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Published in:
Somatosensory and Motor Research

DOI:
10.1080/08990220.2019.1684888

Somatosensory & Motor Research

ISSN: 0899-0220 (Print) 1369-1651 (Online) Journal homepage: https://www.tandfonline.com/loi/ismr20

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SOMATOSENSORY & MOTOR RESEARCH
2019, VOL. 36, NO. 4, 262–269
https://doi.org/10.1080/08990220.2019.1684888

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ARTICLE

Age-specific modifications in healthy adults' knee joint position sense

János Négyesi[a], Kata Galamb[b], Borbála Szilágyi[c], Ryoichi Nagatomi[a,d], Tibor Hortobágyi[e] and József Tihanyi[c]

[a]Department of Medicine and Science in Sports and Exercise, Tohoku University Graduate School of Medicine, Sendai, Japan; [b]Department of Movement, Human and Health Sciences, University of Rome, Rome, Italy; [c]Department of Biomechanics, Kinesiology and Informatics, University of Physical Education, Budapest, Hungary; [d]Division of Biomedical Engineering for Health & Welfare, Tohoku University Graduate School of Biomedical Engineering, Sendai, Japan; [e]Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, the Netherlands

ABSTRACT

Aim: Right-handed young adults perform target-matching tasks more accurately with the non-dominant (ND) compared to the dominant (D) limb, but it is unclear if age affects this disparity. We determined if age affects target-matching asymmetry in right-side dominant healthy adults.
Method: Young ($n = 12$, age: 23.6 y, 6 females) and older ($n = 12$; age: 75.1 y, 7 females) adults performed a passive joint position-matching task with the D and ND leg in a randomized order.
Result: Age affected absolute, constant, and variable knee JPS errors but, contrary to expectations, it did not affect target-matching asymmetries between the D and ND knees. However, older participants tended to underestimate while young subjects overestimated the target angles. Moreover, older as compared to young subjects performed the target-matching task with higher variability.
Conclusion: Altogether, age seems to affect passive knee target-matching behaviour in right-side dominant healthy adults. The present data indicate that healthy aging produces age-specific modifications in passive joint position sense.

Abbreviations: ANOVA: Analysis of variance; JPS: joint position sense; MMSE: Mini-mental state examination; SPPB: Short physical performance battery; SQUASH: Short questionnaire to assess health-enhancing physical activity

ARTICLE HISTORY
Received 22 August 2019
Accepted 22 October 2019

KEYWORDS
Aging; proprioception; asymmetry; position sense; knee

Introduction

Proprioception is the sensation of the static and dynamic position and motion of limbs, an ability that also contributes to joint stability (McCloskey 1978; Gandevia et al. 2002; Proske 2005; Chapman et al. 2009). Right-handed participants tend to perform proprioceptive target-matching tasks with greater accuracy when using the non-dominant left thumb (Roy and MacKenzie 1978; Nishizawa 1991), elbow (Kurian et al. 1989; Goble et al. 2006; Goble and Brown 2008) or multiple joints of the upper limb (ankle, knee, shoulder, finger) (Han et al. 2013) as compared to left-handed participants performing the same task with the non-dominant right hand. It is possible that right-handed healthy participants' kinaesthesia is associated with a network of active brain areas, i.e., motor areas, cerebellum, high-order somatosensory areas, providing evidence for a right hemisphere dominance for perception of limb movement (Naito et al. 2005).

This is in line with the observation that the non-preferred arm/hemisphere system is specialized for static limb position control, whereas the preferred arm/hemisphere system is responsible for dynamic limb trajectory control (Sainburg 2002, 2005). Nevertheless, this asymmetry appears to be selective for right-handers, but not for left-handers (Schmidt, Artinger, et al. 2013), suggesting that right hemisphere specialization underlies proprioceptive feedback (Naito et al. 2005; Goble and Brown 2007). On the other hand, in a few cases left-handed individuals also had smaller target-matching task errors when matching with the non-dominant compared to the dominant arm (Goble, Noble, et al. 2009), and some previous studies even failed to present target-matching asymmetry between upper limb joints on the right and left sides of the body probably due to the inconsistencies in experimental modalities (Roy and MacKenzie 1978; Bullock-Saxton et al. 2001; Naughton et al. 2002). It is however also possible that asymmetries in joint position sense (JPS) predominantly result from a difference in perception and/or reproduction between the sensory-motor systems of the two hemispheres (Adamo and Martin 2009).

