which may have improved the impression of joint movement and sense of acceleration in the ankle joints of the athletes (Mountcastk, 1980).

Findings of the prediction analysis represented by the Model ***a*** (Table 4) suggested that the dependent measure of improvement in proprioception (Active repositioning) evident in the participants were aptly predicted by pre-existing posterolateral performance ability in Y-balance test employing the uninvolved ankle, and the posteromedial performance ability in Y-balance test displayed by the athletes employing their involved ankle-joint movements. Table 4 depicts that the model ***a***, emerged significant, in which afore-mentioned independent predictors could explain as high as 74.5% variance of changes in improvement in proprioception (Active repositioning). Here, we would like to emphasize that while posterolateral performance employing the uninvolved ankle was evident as having facilitative impact on proprioception and posteromedial performance, employing the involved ankle was observed to have inhibitive impact on improvement in proprioception. That means that if the observed facilitative effect of the posterolateral performance in Y-balance test employing the uninvolved ankle as performed during pre-intervention analysis is controlled for or held constant (i. e., remains unchanged), participants who evidently had relatively higher ability to perform the posteromedial task (as they probably had higher pre-existing posteromedial flexibility) employing the involved ankle, would have higher chances of getting improvement in proprioception. Close scrutiny of Beta coefficients implied that irrespective of the contributory impact of all other variables, each 1% improvement in posterolateral performance ability or flexibility in the uninvolved ankle observed during pre-intervention analysis would lead to 667% (refer to the beta coefficient) of corresponding improvement in proprioception in the ankle. Present findings of corroborative relationship were found to be adequately supported by (Hale, Hertel, & Olmsted-Kramer, 2007; Lee, Lin, & Huang, 2006; Gimmon, Riemer, Oddsson, & Melzer, 2011), who confirmed the role of posteromedial and posterolateral ligament strength as an integral part of movement and ankle- stability and balance.

Outcomes from the Table 5 further revealed that the model ***b*** emerged significant. This model explained the role of independent predictors, which could explain as high as 68.3% variance of changes in improvement in proprioception while performing passive repositioning task. Further implications of this model concern the pre-existing ability of the participants in performing posterolateral movements. Stabilizing the involved ankle and posteromedial performance ability employing the involved ankle-joint, while stabilizing the uninvolved ankle, were significant contributors for the improvement in proprioception. Here, detailed and in-depth scrutiny revealed that both posterolateral performance employing the uninvolved ankle and posteromedial performance employing the involved ankle were observed to have facilitative impacts onto improvement in proprioception. The outcomes thus implied that if the observed facilitative effect of the pre-existing posterolateral ability of the participants in performing Y-balance test stabilizing the involved ankle is controlled for or hold constant (i. e., remains unchanged), athletes evident with relatively lower posteromedial flexibility in the uninvolved ankle, would have more improvement in proprioception in passive repositioning tasks. Close scrutiny of Beta coefficients, however, showed that irrespective of the contributory impact of all other variables, each percentile improvement in the posterolateral movements ability evident in the athletes while stabilising the involved ankle, would lead to .955% (refer to the beta coefficient) of corresponding improvement in proprioception based on passive repositioning ability in the ankle. This may be due to enhancements in the orientation and activation characteristics of the skeletal muscle, which might have helped in achievement of heightened dynamic restraint through preparatory and reflexive neuromuscular control (Gollhofer & Kyrolainen 1991; Dietz, Noth, & Schmidtbleicher, 1981; Dunn et al., 1986; Hertel & Olmsted-Kramer, 2007).

Based on the outcomes, it is postulated that neuromuscular-controlled exercise training may assist in the restoration of lost proprioceptive input from the mechanoreceptors in the ankle joint (Freeman et al., 1976), while unconscious proprioception modulated muscle function and initiated reflex stabilization (Gollhofer & Kyrolainen, 1991; Dyhre-Poulsen et al., 1991; Kandel et al., 1996).

## Conclusion

a) The neuromuscular controlled exercise intervention technique appears to have beneficial impacts on various aspects of proprioception in athletes suffering from ankle–lateral ligament injury.
b) Neuromuscular training using BOSU-ball balance trainer has been observed to have beneficial impacts onto the level of proprioception based on active repositioning indices evidenced among the athletes.
c) Efficacy of neuromuscular controlled training is also evidently suitable for enhancing the level of proprioception based on passive repositioning indices as well in young athletes with ankle lateral ligament injury.

**Acknowledgement**

This study was funded by Ministry of Higher Education Research Grant (FRGS - Fundamental Research Grant Scheme - (1001/PPSK/816240). The corresponding author of the present study is indebted to the Grant Authorities for having supported this study.

**References**

Baltaci, G., & Kohl, H. W. (2003). Does proprioceptive training during knee and ankle rehabilitation improve outcome? *Physical Therapy Reviews*, *8*(1), 5-16.

