ORIGINAL ARTICLE

Effect of tai chi exercise on proprioception of ankle and knee joints in old people

D Xu, Y Hong, J Li, K Chan

Br J Sports Med 2004;**38**:50–54. doi: 10.1136/bjsm.2002.003335

See end of article for authors' affiliations

Correspondence to: Professor Hong, Department of Sports Science and Physical Education, The Chinese University of Hong Kong, Shatin NT, Hong Kong; youlianhong@cuhk.edu.hk

Accepted 11 February 2003

Objectives: To assess if tai chi, a traditional Chinese form of exercise, could improve proprioception in old people and if the effects of tai chi on proprioception are more evident than other exercise forms in the elderly.

Methods: By detecting the threshold of passive movement, ankle and knee joint kinaesthesis was measured in 21 elderly long term tai chi practitioners (TC group), 20 elderly long term swimmers/runners (S/R group), and 27 elderly sedentary controls (control group).

Results: Ankle joint kinaesthesis differed significantly among the three groups ($p = 0.001$). Subjects in the TC group could detect a significantly smaller amount of motion than those in the S/R group ($p = 0.022$) and control group ($p = 0.001$). No significant difference was found between the S/R group and the control group ($p = 0.701$). The threshold for detection of passive motion was significantly different in knee extension and flexion. For knee flexion, the TC group showed a significantly lower mean threshold for detection of passive motion than the control group ($p = 0.026$). There were no significant differences between the S/R group and control group ($p = 0.312$), or between the TC group and S/R group ($p = 0.533$). For knee extension, no significant difference was noted among the three groups ($p = 0.597$).

Conclusions: The elderly people who regularly practiced tai chi not only showed better proprioception at the ankle and knee joints than sedentary controls, but also better ankle kinaesthesis than swimmers/runners. The large benefits of tai chi exercise on proprioception may result in the maintenance of balance control in older people.

Tai chi, a traditional Chinese exercise, has been practiced for centuries in China by the elderly and young to attain agility, balance, and posture control. Its beneficial effects on health have been observed, and the maintenance of balance control in older people in particular has drawn increasing attention from scientific researchers. A number of cross sectional and longitudinal studies have provided positive evidence that tai chi practitioners not only have better cardiorespiratory function,[1 2] but also perform better in balance control, flexibility, and muscle strength tests.[3 4] Moreover, a study conducted by Wolf *et al*,[5] with a relatively large sample size, identified that the intervention of tai chi reduced the risk of multiple falls by as much as 47.5%. Although many studies have confirmed the effects of tai chi exercise on balance control for the elderly, little effort has been devoted to determining the underlying mechanism.

Postural equilibrium needs proprioceptive acuity and precise neuromuscular control. Proprioception is the afferent information that contributes to conscious sensation (muscle sense), total posture (postural equilibrium), and segmental posture (joint stability).[6] Many studies have indicated that proprioception diminishes with age.[7–9] Gerontologists have postulated that impaired proprioception makes it difficult for older people to detect changes in body position until it is too late for compensatory behaviour to prevent falls.[10] Indeed, some studies have shown that diminished proprioception is a major contributing factor to falls in the elderly.[11] It is very important for old people to retain this ability.

One strategy to reduce the incidence of poor proprioception and falls with aging may be regular physical activity.[8] Exercise can help to improve a number of sensorimotor systems that contribute to stability.[12 13] However, different forms of exercise may have different effects on postural equilibrium. Gauchard *et al*[14] reported that proprioceptive exercise (yoga and soft gymnastics) appeared to have a greater effect on balance control in the elderly than bioenergetic physical activities. However, the authors did not suggest any underlying reasons.

Tai chi exercise requires continuous, slow movement with small to large expressions of motion, the shift of body weight from unilateral to bilateral, and circular movements of the trunk and extremities, involving both isometric and isotonic contractions. All forms of tai chi emphasise conscious awareness of body position and movement, which seem to contain the characteristics of proprioceptive exercise.[15] Therefore does tai chi exercise have particular benefits for old people's proprioception? Jacobson *et al*[16] reported that a 12 week tai chi programme could increase participants' shoulder kinaesthetic sense at 60°. However, the mean (SD) age of the subjects was 30.4 (4.3) years, and the investigators did not consider the principal joint systems of the lower extremity (ankle, knee, and hip) involved in postural control.