Data for target-matching asymmetry between the dominant and non-dominant joints of the lower extremity are also controversial, so that some (Symes et al. 2010; Han et al. 2013) but not all studies (Bullock-Saxton et al. 2001; Galamb et al. 2018) found more accurate JPS in the non-dominant compared with the dominant knee joint in both older and young participants. The preponderance of studies measuring the differences in JPS between the dominant and non-dominant leg investigated the effect of external supports on proprioception (for review, see (Ghai et al. 2017)) and found

CONTACT János Négyesi negyesi@dc.tohoku.ac.jp Department of Medicine and Science in Sports and Exercise, Tohoku University Graduate School of Medicine, 2-1, Seiryo-machi, Aoba-ku, Sendai 980-8575, Japan

no differences between the dominant and non-dominant leg during the application (Ghai et al. 2018) or in the absence (Zhang et al. 2019) of a compression garment. Nevertheless, results from neuroanatomical studies also support the limb asymmetry-effects in knee JPS because while proximal muscles are innervated by both hemispheres, distal muscles are innervated predominantly by the contralateral hemisphere (Kuypers 1982; Müller et al. 1991). Therefore, proprioceptive asymmetry may be more likely to be evident in the distal than in the proximal joints (Roy and MacKenzie 1978; Scott and Loeb 1994).

Because of age-related declines in neuromuscular function, it is reasonable to expect that JPS declines with age even in the absence of disease (Ribeiro and Oliveira 2007). This is because there is a reduction in the number of motor neurons and functioning motor units (Campbell et al. 1973; Hunter et al. 2016) and the ability to control automatic movements also becomes impaired (Hortobágyi and DeVita 1999; Tirosh and Sparrow 2005; Wu and Hallett 2005). While early studies failed to demonstrate age-effects on JPS (Kokmen et al. 1978; Lovelace and Aikens 1990) recent studies (Adamo et al. 2007, 2009; Wright et al. 2011; Relph and Herrington 2016) reported age-related decreases in proprioception acuity and efficiency of feedback processing (Stelmach et al. 1988; Van Halewyck et al. 2015). Moreover, age did not affect the accuracy and precision of arm position sense (Schmidt, Depper, et al. 2013) most probably due to the different task demands (Cressman et al. 2010). The extent to which limb's JPS is influenced by aging depends on many aspects i.e., the tested joint/limb segment, active/passive task, type of analyzed error (for a review, see Goble, Coxon, et al. 2009) or task goal (Jones et al. 2012).

Although there is some evidence for an age-related decline in JPS, it remains unknown whether age affects target-matching asymmetries between the right-dominant and left non-dominant knee. Therefore, the purpose of the present study was to determine the effects of age on passive JPS in the right-dominant and left non-dominant knee. Based on the preponderance of studies showing that right-handed participants perform proprioceptive target-matching tasks with greater accuracy when using the left non-dominant limb, we hypothesized an age-related increase in the asymmetry in target-matching accuracy so that young compared with older participants would perform knee joint target-matching tasks more accurately with their left non-dominant leg as compare with the right-dominant leg. Voluntarily moving the leg (active repositioning) measures (1) movement and (2) stopping (position) of the leg, so that movement precedes the stopping action We were particularly interested in the effects of age on the ability to sense purely joint position per se without the added influence of voluntarily moving the limb on joint position. For this reason we used a passive JPS task.

Materials and methods

Participants

A sample size calculation (G*Power, version 3.1.7, Germany) (Faul et al. 2007) for knee position sense was based on our previous study (Galamb et al. 2018) which evaluated the effects of handedness on knee JPS in healthy participants using results from a study that used the exact same equipment and procedures as the present study. The power analysis for repeated measures analysis of variance (rANOVA) indicated the need for a total of 24 participants to detect changes in the measured variables, assuming type I error of 0.05 and power of 0.80.