Blackburn, J. T., Hirth, C. J., & Guskiewicz, K. M. (2003). Exercise sandals increase lower extremity electromyographic activity during functional activities. *Journal of Athletic Training, 38*(3), 198-203.

Coughlan, G. & Caulfield, B. (2007). A 4-Week neuromuscular training program and gait patterns at the ankle joint. *Journal of Athletic Training, 42*(1), 51-59.

Dietz, V., Noth, J., & Schmidtbleicher, D. (1981). Interaction between pre-activity and stretch reflex in human triceps brachii during landing from forward falls. *The Journal of physiology, 311*, 113-125.

Dunn, T. G., Gillig, S. E., Ponsor, S. E., Weil, N., & Utz, S. W. (1986). The learning process in biofeedback: is it feed-forward or feedback? *Biofeedback and self-regulation*, *11*(2), 143-156.

Dyhre-Poulsen, P., Simonsen, E. B., & Voigt, M. (1991). Dynamic control of muscle stiffness and H reflex modulation during hopping and jumping in man. *The Journal of Physiology, 437*, 287-304.

Emery, C. A., Rose, M. S., McAllister, J. R., & Meeuwisse, W. H. (2007). A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. *Clinical Journal of Sport Medicine*, *17*(1), 17-24.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. -G. (2013). G*Power Version 3.1.7 [computer software]. Uiversität Kiel, Germany. Retrieved from http://www.psycho.uni-duesseldorf.de/abteilungen/aap/gpower3/download-and-register

Freeman, M. A., Dean, M. R., & Hanham, I. W. (1965). The etiology and prevention of functional instability of the foot. *The Journal of Bone & Joint Surgery (British Volume), 47*(4), 678-685.

Freeman, D. C., Klikoff, L. G., & Harper, K. T. (1976). Differential resource utilization by the sexes of dioecious plants. *Science, 193,* 597-599.

Gollhofer, A., & Kyrolainen, H. (1991). Neuromuscular control of the human leg extensor muscles in jump exercises under various stretch-load conditions. *International Journal of Sports Medicine*, *12*(1), 34-40.

Gribble, P. A., Hertel, J., Denegar, C. R., & Buckley, W. E. (2004). The effects of fatigue and chronic ankle instability on dynamic postural control. *Journal of Athletic Training, 39*(4), 321-329.

Gribble, P. A., Hertel, J., & Denegar, C. R. (2007). Chronic ankle instability and fatigue create proximal joint alterations during performance of the Star Excursion Balance Test. *International Journal of Sports Medicine, 28*(3), 236-242.

Gimmon, Y., Riemer, R., Oddsson, L., & Melzer, I. (2011). The effect of plantar flexor muscle fatigue on postural control. *Journal of Electromyography and Kinesiology*, *21*(6), 922-928.

Garn, S. N., & Newton, R. A. (1988). Kinesthetic awareness in subjects with multiple ankle sprains. *Physical Therapy*, *68*(11), 1667-1671.

Hale, S. A., Hertel, J., & Olmsted-Kramer, L. C. (2007). The effect of a 4-week comprehensive rehabilitation program on postural control and lower extremity function in individuals with chronic ankle instability. *Journal of Orthopaedic & Sports Physical Therapy*, *37*(6), 303-311.

Hertel, J. (2000). Functional instability following lateral ankle sprain. *Sports Medicine*, *29*(5), 361-371.

Hertel, J. & Olmsted-Kramer, L. C. (2007). Deficits in time-to-boundary measures of postural control with chronic ankle instability. *Gait Posture, 25*(1), 33-9.

Hewett, T. E., Myer, G. D., & Ford, K. R. (2005). Reducing knee and anterior cruciate ligament injuries among female athletes: a systematic review of neuromuscular training interventions. *The Journal of Knee Surgery*, *18*(1), 82-88.

Hewett, T. E., Paterno, M. V., & Myer, G. D. (2002). Strategies for enhancing proprioception and neuromuscular control of the knee. *Clinical Orthopaedics and Related Research*, *402*, 76-94.

Herrington, L., Hatcher, J., Hatcher, A., & McNicholas, M. (2009). A comparison of Star Excursion Balance Test reach distances between ACL deficient patients and asymptomatic controls. *The Knee*, *16*(2), 149-152.

Kandel, E. R., Schwartz, J. H., & Jessell, T. M. (1996). *Principles of neural science*. 3rd ed. Norwalk, CT: Appleton & Lange.

Karlsson, J., & Andreasson, G. O. (1992). The effect of external ankle support in chronic lateral ankle joint instability An electromyographic study. *The American Journal of Sports Medicine*, *20*(3), 257-261.

Konradsen, L., Olesen, S., & Hansen, H. M. (1998). Ankle sensorimotor control and eversion strength after acute ankle inversion injuries. *The American Journal of Sports Medicine*, *26*(1), 72-77.

Lamell-Sharp, A. D, Swanik C. B., & Tierney, R. T. (2002). The effect or variable joint loads on knee joint position and force sensation. *Journal of Athletic Training*, *37*(2), 20-29.

