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PHYSICAL MEDICINE

ANKLE PROPRIOCEPTION : a comparison between female teenage gymnasts and controls

AYAK BİLEĞİ PROPRİOSEPSİYONU : Genç kız jimnastikçi ve kontrol grubunun kıyaslanması

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SUMMARY

Proprioceptive mechanisms appear to play a role in stabilizing the joints and may serve as a means for interplay between the static stabilizers and the dynamic muscle restraints. The purpose of this study was to compare the joint position sense and ankle balance pattern between trained gymnasts and healthy nongymnasts. We evaluated the proprioceptive ability of the ankle with four different tests (one-leg-standing test, a single-limb-hopping test, an active angle-reproduction test, and passive angle-reproduction test). Ankle proprioception was measured in 40 subjects who were assigned to two experimental groups: Group 1 (n=20), control group, and group 2 (n = 20), teenage female gymnasts. Joint position sense was actively measured with a Cybex NORMTM isokinetic dynamometer and passively with a proprioception testing device. A Mann-Whitney U test was used to compare the mean values of the gymnastic ankles with the control ankle. Results revealed statistically significant differences (p<0.05) between the trained gymnastic group and the untrained control group. We found no statistically significant difference between the dominant and nondominant ankle in the group of the volunteers and gymnasts in all tests. The results of this study suggest that in addition to an increase in muscle tone, extensive training has a positive influence on ankle joint position sense and balance Although our results cannot be extrapolated to balance abilities during complex gymnastic routines, they do suggest that physical therapy assessment includes active and passive joint position as well as one-legged standing balance task, single-limb-hopping course test.

Key words : Rheumatoid Artritis, subclinical renal dysfunction, renin-angiotensin-aldosterone system

ÖZET

Proprioseptif mekanizma eklemlerin stabilizasyonunda rol oynar ve kapsüloligamentöz yapılar ile dinamik kas kuvvetleri arasında etkileşimi sağlar görülmektedir. Bu çalışmanın amacı, jimnastikçilerle sporcu olmayan kontrol grubunun ayak bileklerinin denge ve eklem pozisyon hislerini karşılaştırmaktı. Ayak bileğinin proprioseptif kabiliyetini 4 farklı testle değerlendirdik (tek bacak üzerinde ayakta durma testi, tek bacak üzerinde hoplama testi, aktif ve pasif açı repozisyon testleri). Ayak bileği propriosepsiyonu toplam 40 kişiden oluşan 2 deneysel grupta ölçüldü. Grup 1 (n=20) jimnastik yapmayan bireylerden ve grup 2 (n:20) genç kız jimnastikçilerden oluşmaktaydı. Eklem pozisyon duyusu aktif olarak Cybex NORMTM izokinetik dinamometre ve pasif olarak propriosepsiyon ölçüm cihazı ile ölçüldü. Mann-Whitney U testi her iki grubun ayak bileği ortalama değerlerini kıyaslamak için kullanıldı. Sonuçlar her grup arasında istatistiksel olarak önemli farklar olduğunu gösterdi (p<0.05). Kontrol ve jimnastikçilerde bütün testlerde dominant ve nondominant ayak bilekleri arasında anlamlı bir fark tesbit edilemedi. Çalışmada elde edilen sonuçlar yoğun antrenmanın kas tonusunda artış meydana getirerek ayak bileği eklem pozisyon hissi ve dengesi üzerinde pozitif bir etkiye sahip olduğunu göstermektedir. Sonuçlarımız kompleks jimnastik aktiviteler sırasındaki denge yeteneğini yansıtmamasına rağmen, aktif ve pasif eklem pozisyon duyu testleri kadar tek bacak üzerinde durma ve tek bacak üzerinde hoplama testlerini içeren fizik tedavi ölçümlerinin yapılmasının yararlı olacağını göstermektedir.