Twenty-four right-side dominant healthy volunteers (young adults: $n = 12$; age = 23.6 ± 3.2 years; range 20–32, 6 females; older adults: $n = 12$; age = 75.1 ± 9.6 years; range 55–87, 7 females) participated in the study. All participants were right side-dominant, determined by hand and leg dominance questionnaires. Handedness was determined using the Edinburgh Handedness Inventory (Oldfield 1971). Leg dominance was determined by one- or two-foot item skill tests such as kicking a ball or stepping up on a chair (Spry et al. 1993). None of the participants had a history of or presented with neurological or orthopaedic disorders. To determine general cognitive function, and lower extremity function, each participant completed the mini-mental state examination (MMSE; young adults: 28.8 ± 1.3; older adults: 27.1 ± 1.4) and the short physical performance battery (SPPB young adults: 11.6 ± 0.5; older adults: 10.3 ± 1.6). After a verbal and written explanation of the experimental protocol, participants signed an informed consent that conformed to the Declaration of Helsinki and was approved by the local institutional Committee of Science and Research Ethics.

Experimental procedure

All participants visited the laboratory once. JPS, the perceived sense of knee joint position, and joint movement per se of the left and right leg was measured in a random order on an isokinetic dynamometer (HUMAC NORM, Computer Sports Medicine Inc., Stoughton, MA). Participants wore blindfolds and headphones emitting white noise to eliminate visual and auditory cues. Participants sat on the dynamometer seat in an upright position. One leg hung freely over the edge of the dynamometer seat and the other leg was attached to the dynamometer's lever arm. Based on the manufacturer's instructions, external straps were provided for optimal stabilization to avoid compensation at the lower extremities, pelvis, and trunk while the load cell ensemble was set perpendicular to the limb being tested. The centre of the knee joint was aligned with the dynamometer's head and the hip angle was kept constant (90° of hip flexion) during the measurement.

By moving the limb attached to the lever arm, we measured JPS passively (Galamb et al. 2018), using the experimental procedure of a previous study (Dieling et al. 2014). This method eliminates input from muscle contractions that could influence the perception of joint position. After one familiarization trial, we collected data in a random order at three target positions, i.e., 30°, 45°, and 60°. Each target angle was repeated five times. The initial starting position was 90° of knee flexion. Participants were instructed to focus on the position of the leg and then the leg was passively moved at

4°/s toward the target angle. The leg was held in this position for 5 s and then returned to the 90° starting position. After 5 s, the knee joint was passively extended again at 4°/s, and the participant was instructed to press the stop button as soon as the participant thought that the previously practiced target position was reached. To maintain attentional alert, after every 5 trials participants counted backwards by seven, starting from a two-digit number given by the experimenter.

JPS was evaluated using four types of error: (1) absolute error, i.e., the measure of the magnitude of the error, without directional bias; (2) relative error, i.e., % of error, considering the range of motion between the initial position and the target angle; (3) constant error, i.e., the measure of the deviation from the target with directional bias and (4) variable error, i.e., the measure of the consistency in performance, determined as the standard deviation from the mean of the constant errors. Although most of the previous studies have measured only absolute repositioning error (Bjorklund et al. 2003; Angyan et al. 2007; Van Tiggelen et al. 2008; Ghai et al. 2018), evaluating relative (Ribeiro et al. 2007, 2008), variable (Romero-Franco et al. 2017; Zhang et al. 2019) and constant (Worringham et al. 1987; Schmidt, Depper, et al. 2013) errors might provide a different information on the integrity of the sensorimotor system by reflecting how accurately the target is represented in the nervous system (Rossetti et al. 1994; Vafadar et al. 2015).

In the present study, any deviation from the target position, discounting direction, was defined as the absolute position error:

$$E_{\text{absolute}} = |X_{\text{participant}} - X_{\text{target}}| \tag{1}$$

The relative error was calculated as the % of absolute error, considering the range of motion between the initial position and the target angle:

$$E_{\text{relative}} = \left(E_{\text{absolute}}/\text{distance}_{\text{initial-target}}(^\circ)\right) * 100 \tag{2}$$

For constant error, the difference between reproduced and actual target angle was used, considering the direction of the error:

$$E_{\text{constant}} = (X_{\text{participant}} - X_{\text{target}}) \tag{3}$$

The variable error was calculated as the overall standard deviation (SD) of constant error from 15 trials, irrespective of the target range:

$$E_{\text{variable}} = \sqrt{\sum (X_{\text{participant}} - E_{\text{constant}})^2} \tag{4}$$