Leanderson, J., Wykman, A., & Eriksson, E. (1993). Ankle sprain and postural sway in basketball players. *Knee Surgery, Sports Traumatology, Arthroscopy, 1*(3-4), 203-205.

Lee, A. J., Lin, W. H., & Huang, C. (2006). Impaired proprioception and poor static postural control in subjects with functional instability. *Journal of Exercise Science and Fitness*, *4*(2), 117-125.

Lentell, G., Baas, B., Lopez, D., McGuire, L., Sarrels, M., & Snyder, P. (1995).The contributions of proprioceptive deficits, muscle function, and anatomic laxity to functional instability of the ankle. *Journal of Orthopaedic & Sports Physical Therapy*, *21*(4), 206-215.

Lloyd, D. G. (2001). Rationale for training programs to reduce anterior cruciate ligament injuries in Australian football. *Journal of Orthopaedic & Sports Physical Therapy, 31*(11), 645-654.

Malliou, P., Gioftsidou, A., Pafis, G., Beneka, A., & Godolias, G. (2004). Proprioceptive training (balance exercises) reduces lower extremity injuries in young soccer players. *Journal of Back and Musculoskeletal Rehabilitation, 17*(3-4), 101-104.

McGuine, T. A., Greene, J. J., Best, T., & Leverson, G. (2000). Balance as a predictor of ankle injuries in high school basketball players. *Clinical Journal of Sport Medicine, 10*(4), 239-244.

McGuine, T. A. & Keene, J. S. (2006). The effect of a balance training program on the risk of ankle sprains in high school athletes. *The American Journal of Sports Medicine*, *34*(7), 1103-1111.

Michell, T. B., Ross, S. E., Blackburn, J. T., Hirth, C. J., & Guskiewicz, K. M. (2006). Functional balance training, with or without exercise sandals, for subjects with stable or unstable ankles. *Journal of Athletic Training*, *41*(4), 393.

Mountcastk V. S. (1980). Physiology. 14th ed. St. Louis: Mosby.

Myer, G. D., Ford, K. R., McLean, S. G., & Hewett, T. E. (2006). The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *The American Journal of Sports Medicine*, *34*(3), 445-455.

Michelson, J. D., & Hutchins, C. (1995). Mechanoreceptors in human ankle ligaments. *Journal of Bone & Joint Surgery, British Volume*, *77*(2), 219-224.

Nashner, L. M. (1973). Vestibular and reflex control of normal standing. In *Control of Posture and Locomotion*, 291-308. New York, US: Plenum Press.

Osborne, M. D., & Rizzo Jr, T. D. (2003). Prevention and treatment of ankle sprain in athletes. *Sports Medicine*, *33*(15), 1145-1150.

Plisky, P. J., Gorman, P. P., Butler, R. J., Kiesel, K. B., Underwood, F. B., & Elkins, B. (2009). The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy, 4*(2), 92.

Refshauge, K. M., Kilbreath, S. L., & Raymond, J. (2000). The effect of recurrent ankle inversion sprain and taping on proprioception at the ankle. *Medicine and Science in Sports and Exercise, 32*(1), 10-15.

Sammarco J. (1977). Biomechanics of the ankle, I: surface velocity and instant centre of rotation in the sagittal plane. *American Journal of Sports Medicine,* 5, 231–234.

Stormont, D. M., Morrey, B. F., An, K. N., & Cass, J. R. (1985). Stability of the loaded ankle Relation between articular restraint and primary and secondary static restraints. *The American Journal of Sports Medicine, 13*(5), 295-300.

Tankevicius, G., Lankaite, D., & Krisciunas, A. (2013). Test-retest reliability of biodex system 4 pro for isometric ankle-eversion and-inversion measurement. *Journal of Sport Rehabilitation*, *22*(3).

Tropp, H., Askling, C., & Gillquist, J. (1985). Prevention of ankle sprains. *The American Journal of Sports Medicine*, *13*(4), 259-262.

Tropp, H. A. N. S., Ekstrand, J., & Gillquist, J. (1983). Stabilometry in functional instability of the ankle and its value in predicting injury. *Medicine and Science in Sports and Exercise*, *16*(1), 64-66.

Watson, A. W. S. (1999). Ankle sprains in players of the field-games Gaelic football and hurling. *Journal of Sports Medicine and Physical Fitness, 39*(1), 66.

Willems, T. M., Witvrouw, E., Delbaere, K., Mahieu, N., De Bourdeaudhuij, I., & De Clercq, D. (2005). Intrinsic risk factors for inversion ankle sprains in male subjects a prospective study. *The American Journal of Sports Medicine, 33*(3), 415-423.

Wright, I. C., Neptune, R. R., van den Bogert, A. J., & Nigg, B. M. (2000). The influence of foot positioning on ankle sprains. *Journal of Biomechanics, 33*(5), 513-519.