Effect of physical exercise and age on knee joint position sense

Fernando Ribeiro, José Oliveira

Abstract

This study aimed to test the hypotheses that knee position sense declines with age and that regular exercise can attenuate that decline. This cross-sectional study encompassed 69 older and 60 young adults divided in four groups (exercised-old, N = 31; non-exercised-old, N = 38; exercised-young, N = 35; non-exercised-young, N = 25) according to chronological age and exercise practice in the past year. Knee position sense was measured by open kinetic chain technique and active positioning and is reported as the absolute and relative angular error. Knee angles were determined by computer analysis of videotape images using the Ariel Performance Analysis System. Compared to their non-exercised counterparts, exercised-young and -old showed lower absolute and relative angular errors. The absolute (1.62 ± 0.71°) and relative errors (0.02 ± 1.65°) for exercised-young were lower than all other groups (p < 0.001). The absolute and relative errors of exercised-old (4.27 ± 2.49° and 5.51 ± 3.42°) were similar to non-exercised-young (4.74 ± 2.67° and 4.18 ± 3.40°). The non-exercised-old exhibited higher absolute (9.35 ± 4.34°) and relative errors (9.73 ± 5.15°) than all other groups (p < 0.001). The present data indicates that age has deleterious effects on knee position sense although regular exercise can attenuate that age-related decline.

1. Introduction

The aging process is accompanied by a decline in neuromuscular control, motor coordination, balance and consequently increasing the risk to falls (Shaffer and Harrison, 2007). The proprioceptive acuity is a central piece of the above-mentioned abilities. Proprioception is the afferent information to the central nervous system provided by specialized nerve-endings called mechanoreceptors that contributes to the conscious and unconscious sensation, automatic control of movement, posture, and balance. Regarding balance, proprioception is paramount to its sensory control (Ribeiro and Oliveira, 2007); for instance, the balance of old aged subjects relies more on proprioception than on vision (Colledge et al., 1994). In older adults, the decline in lower limb proprioception is of great concern since it has been related to balance deficits, which consequently increase the susceptibility to fall (Sorokon and Labiner, 1992; Lord et al., 1999). In addition, the decrease of joint proprioception could lead to abnormal joint biomechanics during functional activities which could lead to, over a period of time, degenerative joint disease (Skinner, 1993). Hence, it is important to develop and implement strategies to attenuate the age-related decline in proprioception. So far, the only strategy that seems to retain/regain joint proprioception in old age subjects is regular physical exercise. However, the beneficial effect of regular exercise on lower limb proprioception of older adults is not consensual (Tsang and Hui-Chan, 2003; Xu et al., 2004; Schmitt et al., 2005; Li et al., 2008). It seems that only the regular practice of forms of exercise emphasizing awareness of joint position and movement, such as tai chi, and not the most common exercises practiced in the Western society, such as swimming and running, improves proprioception. The purpose of the present study is to examine the effects of age and regular exercise on knee proprioception assessed through measurement of joint position sense.

2. Methods

2.1. Subjects

A total of 69 older male adults (mean age = 72.2 ± 5.0 years) and 60 young male adults (mean age = 20.6 ± 3.0 years) voluntarily participated in the present study. The older adults were noninstitutionalized, presented no sign of loss of autonomy, were independent in the daily living activities, and had to have chronological age ≥ 65 years. All subjects were healthy, with no known pathology of the central or peripheral nervous system, neuromuscular deficits, or degenerative joint diseases (e.g., osteoarthritis or rheumatoid arthritis), and none had had orthopedic disorders of the lower back.
or lower limbs during the preceding year. Normal knee range of motion was observed in all subjects.

Four groups were defined according to the chronological age and the practice of regular physical exercise in the past year. The characteristics of the groups are presented in Table 1. Exercised-old subjects were participants in organized exercise programs mainly composed by aerobic, flexibility and strength exercises. Exercised-young subjects practiced soccer or volleyball. To be admitted to one of these two exercised groups, a frequency of three times a week for at least 45–60 min must be achieved. Non-exercised-old and non-exercised-young subjects had not participated in any organized physical exercise programs, and they were not involved in any regular self-exercise activities in the past year. Within each age cohort, no significant difference was observed concerning mean age, weight, height and height.

The dominant lower limb was tested on all subjects. Leg dominance was established by asking the subject which leg they preferred to use to kick a ball. The subjects were familiarized with the experimental protocol and apparatus, and they provided written consent for participation. The experiment was approved by the local Ethics Committee, according to the Declaration of Helsinki.