Anahtar sözcükler : Proprioception, balance, joint position sense, ankle, gymnasts

INTRODUCTION

Over the last 10 years, there has been a greater emphasis on the proprioception research, focusing on different fields, but most commonly on the knee and ankle. Articular mechanoreceptors have morphohistologically been identified in both animal (1,2) and human models in the ankle (3), knee (4,5), and shoulder (6), suggesting an anatomical basis for an active proprioceptive mechanism in all joints. Mechanoreceptors are specialized neuroepithelial structures that are embedded in connective tissue that transduce mechanical deformation into an encoded neural signal that is transmitted to the central nervous system (CNS). Mechanoreceptors are located in the joint capsule, ligaments, muscles, tendons and in skin (7).

Ligaments play a major role in normal joint kinematics, providing mechanical restraint to abnormal joint motion when a stress is placed on the joint. Baxendale et al. (8) and Kennedy et al. (5), however, observed that in addition to performing their mechanical restraining function, articular ligaments provide important neurological feedback that directly mediates muscular reflex stabilization about the joint. Following injury to the articular ligaments, disruption to articular mechanoreceptors results in partial deafferentation of the joint. This has been shown to inhibit normal neuromuscular joint stabilization, and it contributes to repetitive injuries and the progressive decline of the joint (7,9).

Proprioception is the cumulative neural input to the CNS from mechanoreceptors located in the joint capsule, ligaments, muscles, tendons and the skin. Balance refers to the ability to maintain the center of gravity over the base of support without falling (10). The ability to maintain balance requires the integration of proprioceptive input from the periphery with afferent information from the vestibular apparatus in the inner ear and vision. The proprioceptive mechanism is essential for proper joint function in sports, activities of daily living, and occupational tasks (7).

Balance is important for the athlete. If the athlete's strategies to maintain balance are unsuccessful, a fall will result. Inefficient balance strategies will result in poor athletic performance. Additionally, the risk of injury or reinjury may be increased if the athlete cannot maintain balance during performance. In sporting activities such as gymnastics, figure skating, and classical dance, the need for balance is obvious (10). It is widely known that a proprioceptive deficit may detract from the functional success of ligament healing and predisposes the patient to reinjury. Thus, assessment of proprioceptive sensibility is valuable for identification of proprioceptive deficits and subsequent planning of the rehabilitation program. If we could enhance joint proprioception, we might be able to restore the normal protective mechanism within the injured or reconstructed joint. Rehabilitation must therefore focus on restoring the proprioceptive mechanism by enhancing cognitive appreciation of the respective joint relative to position and movement, and providing muscular stabilization of the joint in the absence of structural restraints (7).

The purpose of the present study was to compare the proprioceptive functions between the ankle of gymnasts to the ankle of healthy nongymnasts. We wanted to know what effect, if any, extensive athletic training has on the active and passive ankle position sense and balance. We hypothesized that gymnasts, given their better balance, also have greater balance and proprioceptive ability than healthy nongymnasts. Gymnasts were chosen as the study group because they combine muscle development and flexibility with a constant awareness of joint position and motion (4).

METHODS

Subjects and inclusion criteria

A total of 40 subjects participated in the study in the period between February 1998 and October 1999 at department of the sport medicine of Gülhane Military Medicine Academy. We designed the study to compare a group of healthy, teenage gymnasts with a control group of healthy, age-matched volunteers. All subjects were volunteers, met the inclusion criteria, and provided informed consent as approved by the Human Subjects Review Board of our institution.

Two experimental groups were formed. The inclusion criteria for both groups were as follows: age 10-17 years, no history of injury in either ankle, knee, and hip joints, musculoskeletal injury, no inner ear abnormality, no equilibrium disorder, and no neurological disease. Each prospective subject completed a questionnaire documenting the inclusion criteria, information about general health, and demographic data. Prior to participation in the study, the subjects and the parents or guardians of those under 18 years of age were required to give informed consent meeting the requirements of a local human subjects institutional review board. Table I presents descriptive data on the subjects.

Table I : Physical characteristics of subjects (n: 40)

	Control Group (n: 20)			Gymnasts Group (n: 20)		
Variable	X	s	Range	X	s	Range
Age (yr)	14.3	1.5	11-17	13.6	2.3	10-17
Height (cm)	157.9	6.3	148-170	162.5	11.6	136-175
Weight (kg)	46.9	7.6	35-60	47.1	14.1	27-68
Experience time (yr)	-	-	-	7.3	2.7	3-12

Study groups :

Group 1 (n = 20): Twenty healthy, nongymnast volunteers (mean age 14.3 years; range 11-17 years) were studied. All subjects considered themselves athletically active but did not regularly participate in any lower extremity sports (i.e., football, running).