Statistical analyses

Statistical analyses were performed with SPSS 20 software (SPSS Inc, Chicago, IL, USA). All data were checked for normal distribution using the Shapiro–Wilk test. To examine the effect of age on three type (absolute, relative, constant) of repositioning error (the dependent measure), an age (young/older) × leg (dominant/non-dominant) × target angles (30°/45°/60°) rANOVA was conducted with repeated measures on the last two factors. Moreover, an age (young/older) × leg (dominant/non-dominant) rANOVA was performed to detect age-related changes in variable error (irrespective of the target range). When significant differences were detected, the multiple comparison post-hoc test (Bonferroni correction) was performed. Compound symmetry was evaluated with the Mauchly's test and the Greenhouse–Geisser correction was used when required. Additional post-hoc analyses (complementary one-way ANOVAs and paired sample *t*-tests) were used to determine where specific differences occurred. Cohen's effect size, d, was also computed as appropriate. Furthermore, effect sizes of the independent variables were expressed using partial eta squared ($\eta_p{}^2$) (Peat et al. 2008). Statistical significance was set at $p < 0.05$.

Results

A Shapiro–Wilk's test ($p > 0.05$) (Shapiro and Wilk 1965) and a visual inspection of their histograms, normal Q–Q plots and box plots revealed that the exam scores were approximately normally distributed in each age groups, leg and target angles.

Table 1 shows the descriptive data for each type of proprioceptive target-matching errors in each leg, target angles, and age group. A three-way rANOVA with age as a between subject variable and leg, and target angles as within subjects variables revealed a significant effect of age ($F_{1,22} = 8.5$, $p = 0.008$, $\eta_p{}^2 = 0.279$) but no overall effect of leg ($F_{1,22} = 0.2$, $p = 0.895$, $\eta_p{}^2 = 0.001$) or target angles ($F_{2,44} = 0.9$, $p = 0.410$,

Table 1. Effects of age on passive knee joint position sense in the right dominant and left non-dominant knee.

		Young	Older
Absolute JPS errors (°)	TA		
Overall*		3.7 (0.2)	4.6 (0.2)
Dominant	30°	3.9 (0.3)	4.9 (0.6)
	45°	3.9 (0.5)	3.2 (0.4)
	60°	3.9 (0.3)	5.0 (0.7)
Non-Dominant	30°	3.9 (0.3)	5.2 (0.5)
	45°	4.1 (0.6)	5.0 (0.5)
	60°	2.4 (0.3)	4.5 (0.7)
Relative JPS errors (%)	TA*		
Overall		9.1 (0.6)	10.9 (0.7)
Dominant	30°	8.9 (1.4)	9.5 (0.9)
	45°	8.7 (1.1)	7.1 (0.9)
	60°	11.8 (1.1)	13.2 (1.2)
Non-Dominant	30°	9.4 (2.0)	9.5 (0.5)
	45°	7.4 (0.7)	11.2 (1.1)
	60°	8.3 (1.5)	15.1 (2.9)
Constant JPS errors (°)	TA		
Overall*		2.1 (0.4)	−1.6 (0.5)
Dominant	30°	2.5 (1.2)	−0.9 (1.2)
	45°	3.0 (0.8)	−1.6 (1.4)
	60°	3.6 (0.3)	−3.1 (1.5)
Non-Dominant	30°	0.2 (0.7)	−0.8 (1.0)
	45°	2.4 (0.9)	0.0 (1.2)
	60°	0.8 (0.8)	−2.9 (1.4)
Variable JPS errors (°)			
Overall*		4.0 (0.2)	5.1 (0.3)
Dominant		3.9 (0.2)	4.9 (0.4)
Non-Dominant		4.2 (0.3)	5.2 (0.3)

Absolute, relative, constant and variable position errors in each group, leg and target angles.
JPS: joint position sense; TA: target angles.
*Significant group main effect ($p < 0.05$).

$\eta_p^2 = 0.040$) and no age group by leg ($F_{1,22} = 3.2$, $p = 0.085$, $\eta_p^2 = 0.129$) or age group by target angles ($F_{2,44} = 1.6$, $p = 0.206$, $\eta_p^2 = 0.069$) interactions for the mean absolute repositioning errors.

