JGG 2021;69:6-13
doi: 10.36150/2499-6564-399

The effects of aging on sensory parameters of the hand and wrist

Hasan Atacan Tonak[1], Hanifegul Taskiran[2], Z. Candan Algun[1]

[1] Institute of Health Sciences, Physiotherapy and Rehabilitation, Doctoral Program, Istanbul Medipol University, Istanbul, Turkey; [2] Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, Istanbul Aydin University, Istanbul, Turkey

Received: October 22, 2019
Accepted: November 2, 2020

Correspondence
Hasan Atacan Tonak
Istanbul Medipol University, Institute of Health Sciences, Physiotherapy and Rehabilitation Doctoral Program, Istanbul Medipol University Kavacik Campus Kavacik Mah. Ekinciler Cad. No. 19 Kavacik Kavsagi, 34810 Beykoz, Istanbul, Turkey. Tel.: +90 505 2782254. E-mail: atacantonak@akdeniz.edu.tr

Conflict of interest
The Authors declare no conflict of interest

How to cite this article: Tonak HA, Taskiran H, Algun ZC. The effects of aging on sensory parameters of the hand and wrist. Journal of Gerontology and Geriatrics 2021;69:6-13. https://doi.org/10.36150/2499-6564-399

Background & aims. It is generally accepted that there arises a decrease in sensory integrity with aging. Despite so much emphasis on the lower extremity, studies have not focused sufficiently on age-related sensory changes in the hands and wrists. The aim of our study is to evaluate the hand and wrist sensory parameters of young and geriatric people and to reveal the sensorial differences in young and geriatric hands.

Methods. 60 elderly and 60 young individuals were included in our study. The 3D Motion Sensor mOOver® was used to assess joint position sense. Baseline Pneumatic Bulb Dynamometer® device was used to assess the grip sensitivity. The hand pressure sensitivities was evaluated with Stabilizer Pressure Biofeedback®. The vibration senses, sensory threshold and two-point discrimination were evaluated.

Results. Joint position sense error rates of all movements of dominant and nondominant wrists and errors of grip and pressure sensitivity, sensory threshold and two points discrimination distance were found lower in youths (p = 0.000). Sense of vibration's duration was found higher in youths (p = 0.000).

Conclusions. Our results are of great importance in terms of demonstrating how aging affects sensory changes in the hand and wrist. Adequate and accurate assessment of the sensory parameters in the hand and wrist will be able to enable the accurate detection of pathologies that may be encountered in this region. This data will help professionals working in the fields of geriatric rehabilitation and hand rehabilitation to predict changes in sensory parameters and to design protective rehabilitation and treatment programs.

Key words: geriatrics, hand, proprioception, sensation, wrist

INTRODUCTION

The hand and wrist commonly use in our daily and occupational lives. With the combination of motor and sensory parameters of the hand and wrist, more effective movements come out in our daily living activities. In order to maintain their social lives and daily living activities, the hand and wrist senses are just as important for geriatric group as the young individuals. It is known that the sensory continuity of the hand and wrist is important in fulfilling the functions of the aging hand [1]. Although the effects of aging on dysfunctions of the hand and wrist of healthy elderly individuals are still not well understood, the hands undergo many physiological and anatomical changes associated with aging [2]. When the literature is examined, there are studies showing that the joint position sense [3,4], vibration [5], sensory threshold [6] and two-point discrimination [7] of the hand and the wrist are negatively affected as a result of the aging. However, no studies that show what an effect the senses of grip and pressure sensitivity, which are known to be a parameter of the proprioceptive sensation, healthy aging, have on the hand and the wrist have been encountered in the light of our current knowledge.

Disorder of the senses of hand and wrist, which have an important role in daily life activities, due to various reasons that arise with aging reduces the quality of life and independence of the geriatric population [8]. It is generally accepted that there arises a decrease in sensory integrity with aging. However, despite so much emphasis on the lower extremity, studies have not focused sufficiently on age-related sensory changes in the upper extremity, even in hands and wrists, and the effects of these changes [2,8]. No matter how important and different the characteristics of each part and all internal and external organs of the human body are, the hand and wrist have their own specific sensorial and motor characteristics [9]. Sensorial and functional development of the wrist, hand and fingers allows the individual to easily gain experience in the social environment. Meanwhile, it is also important in terms of self-care skills and academic developments of the individuals [10]. Just like the eyes, the hand is a very significant sensory organ allowing us to perceive our environment. Thanks to many sensory receptors found in the skin and deep tissues, the hand, which can be considered as an information organ, connects with the brain. These connection forms are extremely complex and detailed. The fact that more than 1/3 of the entire primary motor region of the brain belongs to the hand summarizes what a privileged organ the hand is [11]. The very complicated and coordinated functions of the hand require a rich source of motor and sensory innervation of the regional muscles, skin and joints [12]. There are big differences between different regions of the body in terms of density of the sensory receptors. However, the receptor density decreases with the advancing age [2,4].

