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Knee joint proprioception: a comparison between female intercollegiate gymnasts and controls

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Abstract The role of proprioception as a protective mechanism has gained interest in recent years. From the clinical standpoint, several studies have dealt with ways to enhance proprioception following surgery and during rehabilitation. If kinesthesia (ability to detect passive motion) can be enhanced as a consequence of long-term athletic training, such training must be included as a part of the rehabilitation process to protect the patient from reinjury. Consequently, the purpose of this study was to compare the kinesthetic knee pattern between trained gymnasts and healthy nongymnasts. The proprioception testing device (PTD) was used to evaluate knee kinesthesia. From 45° of flexion, the knee was passively extended with the PTD. The device was stopped by the subject when this passive motion was detected. Fifteen healthy college-age female gymnasts (mean age 19.3 years) and 30 normal volunteers (mean age 20.7 years) comprised our study sample. A one-way analysis of variance (ANOVA) was used to compare the mean values of the dominant gymnastic knee to the dominant knee in the control group. Results revealed statistically significant mean differences between the trained gymnastic group and the untrained control group ($F_{1,34}(.95) = 7.17$, $P = 0.011$). The results of this study suggest that extensive training has a positive influence on knee kinesthesia in addition to increasing muscle tone. According to the findings of this and other studies, highly trained athletes possess enhanced neurosensory pathways which are speculated to develop as a result of long-term athletic training. Although definite conclusions cannot be made from our investigation, prospective studies can determine the true role of athletic training in proprioceptive patterns.

Key words Proprioception Kinesthesia · Gymnasts

Introduction

Proprioception research has grown in recent years, focusing on different fields, but most commonly on the knee. Many studies have demonstrated the presence of mechanoreceptors in the knee structures of animals [8, 11, 13, 14, 22] and humans [9, 16, 17, 19–21, 28, 30–32, 35]. Moreover, neurophysiologic experiments investigating the relationship between the neurologic function of the knee and clinical conditions [9] have led to clinical evidence of proprioception in both the normal and the reconstructed knee [2–5, 10, 23, 27, 28, 32–34]. Furthermore, enhanced proprioception has also been noted in the shoulder after surgical capsular repair [24]. According to Guyton, "proprioceptive sensations are those having to do with the physical state of the body, including position sensations, tendon and muscle sensations, pressure sensations from the bottom of the feet and even the sensation of equilibrium, which is generally considered to be a special sensation rather than somatic sensation" [15]. These sensations arise through activity in sensory neurons located in the skin, muscles, and joint tissues [12]. They include pressure, stereognosis, vibration, joint position sense, and kinesthesia. It is widely known that a proprioceptive deficit may detract from the functional success of ligament healing and predisposes the patient to reinjury. Thus, if we could enhance joint proprioception, we might be able to restore the normal protective mechanism within the injured or reconstructed knee. Until recently, most types of rehabilitation programs involved merely muscle strengthening, rather than the improvement of neuromuscular coordination [18]. In contrast, modern protocols include proprioception as an important element in the rehabilitation process [1]. Although the results are inconsistent, a few available studies have shown that extensive athletic training influences knee proprioception [4, 5, 34]. In addition, we have observed that gymnasts have better balance than nonathletes. The purpose of the present study was to compare the kinesthetic patterns between the dominant knee of gymnasts to the dominant knee of healthy nongymnasts. We wanted to know what effect, if any, extensive athletic training has on the detection of passive knee motion. We hypothesized that gymnasts, given their better balance, also have greater kinesthetic 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 [5]. Thus, this study was designed to provide objective information relative to the status of kinesthesia (threshold to detect passive motion) on the gymnastic knee.

Proprioception is most reliably tested using passive range of motion during open-chain exercise. The threshold for detecting joint motion (kinesthesia) and reproducing a set angle (joint position sense) are standard methods for proprioception testing [7, 27]. We performed the kinesthetic evaluation using the proprioception testing device (PTD).

Materials and methods

Design and inclusion criteria

We designed a cross-sectional cohort study to compare a group of healthy, college-age gymnasts with a control group of healthy, age-matched volunteers. The inclusion criteria for both groups were as follows: age 17–23 years, no history of injury in either knee, musculoskeletal injury, inner ear abnormality, equilibrium disorder, or neurological disease. Each prospective subject completed a questionnaire documenting the inclusion criteria, information about general health, and demographic data.

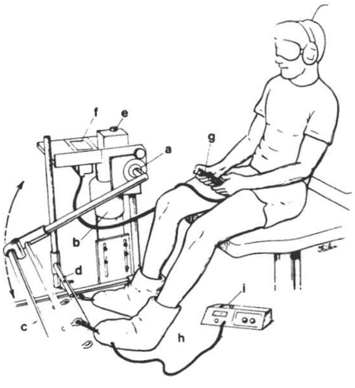

Fig. 1 Proprioception testing device: *a* rotational transducer, *b* motor, *c* moving arm, *d* stationary arm, *e* control panel, *f* digital microprocessor, *g* hand-held disengage switch, *h* pneumatic compression boot, *i* pneumatic compression device

Procedure, sample and data collection

Our study sample included 15 healthy, college-age, female gymnasts (mean age 19.3 years; range 17–22 years) and 30 healthy, nongymnast volunteers (mean age 20.7 years; range 17–23 years). All subjects were volunteers, met the inclusion criteria, and signed the consent form approved by the Human Studies Committee at the University of Pittsburgh.