When analyzing relative JPS errors, no significant effect of age ($F_{1,22} = 3.8$, $p = 0.063$, $\eta_p^2 = 0.149$) or leg ($F_{1,22} = 0.2$, $p = 0.676$, $\eta_p^2 = 0.008$), but an overall effect of target angles ($F_{2,44} = 5.1$, $p = 0.012$, $\eta_p^2 = 0.190$) were found without the interaction with age ($F_{2,44} = 1.5$, $p = 0.232$, $\eta_p^2 = 0.065$) or leg ($F_{2,44} = 15.4$, $p = 0.963$, $\eta_p^2 = 0.390$). To further explore the significant effect of block on overall performance, planned Bonferroni *post-hoc* test was conducted and revealed lower relative JPS errors when matching 45° (8.6 ± 0.6%) as compared with 60° (12.1 ± 1%), irrespective of leg or age (Figure 1).

The analysis of the direction of error (constant error) revealed a significant effect of age ($F_{1,22} = 10.2$, $p = 0.004$, $\eta_p^2 = 0.317$, Figure 2) but no overall effect of leg ($F_{1,22} = 1.1$, $p = 0.305$, $\eta_p^2 = 0.048$) or target angles ($F_{2,44} = 2.4$, $p = 0.102$, $\eta_p^2 = 0.099$). Furthermore, age group by leg ($F_{1,22} = 4.4$, $p = 0.047$, $\eta_p^2 = 0.167$) and leg by target angles ($F_{2,\ 44} = 3.8$, $p = 0.031$, $\eta_p^2 = 0.148$) interactions were found. *Post hoc* analyses showed that although both young and older subjects performed target-matching task more accurately with their non-dominant leg, young adults tended to overestimate-, while older subjects tended to underestimate more with their dominant (3 ± 0.9°, −1.9 ± 0.9°, respectively) compared to their non-dominant knee joint (1.1 ± 0.9°, −1.2 ± 0.9°, respectively) (Figure 2).

Finally, a two-way rANOVA with age as a between subject variable and leg as a within subjects variable revealed a significant effect of age ($F_{1,22} = 8.0$, $p = 0.010$, $\eta_p^2 = 0.267$) but no overall effect of leg ($F_{1,22} = 1.9$, $p = 0.177$, $\eta_p^2 = 0.081$) and no age group by leg ($F_{1,22} = 0.008$, $p = 0.929$, $\eta_p^2 < 0.000$) interaction for the variable position errors. Older subject tended to perform the passive target-matching task with significantly larger variability (5.1 ± 0.3°) as compared with young adults (3 ± 0.9°).

Discussion

We determined the effects of age on passive knee JPS in the right-dominant and left non-dominant leg. We evaluated not only the absolute and relative but also the constant and

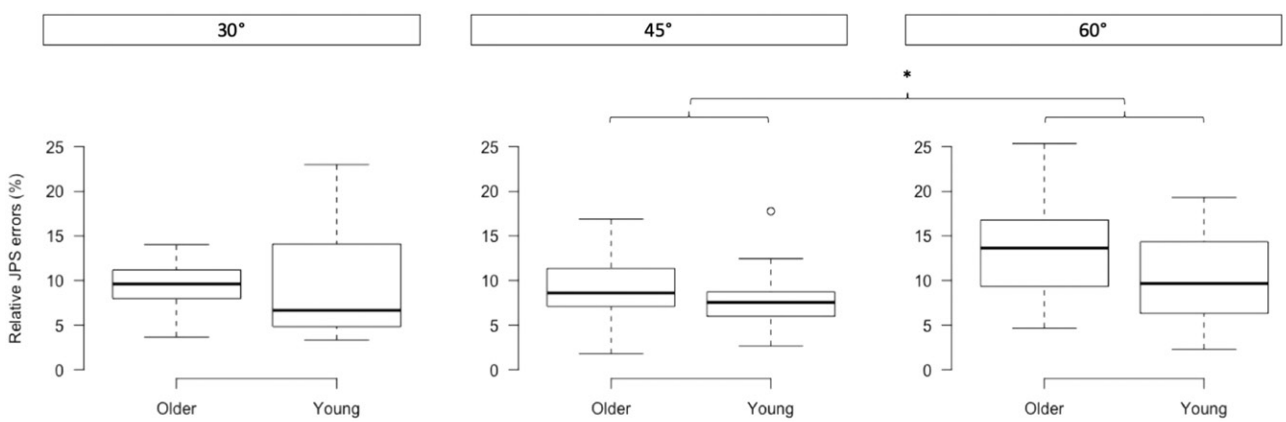

Figure 1. Relative joint position sense (JPS) errors for young and older adults in the right-dominant and the left non-dominant leg. The three target angles (30°, 45° and 60°) are shown next to each other. The boxplots show the median, the upper, and lower quartiles and the min and max value of the age groups. $^*p < 0.05$.