This study was therefore designed to investigate the proprioception of ankle and knee joints in elderly long term tai chi practitioners, long term swimmers/runners, and sedentary controls. The purpose was to assess whether long term tai chi practice could improve proprioception and whether the effect of tai chi on proprioception was more evident than other common activities in the elderly. Such information would help to explain the mechanism whereby tai chi exercise improves balance.

METHODS

Subjects

By means of a questionnaire with a complementary interview about their physical and sporting activities, 68 old people were recruited to the study. They were predominantly healthy with no history of major cardiovascular, pulmonary, metabolic, musculoskeletal, or neurological diseases. Twenty one subjects had regularly practiced tai chi for approximately

1.5 hours a day over the previous four years or more (TC group). Twenty subjects had swum and/or run for at least one hour a day for four or more years (S/R group). The subjects in the TC and S/R groups had not done any other regular physical activity in the previous five years. Twenty seven subjects had not engaged in any regular exercise for more than four years (control group). No significant difference was noted in sex, age, height, and weight across the three groups (table 1).

Each subject gave written informed consent before participation. The study was approved by the local medical ethics committee.

Measurement procedures

Joint kinaesthesis is the sensation of joint movement; it is an important technique used to evaluate proprioception. Kinaesthesis is usually determined by establishing the threshold at which passive motion is detected, an assessment of the ability to detect relatively slow passive joint motion.[17] We used it to assess knee and ankle joint proprioception.

Testing was performed in a well lit and well ventilated room. The room was sound attenuated and isolated so as to reduce any auditory or visual interference that might distract the participants. After their weight and height had been measured, each subject participated in two separate data collection sessions: measurement of ankle joint kinaesthesis and, after a brief rest period, measurement of knee joint kinaesthesis.

Ankle joint kinaesthesis test

Data were collected using the instrumentation and procedures described by Lentell *et al*[18] with minor modifications. As illustrated in fig 1, the custom made device is a box with a movable platform that rotates about a single axis in two directions. With the foot resting on this platform, plantar dorsiflexion of ankle movements can occur. This platform is moved by an electric motor which rotates the foot on an axis at a rate of 0.4°/s. Movement can be stopped at any time by the use of a hand held switch. The angular displacement achieved by the platform is calculated by the dents that the motor rotates.

The device is also equipped with a hanging scale and a fixed pulley supported by a trestle, which is outside of the device. A thigh cuff attached to the lower end of the scale is wrapped around the lower thigh of the subject. By adjustment of the length of the cuff, the extremity is lifted by the scale, and its weight is recorded when the subject fully relaxes the thigh. The thigh cuff is then attached to one end of the rope around the pulley and the other end is hung with weights. The extremity can then be adjusted to where the foot is in contact with the platform. By adding or reducing the weights, the investigator can standardise the weight of the lower extremity resting on the platform during testing.

For data collection, each subject was seated on an adjustable chair and his or her dominant foot was placed on the platform so that the axis of the apparatus coincided with the plantar dorsiflexion axis of the ankle joint. The hip, knee, and ankle were positioned at 90°. To standardise the sensory cues from the contact between the instrument and the plantar surface of the foot, 50% of the lower extremity weight was rested on the platform by the use of the thigh cuff suspension system. During testing, subjects kept their eyes closed and wore headphones with music playing to eliminate visual and auditory stimuli from the testing apparatus.

Table 1 Characteristics of elderly tai chi practitioners (TC group), swimmers/runners (S/R group), and sedentary controls (Control group)

Group	Age (years)	Height (cm)	Weight (kg)
TC (n = 21, 12M, 9F)	66.1 (5.2)	163.6 (7.9)	64.8 (9.9)
S/R (n = 20, 12M, 8F)	65.4 (3.0)	164.1 (8.6)	66.5 (12.4)
Control (n = 27, 15M, 12F)	65.6 (3.9)	163.9 (7.8)	68.5 (10.9)

Values are mean (SD).
M, male; F, female.

