Can Proprioception be Improved by Exercise?

Jing Xian Li, PhD
School of Human Kinetics
University of Ottawa

Acknowledgement

this lecture includes research results from biomechanics laboratory in University of Ottawa, The Chinese University of Hong Kong, and Tianjin University of Sports over the last years. The significant contributions of the following colleagues, current and former graduate students is gratefully acknowledged:

Prof. Y. Hong  Ms. U. Tsung
Dr. D.Q. Xu      Ms. C. Fulop
Dr. D. W. Mao    Ms. S. Becker
Mr. L. Wang      Mr. H. B. Pang

A definition of proprioception

- Proprioception is the afferent information that contributes to conscious sensation (muscle sense), total posture (postural equilibrium), and segmental posture (joint stability), which is mediated by proprioceptors located in the skin, muscles, tendons, ligaments, and joint capsules (Lephart et al, 1997).
- In 1889, Goldschneider measured the smallest joint rotations that could be detected at nine different joints in the body (Goldscheider A, 1889).
- The term “proprioception” was first introduced by Sir Charles Sherrington in 1906.

The Contribution of Different Sensory System in Maintenance of Static Postural Stability

- Vision: 21.3%
- Vestibular: 22.4%
- Proprioception: 56.3%

(Lord, Clark, and Webster, 1991)

- Study in adults (Fitzpatrick, R., 1994).

How Important the Proprioception is?

- Proprioceptive information from ankle and neck muscles in adults (ages 22-55 years) are used for balance control and body orientation (Kavounoudias, A., 1999).
- Proprioceptive information from the leg muscles was found to be able to maintain a sufficient degree of stability in standing in adults (ages 24-50) (Fitzpatrick, R., 1994).
- Proprioceptive information from the lower extremities was observed to be central for the detection of postural sway about the ankles in adults (ages 24-38) (Poppa, R., 1994).
How Important the Proprioception is?

Less accurate in proprioception function of ankle was one of the risk factors for an ankle sprain in female university students (Willems et al. 2005).

Deficiency in proprioception

Risks of injuries

Deficiency in proprioception

Injuries

Proprioceptors in Muscles: Muscle Spindles and Golgi Tendon Organs

- Muscle spindles: ‘length sensors’.
- Golgi tendon organs: ‘tension sensors’.
- The signals in the degree, rate and amount of stretch of muscles are transmit sensory information to the central nervous system.
- Provide afferent information related to muscle length and contraction force (posture and movement) to central nervous system (Marieb, E.N. 2001).

Proprioceptors in Tendon, Ligament, Joint Capsule, and Skin

- Pacinian corpuscles
  - Respond to first application of deep pressure
  - for monitoring vibration to provide information about stationary joint position
- Ruffini’s corpuscles
  - respond to the continuous application of pressure
  - signal the direction, rate, and extent of joint movement and balance
- Free dendrite endings
  - Respond to pain, temperature, and pressure-caused tissue movements
- Cutaneous receptors
  - touch, pain, temperature, pain, pressure

Measurement of Proprioception: Kinesthesia Measurement

- kinesthesia measurement: passive motion sense
- the determination of the lowest threshold for the detection of joint rotation

Measurement of Proprioception: Joint Position Sense Measurement

Position – reposition test: active motion sense
- It is assessed by determining the error associated with active or passive reproduction of a joint angle.

Measurement of Proprioception: Movement velocity and torque measurement

- Reproduction of movement velocity (Deshpande N, 2003)
- Reproduction of torque (Deshpande N, 2003)
- Kinesthesia is demonstrated more repeatable and precise measurement than the joint position sense, and reproduction of movement velocity and torque techniques (Beynon et al., 2000; Xu, et al., 2004; Deshpande N, 2003).
How Does Exercise Influence Proprioception of Knee and Ankle

-Tai Chi Exercise on Proprioception of Knee and Ankle in Elderly People

Tai Chi Exercise, Postural stability, and Falls Prevention

- Tai Chi exercise benefits postural control capacity and deduces risks of falls by 47.5% in elderly people.

Can Tai Chi Exercise Improve Proprioception?