Degenerations in the central and peripheral nervous system with aging influence the sensation of the hand and wrist [8]. Understanding the somatosensorial system of the hand and wrist is important for clinicians working in the field of geriatric rehabilitation and hand and upper extremity rehabilitation. Even though there are studies in the literature that aging affects the sensation of the hand and the wrist [3,4,6,7], in the light of our current knowledge, no studies in which the joint position sense, grip sensitivity, pressure sensitivity, vibration, sensory threshold and two-point discrimination sensations of the hand and the wrist in young and old people were evaluated together have been encountered. Therefore the aim of our study is to evaluate the hand and wrist sensory parameters of young and geriatric people and to reveal the sensorial differences in young and geriatric hands and wrists.

MATERIALS AND METHODS

The residents of Kadikoy Yasam Nursing Home in Maltepe district of Istanbul city, the geriatric individuals living in Maltepe district, the young individuals continuing the university education and the individuals living in Uskudar district and accepted to participate in the study were included in our study. The study included 60 geriatric individuals and 60 young individuals. Ethical approval for the study was obtained from the Non-Interventional Clinical Research Ethics Committee of Istanbul Medipol University (10840098-604.01.01-E.13018). Geriatric individuals, the results of whose routine examinations in retirement homes and family practice clinics indicated no pathology in the upper extremities, and young individuals, whose upper extremity muscle strength and normal joint motions were considered to be gross were invited to the study. Individuals who accepted the invitation were re-evaluated according to exclusion and inclusion criteria before they were included in the study and those who were not considered appropriate were excluded from the study. The study inclusion criteria for the cases were to be between 20 and 25 years of age and between 70 and 75 years of age, to have verbal communication ability to answer questions, to volunteer to participate in the study. The study exclusion criteria for the cases were to have a skin injury, an open wound posing a risk of infection, a posture problem in the upper extremity, a rheumatic disease, a neurological disease, an orthopaedic problem in the hand and wrist and to have a severe mental and cognitive problem. Information was given about the study to the 120 individuals who were deemed appropriate and agreed to participate in the study and they were asked to sign the informed consent form required by Istanbul Medipol University Non-Interventional Clinical Ethics Committee. All assessment were made by a same physiotherapist, in a well-ventilated the same physiotherapy and rehabilitation laboratory, at the same time interval (13:00-15:00), at the same room temperature and under the same lighting. The joint position sense (JPS) assessment was performed using the 3D Motion Sensor mOOver®. JPS assessment was performed all axes of movements of the wrist based on the principle of repeating the previously determined target angle with active movement. The target angles used for the assessment were determined to be 30° for flexion and extension, 10° for radial deviation and 15° for ulnar

Figure 1. 3D Motion Sensor mOOver®.

deviation. After positioning the wrist at the target angle prior to the measurement with the device's own software, which gives visual feedback, individuals were asked to keep this position in mind and then to put the wrist into the same position. The angles of participant's wrist position axes were noted and the absolute value of the difference between the target angle and position angle was recorded as the amount of "Joint Position Sense Error". Measurements were repeated three times for each movement and the arithmetic mean of three error values was recorded as the amount of wrist JPS error [13-15].

Baseline Pneumatic Bulb Dynamometer® (BPBD) device was used to assess the grip sensitivity. The maximum grip strength was measured with the BPBD device, after then 50% of the maximum grip strength was determined as the target force and participant was told to apply the target force by showing the indicator of the device and was asked to keep this force in mind and apply again. This time, participant again applied the target force without showing the indicator and the difference between the target force and the force applied by participant was recorded as the absolute value. Measurements were repeated three times and participant's "Grip Sensitivity Error" was noted by calculating the arithmetic mean of the error values [16-18].

Figure 2. Wrist radial and ulnar deviation joint position sense.