### 2.2. Evaluation of joint position sense

Joint position sense, the ability to replicate a target joint position, was evaluated using an open kinetic chain technique and active knee positioning as previously described (Ribeiro et al., 2007, 2008). The subjects were seated in a comfortable position (with the hip at an angle of 80° of flexion), with the legs hanging freely, and blindfolded to block visual input. Four reflective markers were fixed with double-sided adhesive tape to the skin of the lateral thigh and leg: over the apex of the greater trochanter, iliotibial tract level with the over the apex of the greater trochanter, iliotibial tract level with the posterior crease of the knee when flexed to 80°, neck of the fibula, and prominence of the lateral malleolus. Then, passive positioning by the examiner was performed by extending the knee, at approximately 10°/s, from the starting position of 90° of flexion to a flexion angle between 40° and 60°. The subject maintained the position actively for 3 s without manual contact from the examiner in order to identify the test position. After that, the examiner replaced the leg to the starting position. The subject was then instructed (upon the command “reposition”) to actively reproduce the test position. The subject then returned to the position perceived as the test position and reported “target” to the examiner. This position was held for 3 s, and on the command “return” the subject returned to the initial position. One test position was examined. Each participant performed three consecutive trials trying to reproduce the test position to obtain a realistic sample of joint position sense accuracy and reliability for that test position. The test and the response positions were recorded with a video camera. The tripod-mounted video camera was positioned 5 m from the participant, at the same level of the knee joint, and then manually focused on the field of view. The camera was in the sagittal plane. The same video camera was used over the experimental period. Natural vertical and horizontal lines in the videotaped environment were aligned parallel to the horizontal and vertical edges of the viewfinder to minimize camera tilt. Knee angles were determined by computer analysis of the videotape images of the joint using the two-dimensional automatic digitizing module of the Ariel Performance Analysis System software (Ariel Dynamics, CA, USA). Each test or response position was determined as the average of seven consecutive knee angles digitized at 50 Hz from the videotape view of each position.

Knee joint position sense is reported as: the absolute angular error (defined as the absolute difference between the test position and the position reproduced by the subject), which represents accuracy without directional bias, and the relative angular error (the signed arithmetic difference between a test and response position), which represents accuracy with directional bias.

The reliability of the chosen method of measuring JPS was established in 10 subjects (age 21–26 years) tested on two sessions separated by 5 days. The results demonstrated good to excellent test–retest reliability with intraclass correlation coefficients = 0.92, ranging from 0.71 to 0.98.

### 2.3. Statistical analysis

All data were analyzed using SPSS version 16.0 (SPSS Inc., Chicago, IL) statistical software. Descriptive statistics were used to calculate the mean and standard deviation. One-way analysis of variance was performed to compare the mean values of age, weight, height, absolute angular error, and relative angular error for the four groups. Post hoc comparisons were performed with the Bonferroni test. Statistical significance was set at $\alpha = 0.05$ for all statistical comparisons.

### 3. Results

Mean performances from all three reposition trials of the testing session are shown in Table 1. Compared to their non-exercised counterparts, both exercised-young and -old subjects showed lower absolute and relative angular errors. The mean absolute and relative angular errors for exercised-young subjects were significantly lower than all other groups. In contrast, non-exercised-old subjects showed higher absolute and relative angular errors than the other three groups. Interestingly, the mean absolute and relative angular errors for the exercised-old group were not different from the group of non-exercised-young subjects. The relative error showed directional bias into the extension movement. With the exception of exercised-young group, in all the other groups there was a trend to overestimate the test position. The subjects showed a trend, significantly higher in the non-exercised-old group, to reproduce lower knee flexion angles than the pre-selected flexion angle determined by the examiner (Table 2).

### 4. Discussion

This study compared knee joint position sense between younger and older groups of exercised and non-exercised subjects.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Participant characteristics, mean ± S.D.</th>
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<tr>
<td><strong>N</strong></td>
<td><strong>Age (years)</strong></td>
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<td>Exercised-young</td>
<td>35</td>
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<tr>
<td>Non-exercised-young</td>
<td>25</td>
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<tr>
<td>Exercised-old</td>
<td>31</td>
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<tr>
<td>Non-exercised-old</td>
<td>38</td>
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### Table 2 | Comparisons of joint position sense values in the four groups, mean ± S.D. |
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<tbody>
<tr>
<td><strong>N</strong></td>
<td><strong>Absolute angular error (°)</strong></td>
<td><strong>Relative angular error (°)</strong></td>
<td></td>
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<tr>
<td></td>
<td><strong>Exercised-young</strong></td>
<td><strong>Non-exercised-young</strong></td>
<td><strong>Exercised-old</strong></td>
<td><strong>Non-exercised-old</strong></td>
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<tr>
<td>1.62 ± 0.71</td>
<td>4.74 ± 2.67*</td>
<td>4.47 ± 2.49*</td>
<td>9.35 ± 4.34*</td>
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<td>0.82 ± 1.65</td>
<td>4.18 ± 3.40*</td>
<td>5.51 ± 3.42*</td>
<td>9.73 ± 5.15*</td>
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* Significantly different from exercised-young ($p < 0.001$).
* Significantly different from non-exercised-young and exercised-old ($p < 0.001$).
The results of the present study point out (i) a significant deterioration in knee position sense with age and (ii) an attenuation of the age-related decline in knee position sense by regular physical exercise.