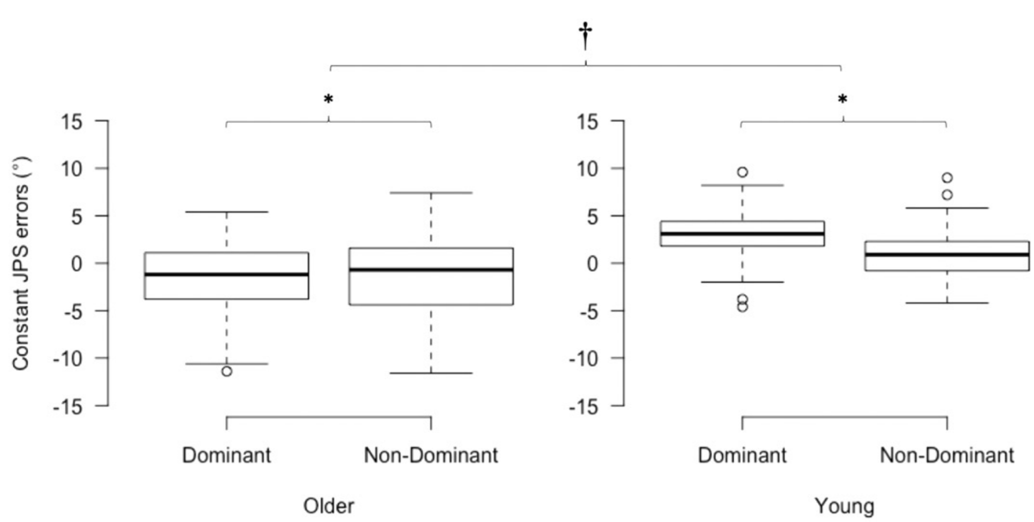

Figure 2. Constant JPS errors in young and older subjects' right-dominant and left non-dominant knee. There were a significant age group × leg (†). The boxplots show the median, the upper, and lower quartiles and the min and max value of the age groups. $^*p < 0.05$.

variable errors, making it possible to detect the direction and the variability of the errors, respectively. We found significant age-effect when analyzing absolute, constant, and variable errors. Both older and young subjects performed target-matching tasks more accurately with their non-dominant as compared to the non-dominant leg hence age did not affect JPS asymmetry between the two knees. However, in contrast to young participants' overestimation of the target angles, older adults tended to underestimate target angles more with their dominant compared to their non-dominant knee joint. Moreover, older subjects tended to perform the passive target-matching task with greater variability.

In line with the well-documented age-related deterioration in neuromuscular and central nervous system function (Campbell et al. 1973; Goble et al. 2012; Hunter et al. 2016) that could affect JPS, we also found an age-effect on proprioception as measured by a passive target-matching task (Table 1). The age-related increased deterioration on limb-target control may be explained by impaired proprioceptive acuity (Goble, Coxon, et al. 2009) and feedback processing efficiency (Stelmach et al. 1988; Van Halewyck et al. 2015). Nevertheless, results from some previous studies showed no age-effects on JPS (Pickard et al. 2003; Boisgontier et al. 2012). One reason for the inconsistent data among studies is the differences in the methods used to measure JPS. For example, low (3–5) trial numbers (Bullock-Saxton et al. 2001; Adamo et al. 2009) can reduce the sensitivity of the target-matching tests, therefore may be insufficient to determine parameters in proprioceptive tests (Ashton-Miller 2000). Another reason could be related to the excessive inter-subject variability in JPS (Adamo et al. 2007; Herter et al. 2014). Individual JPS values at the hip and knee joints can range from 0.6° up to 8.8° (Domingo and Lam 2014; Qaiser et al. 2016) making the detection of an age-effect inconsistent. Age, musculoskeletal dysfunctions, neurological impairments, and physical activity history can all affect JPS and increase between-subject variation (Hasan 1992). Although we also found considerable inter-subject variability in JPS (Figure 3), our data nonetheless yielded statistically significant age-effect on JPS by increasing the number of repetition in the trials and by assigning sufficient number of subjects compared with previous studies.