The PTD, designed at the University of Pittsburgh, consists of a mobile "C" arm and an electric motor (Fig. 1). A rotational transducer between these two components converts the circular movement of the motor to uniplanar movement of the "C" arm. This rotational transducer is also interfaced with a digital microprocessor counter, which provides angular displacement values. It has a hand-held disengage switch and a chair that is placed under the "C" arm. A panel on the machine permits the evaluator to adjust the speed and direction of the "C" arm's movement and to turn the motor on or off.

Our test incorporated the principles discussed by Barrack et al. [2–7] and Skinner [33, 34]: use of the sitting position, a starting position of 45° of knee flexion, elimination of all external cues (auditory, visual, and skin sensations). We used a passive movement speed of $0.5° s^{-1}$ because we have found that more rapid movement is too easily detected.

Testing was performed in a single session. Subjects were asked to wear shorts and were seated at a reclining angle of 60° with the popliteal fossa 4–6 cm from the edge of the seat. A pneumatic compression boot was placed on each foot. The "C" arm was attached to the boot on the side to be tested, enabling it to move the leg passively into extension. The other boot was attached to the stationary shaft. The subjects were blindfolded and asked to wear headphones that played "white noise" to negate any noise of the motor. The "C" arm was used to place the leg passively in 45° of flexion (starting position). Just before the test was started, the subject was touched on the thigh and asked to signal readiness with a "thumbs up" sign. After a random period of time, the examiner started the motor. The "C" arm passively extended the leg at a constant angular velocity of 0.5° s^{-1}. When the subject felt the motion of the leg, he/she stopped the machine using the hand-held switch. This test was repeated five times for each subject. The dominant knee of gymnasts and controls was evaluated.

All data were collected from the digital microprocessor and converted to degrees. Thus, we were able to determine the difference between the starting position and the position at which the PTD was stopped. We used the average of the differences for all five trials. Data were stored in a conventional database.

Statistical analysis

A one-way analysis of variance (ANOVA) was used to compare the mean values of the dominant gymnastic knee to the dominant control knee.

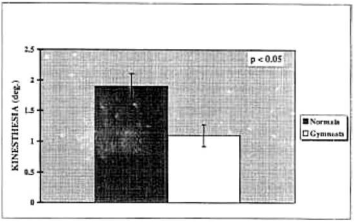

Fig. 2 Mean kinesthesia for the gymnastic knee and for the healthy nongymnastic knee, from starting position of 45° and moving into extension (± SD, $P < 0.05$)

Results

Results revealed statistically significant differences between the trained gymnastic group and the untrained control group ($F_{1,34}(.95) = 7.17$, $P = 0.011$). The group of gymnasts had significantly lower values for kinesthesia (1.1° ± 0.18°) than the control group (1.9° ± 0.21°). In terms of response time, the gymnasts were 73% faster than the control group in detecting passive motion of the knee joint.

Discussion

The results of our study indicate that gymnasts consistently detected passive knee motion faster than the nongymnastic group (Fig. 2). It seems that extensive athletic training has a positive influence on kinesthesia in addition to increasing the muscle tone of any joint. According to the findings of this and other studies [5, 34], highly trained athletes demonstrate a significantly low threshold to detect passive motion 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.

Although this is the first study to evaluate knee kinesthetic ability in gymnasts, others have studied the effect of athletic training on knee proprioception with contradictory results. Barrack et al. [4] 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 [5]. On the other hand, Skinner et al. [34], evaluated the role of fatigue in 11 healthy male volunteers participating in the United States Navy Sea, Air, and Land Team Training (SEALs). They concluded that muscle receptors are primary determinants of joint position sense and that capsular receptors may play a secondary role. These studies indicate that training has some influence on knee proprioception. We consider gymnasts as comparable to ballet dancers and SEALs in their level of training, complexity of movement, grace in execution, muscular development, and ligamentous laxity.

There are three possible explanations for the superior kinesthesia found in gymnasts. Enhanced neurosensory pathways could develop as a result of long-term athletic training; such pathways then appear to improve 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 possess enhanced kinesthesia may excel at sports requiring high levels of neuromuscular control. Alternatively, the superior kinesthetic response 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 [5]: effects of training on muscles and tendons may be the main factor for this enhanced kinesthesia in gymnasts, because muscle receptors provide reliable proprioceptive information [25, 29].

The implications of training in increased kinesthesia, its effect on improved performance, and its reflex protective mechanism should be investigated. Whatever the anatomical and physiological basis for the enhanced kinesthesia in gymnasts, only a long-term prospective study will settle this issue as well as the implications for the selection of athletes. Those individuals suitable for athletics require highly refined coordination and speed in performing exact movements. The role of ligament laxity as suggested by Barrack et al. may be partly genetic [4], and its role in the selection process is a topic of further study.

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