Experiment

- A cross-sectional comparison among three groups of the elderly people
  - Tai Chi practitioners (n=21)
  - Joggers / swimmers (n=20)
  - Sedentary people (n=27)

Proprioception (kinesthesia) Measurement of ankle

A movable platform that rotates about a single axis in two directions at a rate of 0.4°/sec.

Tai Chi group Showed Best Proprioception of Ankle and Knee Flexion among Three Groups

A moveable frame can rotate around a single axis in two directions at a velocity of 0.4°/sec.

The starting position for test was 45° of knee flexion

Summary

- Tai Chi exercise showed a unique training effect on proprioception, especially in the ankle joint complex.
- Long-term regular running/swimming exercisers did not perform better in ankle and knee joint kinesthesia compared with their sedentary counterparts.
- Proprioception can be improved by long-term regular Tai Chi exercise in elderly people.

Experiment

Subjects: 16 Tai Chi master
Movements: 42-form Tai chi movement, and walking
Analysis: foot movement and plantar pressure distribution

Foot Supporting Patterns ...

- Full double support
- Single left support
- Single right support
- Left support with right toe touch
- Left support with right heel touch
- Right support with left toe touch
- Right support with left heel touch

Foot Movement Direction...

- Forward
- Backward
- Sideway
- Up-down
- Turning
- Fixing

The Movement Patterns of Tai Chi Require the Practitioners to Move in Multi-directionally

Movement duration (%) of step in each direction in whole set of Tai Chi

Peak Plantar Pressure in One-leg Stance of Tai Chi

Tai Chi exercise presents a strong challenge to the exertion of the great toe and 1st metatarsal.

training effect on the foot muscles, “force sensors” of foot


Summary

- Tai Chi movement in one-leg stance is characterized by
  - multi-dimensional movements,
  - longer duration in one-leg stance,
  - and increased plantar pressure distribution, especially in big toe and 1st to 5th metatarsal heads.

- The movement characteristics of Tai Chi exercise on each one-leg stance and the plantar pressure distribution during the one-leg stance may improve the ability to balance by training the muscles in the simulated challenge posture and intensifying the feedback from the proprioceptors.

However,

Can Other Exercise with High Demanding to Postural Control and Multi-directional Movements Improve Proprioception

- Proprioception of Ankle Joint Complex in Young Regular Ice Hockey Players, Runners, and Ballet Dancers

Experiment

- Hockey players (n=13, males)
- Runners (n=12, 6 males, 6 females)
- Ballet dancers (n=7, females)
- Sedentary people (n=13, 5 males, 8 females)

Kinesthesia/Passive Motion Sense: Males vs Females

- No significant difference was found in the passive motion sense between males and females.
- However, males performed better in perceiving the passive motion sense.

Experiment

• Kinesthesia of ankle in both ankles were measured in dorsiflexion/plantar flexion, inversion and eversion at 0.4°/second rotation velocity.
Kinesthesia/Passive Motion Sense: Males vs Females

- Sex hormones in the menstrual cycle have an effect on knee joint kinaesthesia (Fridén et al., 2006).
- Further study of examining the gender difference in proprioception is still needed.

Kinesthesia/Passive Motion Sense: Dominant vs Non-dominant Ankle

- No significant difference in passive motion sense was found between dominant and non-dominant ankle.

Kinesthesia/Passive Motion Sense: Dorsiflexion vs Plantarflexion

- Comparison of the kinesthesia in dorsiflexion and plantarflexion in each group did not show any significant difference.

Kinesthesia/Passive Motion Sense: Inversion vs Eversion

- Hockey players and ballet dancers showed significantly better passive motion sense in inversion than eversion.

The possible causes

- Foot structure?
- Biomechanical technique

The evidence found in hockey and dance groups indicates that the sensitivity of the proprioceptors in the foot could be enhanced by exercise.

Kinesthesia/Passive Motion Sense: Dorsiflexion/Plantarflexion vs Inversion/Eversion

- All participants performed significantly better in perceived passive motion sense in dorsiflexion/plantarflexion than in inversion/eversion.
- Medial-lateral postural stability is found very important in postural control.
Kinesthesia/Passive Motion Sense in dorsiflexion/plantarflexion: Effects of Exercise

A comparison in passive motion sense perceived in dorsiflexion/plantarflexion by three groups.