Stabilizer Pressure Biofeedback® (SBP) device was used to assess the pressure sensitivities of the participants' hands. The SBP device was first inflated up to 20 mmHg. The maximum pressure that could be applied on the pressure unit of the device by the palmar surface of the hand was measured. Half of the measured maximum pressure force was determined as the target pressure value and participant was asked to keep the target pressure value in mind by showing the manometer of the device. Participant, who kept this pressure in mind, was told that s/he would repeat the application. This time, participant was asked to apply the determined target pressure without showing the manometer and the absolute value of the difference between the target pressure and the pressure applied was noted. This application was done in the form of three repetitions and the arithmetic mean of the error values was calculated and recorded as "Hand Pressure Sensitivity Error" [19-21].

A 128 Hz diapason was used to assess the vibration on the head of ulna. Patient was asked to remain silent after feeling the vibration until finishing to feel it, and to tell when the sensation was over. The elapsed time was recorded in seconds [22,23]. The Semmes-Weinstein Monofilament Test (SWMT) was used to assess the sensory threshold [24]. The static two-point discrimination assessments were carried out from the distal ends of the all fingers by two point discriminator [25].

Statistical analysis

In the statistical analysis of data obtained in our study, Windows-based SPSS (IBM SPSS Statistics, Version 23.0, Armonk, NY, USA) package program was used. The sample size was calculated based on an observed effect size of d = 0.38 reported for the two point discrimination changes for age groups [7]. To achieve 80% power to detect a difference with 95% confidence using two tailed test, a sample size of 53 participants was required for each group [7]. "One-Sample Kolmogorov-Smirnov Test" was used to confirm the normal distribution compatibility of the data. Parametric tests were performed in the analysis since all data were normally distributed. Descriptive statistical information was demonstrated in