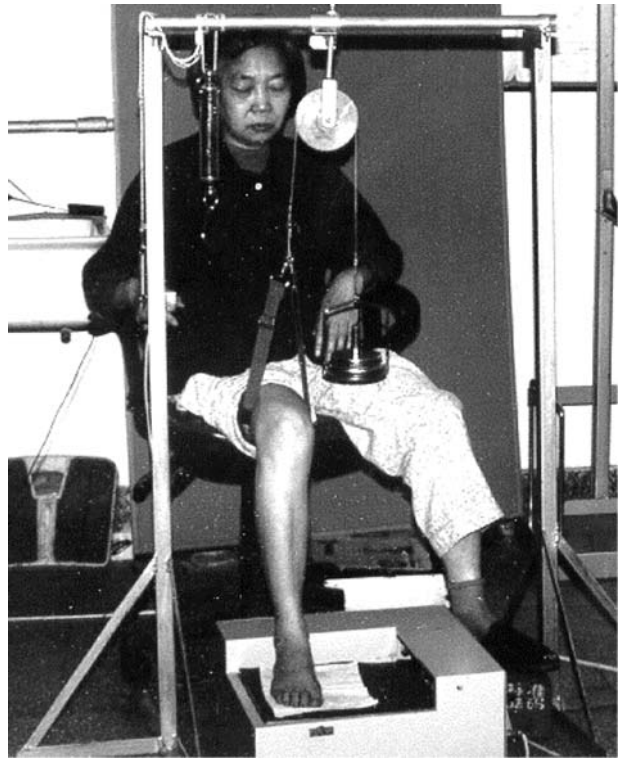

Figure 1 Testing apparatus and a subject positioned for evaluation of passive movement sense of ankle.

Each test movement began with the foot placed on the horizontal platform—that is, the starting position was 0°. The subjects were instructed to concentrate on their foot and to press the hand switch when they could sense motion and identify the direction of the movement. After two practice trials had been performed, the motor was engaged to rotate the foot into dorsiflexion or plantarflexion at a random time interval between two and ten seconds after subject instruction. The researcher recorded the rotation angles of the platform and the direction of movements as passive motion sense. At least six randomised trials were conducted: three for plantarflexion, three for dorsiflexion. The mean values of the three angles sensed in one direction were calculated.

Knee joint kinaesthesis test

The method of assessing knee kinaesthesis was similar to those described in previous studies.[7 19] As shown in fig 2, the apparatus consists of electric motor, governor, counter system, transmission, and linkage system. A moveable frame can rotate around a single axis in two directions at a velocity of 0.4°/s. Angular displacement of the frame is calculated by the dents that the motor rotates.

Each subject performed two practice tests to become familiar with the test process before completing the trials. At least six randomised trials (three trials for extension, three trials for flexion) were performed on the dominant leg according to the following protocol. The subjects wore shorts to negate any extraneous skin sensation from clothing at the knee area. They sat in an adjustable chair with legs hanging

Figure 2 Customised apparatus used to test passive motion sense of the knee joint.

freely over the edge of the seat 5 cm proximal to the popliteal fossa. A custom made inflatable cuff was fitted above the knee joint and inflated to 20 mm Hg to neutralise cutaneous sensation. The axis of rotation of the knee joint was aligned with the axis of rotation of the frame. Then the researcher placed the lower part of the shank of the subject on the frame. An ankle inflatable cuff was applied and inflated to 20 mm Hg to reduce multisensory afferent discharge at the shank-machine interface. To further reduce unwanted sensory input, the subjects kept their eyes closed and wore headphones with music playing to eliminate the sight and sound of the apparatus.

The starting position of each trial was 45° of knee flexion as measured by an electrogoniometer (Penny and Giles, Christchurch, Dorset, UK). Subjects were told that their legs could move in a flexed or extended direction beginning at a random delay of 2–10 seconds after the examiner signalled the start of the test. Once the subject detected motion of the leg, he or she pressed a hand held stop button and confirmed the direction of the motion. The rotation angles of the frame were defined as the threshold of detection for the knee joint. Mean values of three trials in one direction were used for analysis.

Data analysis

All variables are presented as mean (SD). Values for passive motion sense of ankle and knee joint in different directions were respectively compared using paired *t* test in each group. Because there were no significant differences between the directions of ankle movement, plantarflexion, and dorsiflexion, data were averaged to produce ankle kinaesthesis. One way analysis of variance was used to estimate significant differences among groups. Post hoc Scheffe tests were performed when necessary to isolate the differences, and $p \leqslant 0.05$ was considered significant.