4.1. Knee position sense and age

Previous studies reported that aging is related to the decline of several aspects of proprioceptive sensitivity, namely the decrease of joint position sense and the increase of movement detection threshold. Collectively the studies that assessed knee proprioception, despite using different methodologies, found evidence to support the hypothesis that knee position sense declines with age (Pai et al., 1997; Petrella et al., 1997; Hurley et al., 1998). Our results are in agreement with the results of those studies, as our data indicates that the acuity of knee position sense is two times higher in young subjects comparatively to their old counterparts. Indeed, older adults showed a reduced ability to discriminate static knee angles combined with a larger variation in discriminative ability (Table 2).

Since proprioception involves peripheral and central components, the observed age-related deterioration in joint position sense may be elucidated by age-related changes in both central and peripheral components. The relative contribution of each component is not established. At peripheral level the aging process induces several modifications within articular, cutaneous and muscle receptors (for Ref.: Ribeiro and Oliveira, 2007). One should focus the rationalization in the muscle spindles modifications, as position sense acuity is, to a large extent, dependent upon muscle spindle activity (Prosk, 2005) and the reproduction tests used to assess joint position sense in our study were actively performed in the intermediate range of knee flexion where the input of muscle spindles is thought to be the major source mediating sense of knee position. Several studies had shown anatomical and physiological changes in muscle spindle with age, namely a decrease in the dynamic response of the muscle spindle primary afferents to ramp stretch (Miwa et al., 1995), a decrease in the total number of intrafusal muscle fibers and nuclear chain fibers per spindle, and an increase in spindle capsule thickness (Miwa et al., 1995; Liu et al., 2005). Additionally, aging leads to deficits in the processing of sensory input due to myelin abnormalities, axonal atrophy and declined nerve conduction velocity (Verdu et al., 2000).

The central component of proprioception, e.g. the integration of the sensory input, is also affect by the aging process. The conductive function of the central somatosensory pathways is impaired by the progressive loss of the dendrite system in the motor cortex (Scheibel et al., 1975; Nakamura et al., 1985), the decrease in the number of neurons and receptors, and the neurochemical modifications in the brain (Masliah et al., 1993; Pakkenberg and Gundersen, 1997; Strong, 1998). Additionally, the decrease in muscle spindle sensitivity can also result from supraspinally mediated changes in the gamma drive to the spindles themselves (Mynark and Koceja, 2001).

4.2. Effect of regular physical exercise on knee position sense

It is widely acknowledged that regular physical exercise promotes beneficial effects in many physiologic systems. Regarding proprioception our results support the valuable role of physical exercise performed on a regular basis in the attenuation of the age-related decline of knee position sense. Our results are in agreement with the conclusions drawn by Petrella et al. (1997), who reported better knee joint proprioception in exercised-old subjects than in non-exercised-old subjects, and in disagreement with the findings of Xu et al. (2004), who point towards that knee proprioception of older swimmers/runners is not different from their non-exercised counterparts and it is inferior than proprioception of tai chi practitioners. The present data suggests that “usual” exercise and not only exercise that puts a great emphasis on the awareness of joint position and direction, such as tai chi, is effective to preserve joint proprioception.

It is very important to note that the proprioceptive acuity of exercised-old subjects was identical to the non-exercised-young subjects and significantly superior to non-exercised-old subjects, suggesting that regular exercise may attenuate the age-related proprioceptive decline. Our data is similar to the results observed by Pickard et al. (2003) at the hip joint. The authors did not find significant differences in hip position sense between non-exercised-young subjects and exercised aged subjects.

Several mechanisms by which exercise ameliorates joint proprioception can be point towards based on the best evidence available. Since central and peripheral components of proprioception are implicated in the proprioceptive age-related decline, it is not surprising that they are also both involved in the improvement of proprioception observed in result of engagement in regular physical exercise.

At peripheral level exercise induces morphological adaptations in the muscle spindle. There are adaptations on a microlevel, the intrafusal muscle fibers could show some metabolic changes, and on a more macrolevel, the latency of the stretch reflex response decrease and the amplitude increase (Hutton and Atwater, 1992).

At central level, exercise can modify proprioception through the modulation of the muscle spindle gain and the induction of plastic modifications in the central nervous system. During physical exercise there is an increase in the muscle spindle output through the γ route, hence enhancing proprioception by facilitating its cortical projection. Thus, regular exercise can increase the muscle spindle output, which could induce plastic changes in the central nervous system, such as increased strength of synaptic connections and/or structural changes in the organization and numbers of connections among neurons (Ashton-Miller et al., 2001). The demands of regular exercise and more specifically regular and repetitive afferent inputs from the mechanoreceptors could be able to induce plastic changes in the cortex hence modifying the cortical maps of the body over time (increasing the cortical representation of the joints leading to enhanced joint proprioception) (Ashton-Miller et al., 2001).

5. Conclusions

The results from this study suggest that: (i) regular physical exercise has a positive impact on knee joint position sense both in younger and older subjects; (ii) age has a deleterious effect on knee position sense; and (iii) regular physical exercise can attenuate the age-related decline in knee position sense.

Conflict of interest statement

None.

References