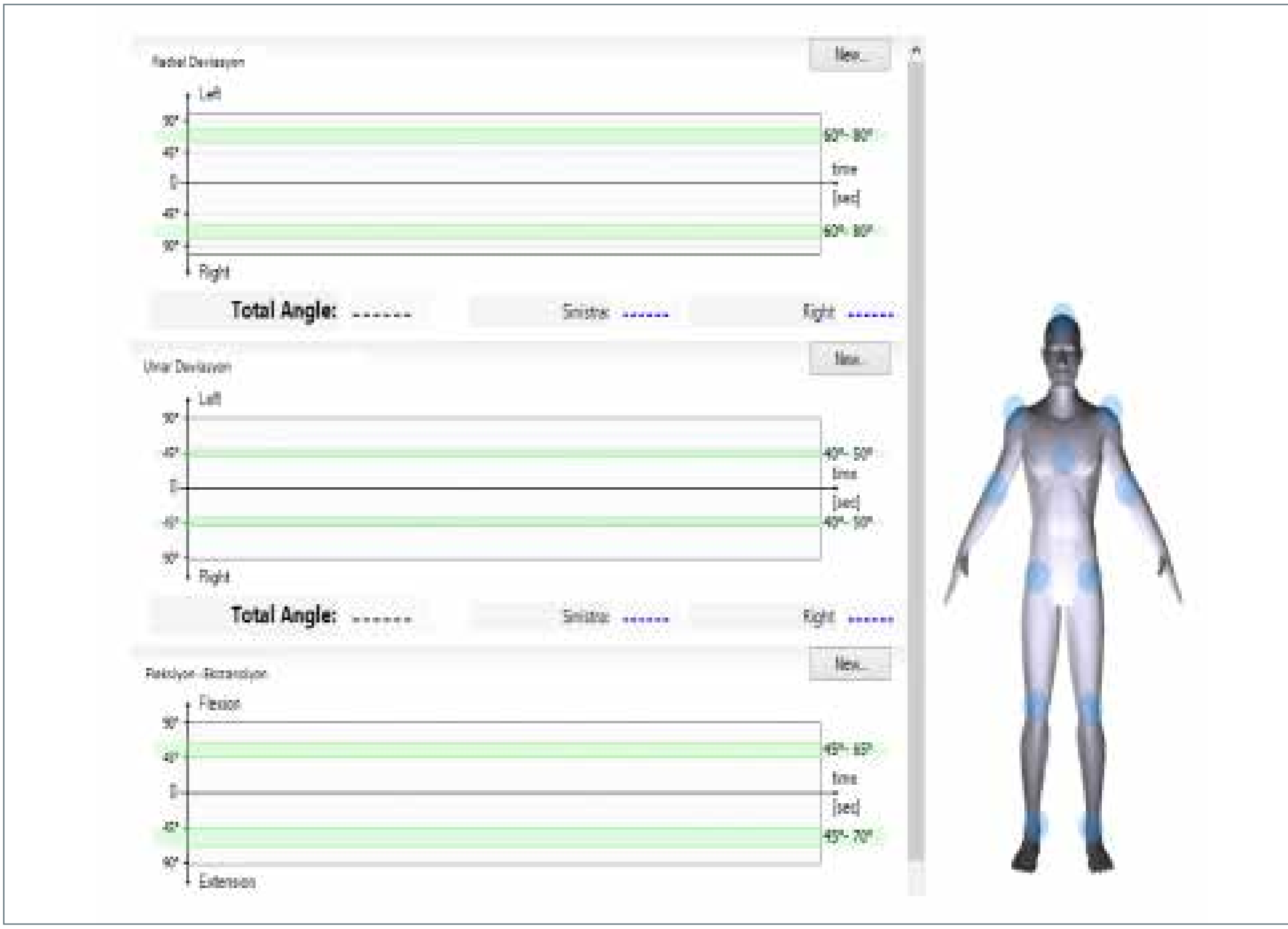

Figure 3. FreeSTEP software.

the form of mean ± standard deviation ($\bar{x}$ ± SD). Independent-Samples t Test was used in the comparisons of wrist joint position senses, grip and pressure sensitivities, sensory threshold and two-point discrimination and vibration durations according to age groups. The statistical significance level was accepted as $p < 0.05$.

RESULTS

60 young individuals (30 females, 30 males) whose ages ranged between 20 and 25 with a mean age of 21.61 ± 1.58 years and 60 geriatric individuals (30 females, 30 males) aged between 70 and 75 with a mean age of 71.68 ± 1.61 years, a total of 120 individuals participated in the study.

Results and comparisons of Joint Position Sense Assessment

A statistically significant difference was found between the young group and the geriatric group in terms of all directions of movement of the wrist ($p = 0.000$) (Tab. I).

Results and comparisons of Grip Sensitivity and Pressure Sensitivity Assessment

The error amounts of grip sensitivity and pressure sensitivity were found to be significantly lower in young individuals ($p = 0.000$) (Tab. II).

Results and comparisons of Vibration Sensation Assessment

There was a statistically significant difference in both the dominant extremity and the nondominant extremity when the young group and the geriatric group were assessed in terms of vibration sensation durations ($p = 0.000$) (Tab. II).

Results and comparisons of Sensory Threshold Assessment and Two Point Discrimination Assessment

There was a statistically significant difference between the young group and the geriatric group at the distal end of all fingers ($p = 0.000$) (Tab. III).

Table I. Comparisons of joint position sense error between the age groups.

	JPS	Young group $\bar{x} \pm SD$ $(^0)$	Geriatric group $\bar{x} \pm SD$ $(^0)$	p^a
Dominant extremity	Flexion	3.95 ± 1.52	5.91 ± 0.97	**.000**
	Extension	4.05 ± 1.64	6.05 ± 1.13	**.000**
	Radial deviation	2.48 ± 1.03	4.19 ± 0.79	**.000**
	Ulnar deviation	2.69 ± 1.05	4.49 ± 0.86	**.000**
Nondominant extremity	Flexion	4.88 ± 2.10	6.92 ± .095	**.000**
	Extension	4.69 ± 1.75	6.90 ± 1.10	**.000**
	Radial deviation	3.27 ± 1.22	5.13 ± .088	**.000**
	Ulnar deviation	3.50 ± 1.13	5.42 ± 1.07	**.000**

$p < 0.05$; p^a: independent-samples t-Test; JPS: joint position sense; ^{0}: degree

Table II. Comparisons of grip, pressure sensitivity errors and vibration sensation duration between the age groups.