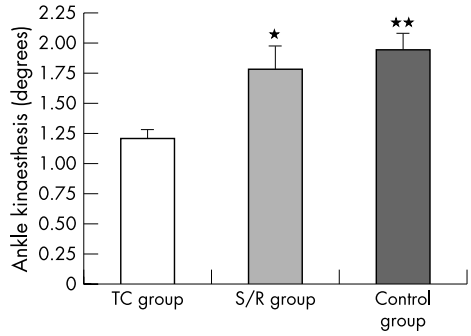

Figure 3 Comparison of ankle kinaesthesis in elderly tai chi practitioners (TC group), swimmers/runners (S/R group), and sedentary controls (Control group). Error bars indicate SEM. **p<0.01, *p<0.05 compared with the TC group.

RESULTS

Ankle joint kinaesthesis

Ankle joint kinaesthesis differed significantly among the three groups (p = 0.001). Movements of 1.21 (0.33)° were perceived in the TC group, 1.78 (0.82)° in the S/R group, and 1.95 (0.66)° in the sedentary control group. The post hoc test showed that the TC group could detect a significantly smaller amount of motion than the control group (p = 0.001) and S/R group (p = 0.022), while no significant difference was found between the S/R group and sedentary control group (p = 0.701) (fig 3).

Knee joint kinaesthesis

The threshold for detection of passive motion was significantly different in extension and flexion for each group; the knees were more sensitive to a flexion arc than to an extension arc. One way analysis of variance indicated significant differences in passive motion sense in knee flexion across the three groups (p = 0.025). Further analysis showed that the TC group had a significantly lower mean threshold for detection of passive motion than the subjects in the control group (p = 0.026). There were no significant differences between the S/R group and control group (p = 0.312), or between the TC group and S/R group (p = 0.533). For knee extension, no significant difference was found among the three groups (p = 0.597) (fig 4).

DISCUSSION

Although many studies have indicated that adoption of regular physical activity can attenuate the age related decline in many physiological systems, few have examined the effects of exercise on proprioception of old people, especially

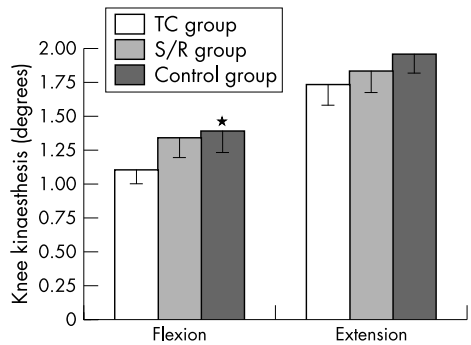

Figure 4 Comparison of knee kinaesthesis in elderly tai chi practitioners (TC group), swimmers/runners (S/R group), and sedentary controls (Control group). Error bars indicate SEM. *p<0.05 compared with the TC group.

the effects of different kinds of exercise. Our study shows that long term tai chi practitioners not only have better ankle and knee joint kinaesthesis than sedentary controls but also their ankle joint kinaesthesis is better than regular swimmers/runners. Furthermore, the latter did not perform any better in ankle and knee joint kinaesthesis tests than their sedentary counterparts.

The postural control system operates as a control circuit between the sensory sources, central nervous system, and the musculoskeletal system. Proprioceptors and visual and vestibular centres contribute afferent information to the central nervous system on body position and balance.[20] Colledge and his colleagues[21] studied the relative contributions to balance of vision, proprioception, and the vestibular system in different age groups. They found all age groups were more dependent on proprioception than on vision for the maintenance of balance. Camicioli *et al*[22] also showed that disruption of proprioceptive input was the most important determinant of quantitative balance performance in subjects older than 80 years. Thus proprioception may greatly influence postural stability, and a decline in proprioception with aging could be associated with the increased propensity of elderly people to fall.[8] The considerable benefits of tai chi exercise on proprioception may have significance for old people in maintaining balance.

Training has been widely reported to be one of the best ways to improve balance in the elderly.[23–25] However, different kinds of exercise have been shown to have different effects on balance. Gauchard *et al*[14] chose yoga and soft gymnastics as proprioceptive exercise, which consist of slow movements performed sequentially under different postural conditions; they compared the effects of proprioceptive exercise, bioenergetic physical activities (swimming, cycling, or jogging), and no exercise on postural control in elderly people. The results indicate that muscular strength was significantly increased in the bioenergetic exercise group, but proprioceptive exercise appeared to have the greatest effect on balance control. The authors pointed out that the ritual motions of tai chi are also proprioceptive exercise. From our results showing that elderly tai chi practitioners have improved proprioception, we suggest that maintaining, or delaying the decline, in proprioception is closely associated with tai chi exercise improving balance control in old people.