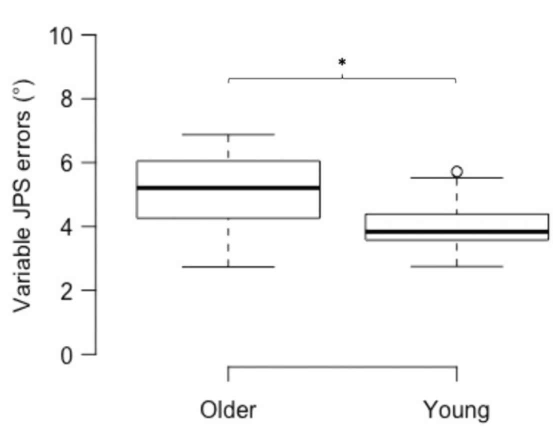

Figure 3. Variable JPS errors in young and older subjects. The boxplots show the median, the upper, and lower quartiles and the min and max value of the age groups. *Significant main effect of age ($p < 0.05$).

In agreement with some (Symes et al. 2010; Han et al. 2013) but not all studies (Bullock-Saxton et al. 2001; Galamb et al. 2018), our data show that target-matching is more accurate in the non-dominant compared with the dominant knee joint in both older and young participants (Figure 2). Neuroanatomical organization would also favour the limb asymmetry-effects in knee JPS because while proximal muscles are innervated by both hemispheres, distal muscles are innervated predominantly by the contralateral hemisphere (Kuypers 1982; Müller et al. 1991). Therefore, proprioceptive asymmetry may be more likely to be evident in the distal than in the proximal joints (Roy and MacKenzie 1978; Scott and Loeb 1994). As stated above, differences in methodology (e.g., number of testing trials, active vs. passive repositioning, degree of joint loading) among studies may contribute to the lack of asymmetry in proprioceptive matching tasks. Although both age groups performed target-matching task more accurately with their non-dominant leg, young adults tended to overestimate while older subjects tended to underestimate the target more with the dominant ($3 \pm 0.9°$, $-1.9 \pm 0.9°$, respectively) compared to their non-dominant leg ($1.1 \pm 0.9°$, $-1.2 \pm 0.9°$, respectively) (Figure 2). This somewhat unexpected result may be related to an age-related increase in the involvement of cortical and cognitive control of joint motions in general and JPS in particular (Piitulainen et al. 2018; Berghuis et al. 2019). Older adults even without overt cognitive and motor dysfunctions tend to execute the simplest motor tasks with overactivation of putative brain areas and activation of remote areas (Berghuis et al. 2019), leading to an altered JPS.

Movement variability is essential for flexibility and stability (Mathiassen et al. 2003). However, when increased beyond its optimal level, the neuromuscular system gets too noisy and less adaptable (Stergiou et al. 2006). On the other hand, when it is reduced below its optimal value, the individual cannot have all the beneficial effects of redundancy in the motor system (Madeleine et al. 2008). Therefore, each condition leads to an increased chance of injury. In the present study, we found that older subjects tended to perform the passive target-matching task with significantly higher variability. Although the age-differences in variable JPS errors were minimal (1–2°), the variability data may help us better understand how an increased variability in JPS by aging can increase the risk of musculoskeletal injuries during daily life or sport activities. To the best of our knowledge, our study is the first calculating variable knee JPS errors for different age groups, it is therefore difficult to judge if such age-differences in variable JPS errors may provide evidence for increased risk of musculoskeletal injuries.

Previously we reported that despite the randomization of the target positions, an increase in the range of motion increases the cognitive difficulty of the task, resulting in greater JPS errors in more extended knee joint positions (Negyesi et al. 2018). In contrast with the expectation, in the present study, we found that relative target matching errors were less at a more extended knee joint position, i.e., 45° ($8.6 \pm 0.6\%$) compared with 60° ($12.1 \pm 1\%$), irrespective of leg or age (Figure 1).