Variables	Young group	Geriatric group	p^a
Grip densitivity	**$\bar{x} \pm SD$ (psi)**	**$\bar{x} \pm SD$ (psi)**	
Dominant extremity	1.98 ± 1.49	8.22 ± 3.21	**.000**
Nondominant extremity	2.80 ± 1.65	10.81 ± 4.72	**.000**
Pressure sensitivity	**$\bar{x} \pm SD$ (mmHg)**	**$\bar{x} \pm SD$ (mmHg)**	
Dominant extremity	3.88 ± 3.08	11.46 ± 3.37	**.000**
Nondominant extremity	6.13 ± 3.13	14.76 ± 4.17	**.000**
Vibration sensation	**$\bar{x} \pm SD$ (sec)**	**$\bar{x} \pm SD$ (sec)**	
Dominant extremity	11.96 ± 2.62	8.21 ± 1.27	**.000**
Nondominant extremity	8.51 ± 2.36	6.87 ± 1.52	**.000**

$p < 0.05$; p^a: independent-samples t-Test; psi: pounds per square inch; sec: second

Table III. Comparisons of sensory threshold and two point discrimination between the age groups.

		Sensory threshold			Two point discrimination		
	Fingers	Young group $\bar{x} \pm SD$ (gr)	Geriatric group $\bar{x} \pm SD$ (gr)	p^a	Young group $\bar{x} \pm SD$ (mm)	Geriatric group $\bar{x} \pm SD$ (mm)	p^a
Dominant extremity	1. Finger	0.23 ± 0.60	3.48 ± 1.00	**.000**	3.30 ± 0.53	6.35 ± 0.89	**.000**
	2. Finger	0.09 ± 0.08	3.48 ± 1.00	**.000**	3.25 ± 0.47	6.35 ± 0.89	**.000**
	3. Finger	0.10 ± 0.10	3.48 ± 1.00	**.000**	3.45 ± 0.59	6.35 ± 0.89	**.000**
	4. Finger	0.11 ± 0.10	3.48 ± 1.00	**.000**	3.61 ± 0.71	6.36 ± 0.91	**.000**
	5. Finger	0.11 ± 0.11	3.48 ± 1.00	**.000**	3.63 ± 0.71	6.36 ± 0.91	**.000**
Nondominant extremity	1. Finger	0.11 ± 0.11	3.74 ± 0.85	**.000**	3.61 ± 0.69	7.20 ± 0.83	**.000**
	2. Finger	0.11 ± 0.11	3.74 ± 0.85	**.000**	3.60 ± 0.66	7.20 ± 0.83	**.000**
	3. Finger	0.11 ± 0.12	3.74 ± 0.85	**.000**	3.78 ± 0.82	7.20 ± 0.83	**.000**
	4. Finger	0.13 ± 0.13	3.74 ± 0.85	**.000**	3.85 ± 0.87	7.21 ± 0.82	**.000**
	5. Finger	0.13 ± 0.13	3.74 ± 0.85	**.000**	3.85 ± 0.86	7.23 ± 0.83	**.000**

$p < 0.05$; p^a: independent-samples t-Test

DISCUSSION

Although studies [26-31] on sensory parameters in the literature have been commonly conducted in areas such as knee, ankle, shoulder and spine, it was found that the number of studies on the hand and wrist was limited. A study investigated the age-related changes occurring in the joint position sense of the human hand in 2012 revealed that aging affected the joint position sense negatively [4]. It has been shown that JPS decreases with aging due to the changes in the muscle spindle function [32]. Additionally, with the advancing age, a decrease is observed in JPS as a result of myelin abnormalities, axonal atrophy, and decrease in nerve conduction speed as well as the decrease in the sensory input processing and neuromuscular performance [33]. When examined at