Tai chi exercise is a series of individual graceful movements in a slow, continuous, circular pattern. In performing tai chi, awareness of movement sequencing starts from the feet, ankles, and legs, and the strong thigh muscles are used to concentrate the movement through and around the turning of the hips and waist, with the latter acting as the axis around which all body movements are executed. The movements of tai chi are gracefully fluent and consummately precise because specificity of joint angles and body position is of critical importance in accurately and correctly performing each form.[16] Acute awareness of body position and movement is demanded by the nature of the activity. Thus it is logical that the practice of tai chi has benefits for proprioception, which is confirmed by our study.

Swimming and running are two of the most common exercises practiced by elderly people; they are excellent forms of aerobic exercise, and provide good training stimuli for cardiopulmonary function and muscle strength. Compared with tai chi, swimming and running involve cyclic repetitive actions. Awareness of joint position and movement is not emphasised during these exercise forms. In addition, most elderly people exercise only to enhance health and for recreation; they usually do not pay much attention to joint position and angles during exercise, unless such awareness is required in certain forms of exercise, such as tai chi. This may help to explain why the swimmers/runners did not have better scores for knee and ankle kinaesthesis in this study.

Take home message

The elderly people who regularly practiced tai chi not only showed better proprioception of the ankle and knee joints than sedentary controls, but also showed better ankle kinaesthesis than elderly regular swimmers/runners. The prominent benefits of tai chi exercise on proprioception may be helpful in maintaining balance control in the elderly.

It is of particular interest that the effects of tai chi on proprioception were different in the knee and ankle joints. The effect on ankle joint kinaesthesis was more prominent than on knee joint kinaesthesis. The passive motion sense of the ankle joint in the TC group was significantly better than in both the sedentary control group and the S/R group. However, for the knee joint, tai chi exercise only produced a better effect than in the sedentary control group. These results may be attributable to the characteristics of tai chi movements. The old tai chi proverb states, ''When performing tai chi, the feet act as roots''. Although almost all tai chi forms are performed in a semi-squat position, which enhances the loading of the muscles and motion ranges of the knee joints, the continuous transformation of different postures and steps cause more changes in ankle joint movements, such as turning the toes outward or inward and raising or lowering the toes. Moreover, while making a stride, foot placement is slow and deliberate. These movements may help to retain the sensitivity of proprioceptors located in the joint capsules, ligaments, tendons, and muscles.

Ankle proprioception is very important for the elderly to maintain proper postural control. Many studies have indicated that the movement pattern for postural correction in elderly adults is different from that of young adults. The elderly rely more on hip movements, while young people rely on ankle movements to control postural stability.[26] A decline in somatosensory information from the feet is a major factor in this pattern change with age.[27] Therefore the considerable impact of tai chi practice on ankle proprioception is of great benefit in the retention of balance control in old people.

The decline in proprioception with age may be an important contributing factor to falls in the elderly, and this may be influenced by regular physical activity. This study shows that, compared with other common activities, long term tai chi exercise may have more benefit in retaining proprioception of the ankle and knee joints, which may be valuable for maintaining balance control in the elderly.

ACKNOWLEDGEMENTS

This work was fully supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region (project no CUHK4360/00H).

Authors' affiliations

D Xu, Y Hong, J Li, Department of Sports Science and Physical Education, The Chinese University of Hong Kong
K Chan, Department of Orthopedics and Traumatology, The Chinese University of Hong Kong

REFERENCES

1 **Lai JS**, Lan C, Wong MK, *et al*. Two-year trends in cardiorespiratory function among older Tai Chi Chuan practitioners and sedentary subjects. *J Am Geriatr Soc* 1995;**44**:1222–7.