Group 2 (n = 20): This group included 20 healthy, teenage, female gymnasts (mean age 13.6 years) They were requested to refrain from unusual activities or vigorous exercise 24 hours before their testing session. These gymnasts were tested at least 3 years after beginning of gymnastics (mean ± SD,7.3 ± 2.7 years).

Test Procedures

We evaluated the proprioceptive ability of the ankle with four different tests. We used a one-leg-standing test, a single-limb-hopping test, an active angle-reproduction test, and passive angle-reproduction test. The one-leg-standing test and the single-limb-hopping course incorporated the principles discussed by Jerosch et al. (11). In an attempt to minimize the effect of fatigue on the testing procedures, passive joint position sense testing was performed first, followed by active reposition, one-leg-standing test and single-limb-hopping course, respectively. A practice session was immediately followed by the test session.

Single-limb-hopping course

This test is especially useful to document the function of the ankle on an uneven surface (11). The jumping course consists of eight squares, four of which are even, one square has a 15° increase, another square has a 15° decrease, and two squares show a 15° lateral inclination (Fig. 1). The volunteers are asked to jump across this course on one leg by touching each area once as fast as possible without leaving the course (Fig 2) The test result is quantified by the seconds used to pass the course. Each failure adds an extra second to the time taken to complete the course.

One-leg-standing test

The one-leg-standing test evaluates the volunteer's ability to keep balance while standing on one leg (11,12). The volunteer is asked to stand on one leg for one minute with open eyes and for another minute with eyes closed to exclude the visual perception. In contrast to the current literature we performed this test not on a hard surface but on a soft surface to increase the failure rate (Fig. 3). Each surface contact with the contralateral leg was counted as one failure point.

The active angle-reproduction test

Joint position sense was determined by measuring the subject's ability to actively reproduce a passively placed joint position. For the test of active reproduction, a Cybex Norm dynamometer served as the position sense testing device. The reliability and validity of this device have been favorably demonstrated in several studies (13,14). Testing was performed at positions of 300 of plantar flexion (Figure 4) and 150 of inversion (Figure 5). The test foot was placed on the plantar flexion-dorsiflexion foot plate of the Cybex, according to the manufacturer's instructions for isolating inversion-eversion and plantar flexion-dorsiflexion, and was secured with Velcro straps (15). For this study, the dominant ankle served as the testing limb for all tests since lower extremity proprioception does not appear to be influenced by limb dominance (2).

Prior to the testing, Cybex dynamometer was calibrated as part of the regular equipment maintenance schedule for this testing device (15). The subject was tested in a supine position as in the former studies done on ankle proprioception by Heit et al.

(13). The knee was placed in 900 of flexion and thigh was stabilized with a Velcro strap. To initiate the test, the foot was placed in the neutral (0°) position. All subjects were blindfolded in an effort to eliminate the contribution of visual cues to joint repositioning. To familiarize themselves with the testing device, subjects were instructed to actively perform three repetitions of ankle movement ranging from maximal plantar flexion to maximal dorsiflexion. The test began with the tester passively moving the test limb into the test position of 30° of plantar flexion and maintaining that position for 10s. After 10 seconds of static positioning, the ankle was moved back passively from the presented angle to the reference angle. The subject was asked to actively reproduce the previously presented test angle of 30° of plantar flexion. Two trials were performed. Following the first test, the same test protocol used for the second test of active reproduction of passive positioning at 15° of inversion.

Evaluation of Passive Movement Sense

Data were collected using the instrumentation and procedures developed and described by Lentell (14). The investigator responsible for this aspect of data collection spent approximately 10 hours in pilot testing the device to become proficient in its use. As illustrated in Figure 6, the device is a box with a movable platform that rotates about a single axis. With the foot resting on this platform, movement in to ankle inversion from a starting position of 0° can occur. This platform is moved by an electric motor that rotates the foot on an axis at a rate of 0.5°/sec. The consistency of generated movement speed was confirmed by separated time trials using a stop watch. Movement can be stopped any time by a hand-held switch. The angular motion achieved by the platform is measured by an attached stationary protractor, with measurements rounded off to the nearest degree by visual sighting of the static placement of the platform's parallel surface (Figure 6).