Kinesthesia/Passive Motion Sense in inversion/eversion: Effects of Exercise

Both hockey and ballet groups perceived significantly better passive motion sense in inversion/eversion than that in running group (P<.05) and sedentary group (P<.01).

Kinesthesia/Passive Motion Sense: Effects of Exercise

- Proprioceptive exercises require to take account of three parts: (Irrgang & Neri, 2000)
  - proprioception of joints
  - balance capacity
  - and neuromuscular control.

Passive Motion Sense: Effects of Exercise

- Current used training programs, eg. ankle disc, or balance board, do not specifically enhance ankle proprioception (Chong et al., 2001).
- Hockey boot allows small motion range in ankle. The range of supination of the bare foot inside the boot was 12.3° ± 4.6° in ankle joint in a high-cut hockey boot (Avramakis et al., 2000).
- Ballet shoes permit full range of motion in ankle joint.

Whole body movement coordination should be emphasized instead of focusing on one segment.

Summary

- Regular young hockey players and ballet dancers have a significantly better passive motion sense in dorsiflexion/plantarflexion and inversion/eversion than their sedentary counterparts.
- Regular young runners did not perceive a better passive motion sense of the ankle than their sedentary counterparts.
- Ankle proprioception could be improved by hockey and ballet dancing movements. The high demand for balance control, multi-directional movement, and very fine movement control might contribute the training effects.

How Long Exercise Training can Improve Proprioception of the Knee and Ankle?

- 16-weeks Tai Chi exercise Intervention on Proprioception of Knee and Ankle in Elderly People
40 Subjects

Pre- and post - intervention tests in proprioception of the knee and the ankle

- Tai Chi intervention group (n=22)
- Control group (n=18)
- 3 sections of 1 h Tai Chi exercise per week for 16 weeks

Effects of Tai Chi Intervention on Proprioception of the Knee and the Ankle

- A significant training effects were found for knee kinesthesia only.
- 16-week Tai Chi intervention program could not improve ankle proprioception significantly.

Summary

- The 16-week Tai Chi intervention program resulted in improved proprioception in the knee joint but not in the ankle.
- To improve proprioception capacity, a longer training time is needed, especially for the ankle joint.

Does Overweight/Obesity Influence the Proprioception of the Knee and the Ankle Joint

- Proprioception of Knee and Ankle Joint in Obese and Nonobese Prepubertal Boys

53 Subjects

Age: 9 ± 1.6 years

- Non obese group, n=26 BMI: 16.3 ± 1.4 kg/m²
- Obese group, n=27 BMI: 25 ± 4.1 kg/m²

Measurement of the Kinesthesia (Passive Motion Sense) in Knee and Ankle

Body mass index (BMI) Overweight cut-off = 21.4 kg/m² (Ji, 2004)
The Comparison in Passive Motion Sense Between Obese and Nonobese Boys

- Difference in passive motion sense was found in knee flexion only between groups.
- Obese group: 2.30 ± 1.82°
- Nonobese: 1.49 ± 0.77°
- Is it a degeneration evidence?

Summary

- The obese boys showed deficiency in proprioception in knee flexion.
- The alteration in proprioception of the knee in obese boys might be related to the their experience of greater loads at these joints as compared to individuals of normal weight.

Conclusion

- Exercise can improve proprioception in adults and elderly people. However, the modality of the exercise and the type of the exercise are key factors that influence the effects.
- The exercises that can enhance the proprioceptive function should extensively involve multi-directional movement and have a high demand on balance, postural control, and movement coordination.
- To improve proprioception, a longer training time is needed, especially for ankle proprioception.
- Overweight and obesity lead to a deficiency in proprioception which is evident in less sensitivity in determining passive knee flexion movement.

The following questions still remain to be answered:
- How long should a regular exercise be done before an improvement in ankle proprioception can be evident?
- Can the effects of exercise on proprioception be maintained even after stopping the exercise?
- Is there really a gender difference in proprioception?
- Is reversible the deficiency in knee proprioception of obese pre-pubertal boys?
- How is the proprioception of the knee and the ankle in obese adults?