2 **Young DR**, Appel LJ, Jee SH, *et al*. The effects of aerobic exercise and T'ai Chi on blood pressure in older people: results of a randomized trial. *J Am Geriatr Soc* 1999;**47**:277–84.
3 **Hong Y**, Li JX, Robinson PD. Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. *Br J Sports Med* 2000;**34**:29–34.
4 **Tse SK**, Bailey DM. T'ai chi and postural control in the well elderly. *Am J Occup Ther* 1992;**46**:295–300.
5 **Wolf SL**, Barnhart HX, Kutner NG, *et al*. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. *J Am Geriatr Soc* 1996;**44**:489–97.
6 **Lephart SM**, Pincivero DM, Giraldo JL, *et al*. The role of proprioception in the management and rehabilitation of athletic injuries. *Am J Sports Med* 1997;**25**:130–7.
7 **Pai YC**, Rymer WZ, Chang RW, *et al*. Effect of age and osteoarthritis on knee proprioception. *Arthritis Rheum* 1997;**40**:2260–5.
8 **Petrella RJ**, Lattanzio PJ, Nelson MG. Effect of age and activity on knee joint proprioception. *Am J Phys Med Rehab* 1997;**76**:235–41.
9 **Skinner HB**, Barrack RL, Cook SD. Age-related decline in proprioception. *Clin Orthop* 1984;**184**:208–11.
10 **Robbins S**, Waked E, McClaran J. Proprioception and stability: foot position awareness as a function of age and footwear. *Age Ageing* 1995;**24**:67–72.
11 **Mion LC**, Gregor S, Buettner M, *et al*. Falls in the rehabilitation setting: incidence and characteristics. *Rehabil Nurs* 1989;**14**:17–22.
12 **Lord SR**, Ward JA, Williams P, *et al*. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr* 1994;**42**:17–21.
13 **Lord SR**, Rogers MS, Howland A, *et al*. Lateral stability, sensorimotor function and falls in older people. *J Am Geriatr* 1999;**47**:1077–81.
14 **Gauchard GC**, Jeandel C, Tessier A, *et al*. Beneficial effect of proprioceptive physical activities on balance control in elderly human subjects. *Neurosci Lett* 1999;**273**:81–4.
15 **Irrgang JJ**, Neri R. The rationale for open and closed kinetic chain activities for restoration of proprioception and neuromuscular control following injury. In: Lephart SM, Fu FH, eds. *Proprioception and neuromuscular control in joint stability*. Champaign, IL: Human Kinetics, 2000:363–74.
16 **Jacobson BH**, Chen HC, Cashel C, *et al*. The effect of Tai Chi Chuan training on balance, kinesthetic sense, and strength. *Percept Mot Skills* 1997;**84**:27–33.
17 **Rozzi S**, Yuktanandana P, Pincivero D, *et al*. Role of fatigue on proprioception and neuromuscular control. In: Lephart SM, Fu FH, eds. *Proprioception and neuromuscular control in joint stability*. Champaign, IL: Human Kinetics, 2000:375–83.
18 **Lentell G**, Baas B, Lopez D, *et al*. The contributions of proprioceptive deficits, muscle function, and anatomic laxity to functional instability of the ankle. *J Orthop Sports Phys Ther* 1995;**21**:206–15.
19 **Beynnon BD**, Renstrom PA, Konradsen L, *et al*. Validation of techniques to measure knee proprioception. In: Lephart SM, Fu FH, eds. *Proprioception and neuromuscular control in joint stability*. Champaign, IL: Human Kinetics, 2000:127–38.
20 **Guyton AC**. *Textbook of medical physiology*. London: Saunders, 1991.
21 **Colledge NR**, Cantley P, Peaston I, *et al*. Ageing and balance: the measurement spontaneous sway by posturography. *Gerontology* 1994;**40**:273–8.
22 **Camicioli R**, Panzer VP, Kaye J. Balance in the healthy elderly: posturography and clinical assessment. *Arch Neurol* 1997;**54**:976–98.
23 **Buchner DM**, Cress ME, Lateur BJ, *et al*. The effect of strength and endurance training on gait, balance, fall risk, and health services use in community-living older adults. *J Gerontol* 1997;**52**:M218–24.
24 **Wolfson L**, Whipple R, Judge J, *et al*. Training balance and strength in the elderly to improve function. *J Am Geriatr Soc* 1993;**41**:341–3.
25 **Woollacott MH**, Moore S, Hu MH. Improvements in balance in the elderly through training in sensory organization abilities. In: Stelmach GE, Homberg V, eds. *Sensorimotor impairment in the elderly*. Boston: Kulwer Academic Publishers, 1993:377–92.
26 **Okada S**, Hirakawa K, Takada Y, *et al*. Age-related differences in postural control in humans in response to a sudden deceleration generated by postural disturbance. *Eur J Appl Physiol* 2001;**85**:10–18.
27 **Manchester D**, Woollacott M, Zederbauer-Hylton N, *et al*. Visual, vestibular and somatosensory contributions to balance control in the older adult. *J Gerontol* 1989;**44**:M118–27.