For data collection, subjects were seated on a table with the limb to be tested resting on the platform of the device. The hip, knee, and ankle were positioned at 90°, respectively, with the foot flat. The foot was placed about the axis of the device to promote subtalar joint axis of rotation, aligning the midpoint of the heel to the interval between the first and second toe. To further reduce unwanted sensory input, subjects were blindfolded and were wearing a headset with music playing to eliminate the sight and sound of the apparatus moving the foot. Data collection began with the foot placed in a starting position of 0°. The subject was instructed to concentrate on their foot and to shut off the hand-held switch when movement was sensed. The motor was then engaged to rotate the foot into inversion at a random time interval between 5 and 30 seconds after subject instruction. The position at which the subject sensed movement and turned off the unit was visually noted by the investigator and recorded as the angle at which passive movement was felt. Two trials were performed on each foot with a mean value in degrees of passive movement calculated. We used a passive movement speed of 0.50-1°/s because we have found that more rapid movement is too easily detected.

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Statistical analysis

A Mann-Whitney U test was used to compare the mean values of the gymnastic ankle to the control ankle. The level of significance for all statistical analysis was set at a p value of < 0.05.

RESULTS

Results revealed statistically significant differences between the trained gymnastic group and the untrained control group (Table II).

Single-limb-hopping course

The control and gymnastic groups performed the parcour two times with each leg. The mean value of the two scores was taken as the total score. The test scores ranged from 6.5 to 12 s for control group and from 5 to 7.5 s for gymnastic group. The average score of control group was 9.35 ± 1.6 s, while average score of gymnastic group was 6.23 ± 0.8 s. We found no statistically significant difference between the dominant and nondominant ankle in the group of the volunteers and gymnasts.

One-leg-standing test

The failure rate (ground contact with the contra-lateral leg) for the one-leg-standing test ranged between 2 and 21 failure points for control group and 0.5 and 9 failure points for gymnastic group. The average failure for control group and gymnastic group was 9.75 ± 6.0 and 3.0 ± 2.0 points, respectively. There was no statistically significant difference between the dominant and nondominant ankle in the group of volunteers and gymnasts.

Passive Joint Position Sense Test

A Mann-Whitney U test revealed no significant differences in RPP between dominant and nondominant ankles in the both groups for any of the test condition. The mean values for RPP ranged from 0.78 to 1.68° for gymnastic group and 3.25° to 4.78° for the control group. The mean value scores in degrees of the normal ankle proprioception are shown in Table 2.

Active Joint Position Sense Test

No significant mean differences were revealed between dominant and nondominant ankles in the both groups for RAP in any of the test conditions. Mean values for RAP ranged from 3.45° to 3.75° for control group and 1.23° to 2.70° for gymnastic group (Table II).

Comparison between the trained gymnastic group and the untrained control group ankle joints

All tests showed highly significant differences ($p<0.05$) between the trained gymnastic group and the untrained control group ankle joints (Table II). The used time for the single-limb-hopping course was 6.23±0.8 s in the trained gymnastic group and 9.35 (1.6 s in the untrained control group ankle joints (U=12.5; p= .0001). The score of one-leg-standing test was 3.0

Table II : Comparison between the trained gymnastic group and the untrained control group ankle joints of all four tests.

	Single-limb-hopping course (sec)		**One-leg-standing test (points)**	
Gymnastic ankle	6.23±0.8 (5-7.5)		3.0±2.0 (0.5-9)	
Nongymnastic ankle	9.35±1.6 (6. -12)		9.75±6.0 (2-21)	
P-value	p< 0.001		p< 0.001	
	Passive Joint Position Sense Test (deg.)		**Active Joint Position Sense Test (deg.)**	
	Inversion	**Plantarflexion**	**Inversion**	**Plantarflexion**
Gymnastic ankle	0.78±0.7 (0-2)	1.68±0.7 (0-2.5)	1.23±0.6 (0.5-2.5)	2.70±2.6 (0.5-8.5)
Nongymnastic ankle	3.25±1.9 (1-6.5)	4.78±4.5 (0-14)	3.45±1.3 (1.5-5)	3.75±2.8 (1-10.5)
P-value	p< 0.001	p< 0.05	p< 0.001	p< 0.05