Age-related decline in proprioception of the lower extremity joints can modify gait (Nurse and Nigg 1999; Courtine et al. 2001). The data are inconsistent concerning the relationship between neural feedback and gait patterns in patients with sensory impairments as in some (Lin 2005) but not all cases (Okuda et al. 2006) there was an effect of JPS on gait. Furthermore, knee JPS was more accurate in stroke patients who had no history of falls or were one-time fallers compared with repeat fallers (Soyuer and Ozturk 2007). To the best of our knowledge, there is no data in the literature on the relationship between knee JPS and gait performance in healthy adults, however, results from clinical studies suggest a weak but significant correlation between gait patterns/falls and knee JPS error, placing our data into a functional perspective. Our data provide evidence for altered knee JPS through ageing reflecting age-specific adaptations in the neuromuscular system that may contribute to the altered gait patterns in the elderly.

In the current study, JPS was measured passively by moving the limb attached to the lever arm of the dynamometer. Although this method eliminates input from muscle contractions that could influence the perception of joint position, it may also contribute to the different target matching behaviour between young and older participants. MMSE scores (27.1 ± 1.4) suggest that older participants were cognitively healthy, however, is might be not sufficient enough to remove such confounding factors like reaction time and cognitive process that could impact JPS, as participants had to push a button while their knee was passively extended at 4°/s. Moreover, memory can be also a confounding factor and it is therefore impossible to detect if the age-related difference is due to proprioceptive differences or ability to remember (Boisgontier and Nougier 2013). A contralateral concurrent matching paradigm would therefore have been a better test for JPS in older individuals. This may explain part of the difference between young and adults, therefore we acknowledge it as a limitation of the study. Nevertheless, we found lower relative JPS errors when matching 45° (ROM: 45°) as compared with 60° (ROM: 30°), irrespective of leg or age.

In our previous studies (Galamb et al. 2018; Negyesi et al. 2018) we discussed that active vs. passive repositioning measurement paradigms are more suitable to assess JPS, due to the involvement of the fusimotor drive and muscle spindle feedback during an active movement (Zazulak et al. 2007). However, voluntarily moving the leg during active repositioning measures 1) movement and 2) stopping (position) of the leg, so that movement precedes the stopping action In this study, we were particularly interested in the effects of age on the ability to sense purely joint position per se without the added influence of voluntarily moving the limb on joint position, hence we used a passive JPS task. Nevertheless, future studies should use active repositioning measurements to measure proprioception and kinaesthetic movement reproduction without a potential bias of memory. Also, because it was shown that age-related declines in JPS ability cannot be clearly identified when the task is relatively simple, future studies may need to consider using more challenging dual-task paradigms. Finally, it is recommended to determine the effects of age on the functional relevance of JPS in walking, running, jumping, stair climbing and changing directions while ambulating.

The interpretations of our results are based on significant differences, nevertheless, differences in each type of JPS errors were minimal taking our data into consideration whether such minimal detectable differences have any physiological/functional importance. Because the magnitude of differences in JPS errors between groups and conditions of 1–3° we observe are similar to effects of 1–3° after the application of external supports (Tiggelen et al. 2008; Van Tiggelen et al. 2007; Ghai et al. 2018; Negyesi et al. 2018; Zhang et al. 2019), or other experimental manipulations (Galamb et al. 2018) or between different age groups (Relph and Herrington 2016), it is likely that our results are not due to measurement error.

Conclusion

Healthy aging produces age-specific modifications in JPS. Older as compared to young participants produced more knee JPS errors measured by passive repositioning, but target-matching asymmetry was not altered through ageing. However, while young adults tended to overestimate-, older subjects tended to underestimate more with their dominant compared to their non-dominant knee joint. Moreover, older subjects tended to perform the passive target-matching task with significantly greater variability. Finally, it is possible that age selectively affects JPS when the knee is more flexed. Future work will consider how age affects active JPS and its relationship with function such as walking speed, ability to change directions, and climb stairs.

Acknowledgements

The authors acknowledge that young participants' absolute JPS data was used in our previous manuscript (Galamb et al. 2018) that aimed to determine if side-dominance affects knee joint target-matching asymmetries between the dominant and non-dominant legs in healthy young participants.

Disclosure statement

All authors declare that they do not have any conflict of interest.

ORCID

János Négyesi http://orcid.org/0000-0001-5055-3242
Ryoichi Nagatomi http://orcid.org/0000-0003-3038-7202

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