(2.0 points in the trained gymnastic group and 9.75±6.0 points in the untrained control group ankle joints (U=46; p= .0001). The untrained control group ankle demonstrated significantly less accurate RPP values compared with the gymnastic group ankle joints, from a starting position of 00 neutral position to plantarflexion of 30° (4.78±4.5 vs 1.68±0,7 ; U=124; p= .037) and inversion of 15° (3.25±1.9 vs 0.78±0.7 ; U=38.5; p= .0001). The group of gymnasts had significantly lower values than the control group for PAP, from a starting position of 00 neutral position to plantarflexion of 30° (3.75±2.8 vs 2.70±2.6 ; U=130; p= .041) and inversion of 15° (3.45±1.3 vs 1.23±0.6 ; U=24; p= .0001). In terms of velocity, the gymnasts were 33.4% faster than the control group in single-limb-hopping course test. The failure rate for the one-leg-standing test, the gymnasts were 69.2% more successful than the control group. In terms of average error score, the gymnasts were lesser than the control group in reproducing both passive position (76% for inversion and 65% for plantarflexion), and active position (64.3% for inversion and 28% for plantarflexion) of the ankle joint.

DISCUSSION

The results of our study indicate that gymnasts consistently had better proprioceptive ability than the nongymnastic group in all tests (Table 2). It seems that extensive athletic training has a positive influence on balance and proprioception in addition to increasing the muscle tone of any joint. According to the findings of this and other studies (16), highly trained athletes demonstrate a significantly lesser error RPP and RAP and better balance during the one-legged stance and single-limb-hopping course which implies enhanced neurosensory pathways. It is thought that athletes are able to develop enhanced neurosensory pathways as a result of long-term athletic training.

Joint Position Sense

We found that gymnasts had markedly increased their ability to reproduce both passive and active position of ankle angles in comparison with the control subjects. When compared to the control group, trained gymnastic group significantly improved joint position sense for both inversion and plantar flexion motions. These improvements in proprioception, demonstrated by enhanced joint position sense, suggest that long-term athletic training is sufficient to stimulate cutaneous nerve receptors and/or mechanoreceptors in the muscle, ligaments, and joint capsule of the ankle joint. Stimulation of these mechanoreceptors may result in earlier and enhanced muscular contractions, thus protecting and stabilizing the joint (13,16).

This is the first study to evaluate ankle joint position sense ability in gymnasts, others have studied the effect of athletic training on knee proprioception with contradictory results. Lephart et al. (16) evaluated kinesthetic ability of knee joint in gymnasts. They found that group of gymnasts had significantly lower values and 73% faster response time than the control group in detecting passive motion of the knee joint. They thought that gymnasts are able to develop enhanced neurosensory pathways as a result of long-term athletic training. Barrack et al. (17) evaluated knee position sense in 12 dancers. They found that dancers were markedly deficient in their ability to reproduce knee angles in comparison with the control subjects. In a later study, the same authors found that 12 highly trained dancers were more sensitive than control subjects in detecting knee passive motion (18). On the other hand, Rozzi et al. (19) studied the role of balance training in persons with functionally unstable ankles. They concluded that balance training was an effective means of improving joint proprioception and single-leg standing ability in subjects with unstable and nonimpaired ankles. These studies indicate that training has some influence on knee and ankle proprioception.

Our study revealed that passive position sense was significantly better than active position sense all two groups. Consistent with our study, Gross (20) and Bernier and Perrin (21) reported that passive inversion and eversion positioning at the ankle was significantly better than active positioning in both the injured and uninjuried subjects. Joint receptors may have the dominant role in signaling joint position. Muscle receptors may be more involved in the perception of joint movement and may be less valuable in fine judgments of joint position, as compared with joint receptors. This model may be used to better understand why the total error for active judgments of joint position was significantly greater than the total error for passive judgments. The processing and interpretation of additional input from muscle afferent and efferent (alpha and gamma) signals possibly might have resulted in the increase in the total error for active judgments of joint position.

We found that both the maximum inversion position and maximum plantar flexion position during passive testing were better than active testing. This is consistent with the findings of Bernier and Perrin (21). Their study showed that the maximum inversion position had the lowest mean score when tested passively and the highest mean score when tested actively. The results of this study is inconsistent with the findings of Glencross and Thornton (22), who found greater error in reproduction of joint position angles with the largest angles of movement. As the test angle approached to the limit of range of motion, the error in reproduction became greater. In our study, the maximum inversion and plantar flexion position had the lowest mean score when tested passively and the highest mean score when tested actively.

If muscle mechanoreceptors are best suited to sense quick changes, this would explain why active joint position sense was worse than passive. When tested at a slow angular velocity (0.5 to 2 deg/sec), threshold to detection of passive motion as well as the reproduction of passive positioning is thought to selectively stimulate Ruffini or Golgi-type mechanoreceptors. Because the test is performed passively, it is believed to maximally stimulate joint receptors, thereby relying on the cortical pathway in the neuromuscular control system. After ligament lesions, passive joint sensibility testing is often chosen to assess afferent activity because muscle activity is negated. Stimulation of both joint and muscle receptors is done by the reproduction of active positioning, which provides a more functional assessment of the afferent pathways. An extremely slow speed, such as the one used in our study (40/sec.) during active joint positioning, may cause an interference with normal functioning of the muscle proprioceptors. If active position sense testing is a measure of interest, perhaps a test which is more physiological in nature, such as a self-selected speed, would produce more meaningful results.

One-leg-standing test and single-limb-hopping course test

There were highly significant differences in single-limb-hopping course test and one-leg-standing test between the gymnasts and the nongymnastic group. When compared to the control group, trained gymnastic group had markedly an increase in their ability to balance as a result of long-term athletic training. In terms of pass time, the gymnasts were 33.4% faster than the control group in single-limb-hopping course test. The failure rate for the one-leg-standing test were 69.2% better in the gymnasts than the control group. This result indicates that gymnasts had a faster reaction time than normal untrained people, because of exercises being done to improve joint proprioception, balance and coordination of the ankle

Proprioceptive deficits have been shown to exist following ankle injuries (11,12,13,14,20,21). Several authors have demonstrated that proprioceptive ankle disk training decreases injury-induced postural sway changes (19,21). Jerosch and coworkers (11) examined the proprioceptive capabilities of the ankle in stable and unstable joints. Angle reproduction, hopping on one leg, and standing on a soft surface were performed. A score was calculated by counting the number of failures over a period of time (eg, touching the ground with the opposite leg). They found that all tests showed significant differences between the injured and non-injured ankle joint.

Standing on one leg is a complex coordinative task performed within a set of mechanical constraints. Nashner and McCollum (23) designed a model for postural sway in the sagittal plane. According to their theory, there are two basic strategies for maintaining single-limb stance: an ankle strategy that makes use of torques around the ankle joint and a hip strategy that generates shear forces. Substantial disturbances of balance are corrected by the hip strategy, whereas fine-tuning is achieved by the ankle strategy. Nashner and McCollum (23) predict that hip strategy prevails if mechanical constraints (like standing on a narrow surface) makes ankle strategy ineffective.

Gleitz et a1(24) documented the one-leg-standing ability in the injured and non-injured ankle. They also found a proprioceptive deficit in this test. Gleitz et a1 (24) and Freeman et a1 (25) found an increase in the proprioceptive function after neurophysiological training. Similar results were confirmed by Tropp et al (26) who performed a special proprioceptive training on an ankle disk in soccer players of the Swedish National League suffering from unstable ankle joints. The patient group who takes exercise five times a week, each time for 10 mm, endured significantly fewer ankle sprains during the following season. The results need to be interpreted in light of the type of athlete and mechanism of injury. We limited our sample to one group of athletes, gymnasts, and did not explore the influence of mechanism of training on joint position sense or one-leg-standing test and single-limb-hopping course test.

Gymnasts use both static and dynamic balance abilities in their daily routines. Therefore, our results on the static one-legged balance test may not be reflective of dynamic balance abilities performed routinely by gymnasts. Winstein has determined that static balance tasks are not representative of dynamic balance tasks (27). Assessments of balance abilities, therefore, should be performed in the context in which the subject will be using those abilities. Winstein found that balance abilities are task specific; thus, female gymnasts should be tested using balance beam activities or other activities specific to their training.

Control of posture entails reflexs mechanism involving coordinated activity of three balance senses: visual, vestibular, and somatosensory systems (10). Vision can be eliminated during the one-legged standing balance test by having the subject close his eyes. The relative contribution of the vestibular and kinesthetic systems cannot be differentiated in the one-legged standing balance test. The test does not provide sufficient information to determine whether the subjects' balance impairment was due to the interaction of the remaining sensory systems, biomechanical alignment, or other neuromusculoskeletal factors. Future studies will examine the relative contribution of each sensory system to dynamic balance abilities in the athletes. Gymnasts may be able to compensate for some of the somatosensory deficits of an injured ankle by relying on somatosensory inputs of other limb segments as well as other sensory input from visual and vestibular systems. Individuals with decreased somatosensory input are often able to execute a balance response despite this insufficient sensory input. Gymnasts, by the nature of their sport, learn to balance under different conditions and this learning effect may enable them to resume training shortly after an ankle injury.

There are some possible explanations for the superior joint position sense and balance found in gymnasts. Gymnasts are able to develop enhanced neuromuscular control (NMC) and junctional stability as a result of long-term athletic training. NMC is influenced by proprioceptive, kinesthetic, visual, and vestibular information as well as cortical and spinal motor commands (28). Four elements crucial for reestablishing neuromuscular control and functional stability are joint proprioception and kinesthesia, dynamic stability, preparatory and reactive muscle characteristics, and conscious and unconscious functional motor patterns (7). Athletic training could develop enhanced neurosensory pathways; such pathways then appear to improve joint position and kinesthesia through enhanced central and peripheral neural mechanisms. Those central neural mechanisms may involve increased processing and facilitation, while the peripheral neural mechanisms may involve muscle and tendon receptors.

Athletes who inherently posses enhanced joint proprioception may excel at sports requiring high levels of neuromuscular control. To improved NMC and functional stability, athletes may use exercise techniques including closed kinetic chain activities, balance training, eccentric and high-repetition/low-load exercises, reflex facilitation through reactive training, stretch-shortening activities and biofeedback training. These techniques produce adaptations in the sensivity of peripheral receptors and facilitate afferent pathways, agonist/antagonist coactivation, muscle stiffness, reflex muscle activation, and discriminatory muscle activation. Alternatively, the superior balance and joint position sense of gymnasts could be genetically determined.

A third explanation is that the proprioceptive demands of gymnastics require having a faster reaction time than normal untrained people, yet this assertion remains to be studied. Therefore, the potential existence of genetic predisposition versus the effect of training has to be clarified. Although definite conclusions cannot be drawn from our study or previous studies, we agree with the postulate put forth by Barrack (18) and Lephart (16): effects of training on muscles and tendons may be the main factor for this enhanced joint position sense and balance in gymnasts, because muscle receptors provide reliable proprioceptive information.

CONCLUSION

The superior joint position sense and balance play an important preventive role in gymnasts who are at risk for recurrent ankle sprains. Gymnasts in this study demonstrated a higher incidence of balance and superior joint position sense in their ankle than the nongymnastic group as measured by the one-legged standing balance task, single-limb-hopping course test and active and passive joint position sense test. Although our results cannot be extrapolated to balance abilities during complex gymnastic routines, they do suggest that physical therapy assessment should include active and passive joint position as well as one-legged standing balance task, single-limb-hopping course test, and that the need for clinicians to assess balance and proprioceptive deficits in athletes who sustain one or more ankle sprains. Such information, in conjunction with clinical data, can provide clinicians additional clinical insight for classifying or categorizing impaired posture and/or movement conditions with a focus on causal elements. This information might be useful for identifying gymnasts who are at risk for recurrent ankle sprains. In addition, it is recommended that rehabilitation programs for athletes include balance training and, more specifically for gymnasts, balance rehabilitation programs that incorporate elements of their gymnastic routines.

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