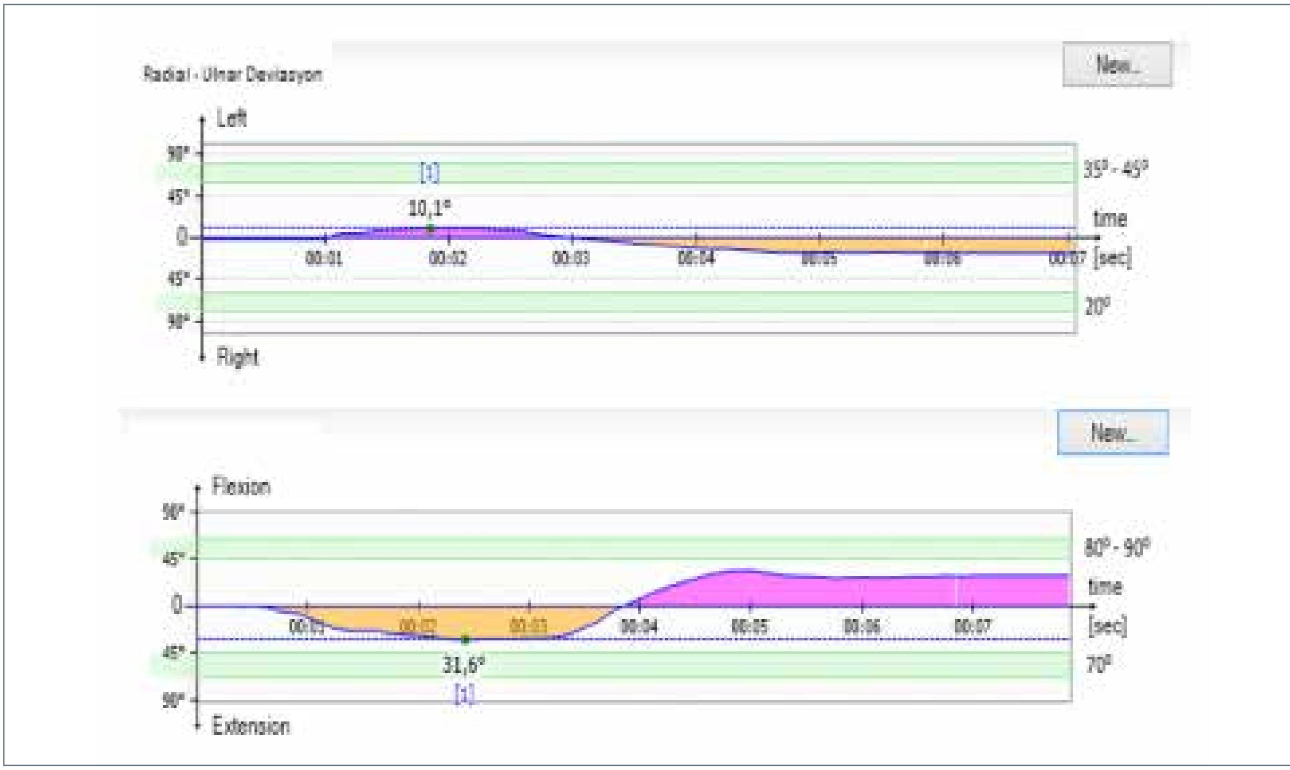

Figure 4. JPS evaluation in FreeSTEP software.

a central level, there are studies showing that the somatosensory system is negatively affected by normal aging [34,35]. Aging causes JPS to be affected negatively by leading to gradual reduction of the dendrites in motor cortex [32], losses in the number of neurons and receptors and neurochemical changes in the brain [32,36]. As seen in the literature, it can be concluded that JPS, which is assumed to be one of the significant parameters of proprioceptive sensation [35], decreases as a result of age-dependent changes in the central and peripheral nervous system [29]. Our results that negatively affects JPS supports the literature. It may be considered that age-related negatively affected joint position sense, which is one of the most important parameters of the proprioceptive sense, will lead to a reduction in the functionality of the hand and wrist, and will lead individuals to have difficulties in their daily living activities.

It was seen that there were not many studies in the literature on hand pressure sensitivity and grip sensitivity assessments [19,26]. An article investigated the Parkinson's disease-related pressure sensitivity sense, pressure sensitivities in different regions of the body were investigated and statistically negative differences were found in the pressure sensitivities of 11 different body points of 29 patients diagnosed with Parkinson's disease [37]. A study conducted by Ünver in 2017 investigated the changes in the sole pressure distribution of healthy elderly and young individuals, and emphasized that the sole pressure distributions in the elderly individuals were affected negatively, and that this resulted in falls [38]. Despite the fact that the change in pressure sensitivities in different regions of the human body has been demonstrated to lead to negative results by these two studies, it is interesting that there was no study investigating the hand-related pressure sensitivity which is very important in terms of upper extremity functionality. The grip and hand pressure sensitivity is considered as a component of the proprioception [16,17]. If we consider that pressure sensitivity is a parameter of proprioceptive sense, it can be used quickly and reliably by physiotherapists to evaluate proprioception in the hand and wrist.

Another technique that we investigated what kind of age-related change may occur in the hand and wrists is the assessment of vibration sensation. A study conducted by Özay et al. in 2012 argued that balance training provided to neuropathic patients due to type II diabetes has improved the vibration sensation and contributed to the gait [39]. A study of Akseki et al. conducted on patients with patellofemoral pain syndrome indicated that as the perception of joint position sense worsened, the duration of vibration sensation shortened [27]. These two studies have shown us that the vibration sensation had a very important role in measuring the proprioceptive sense and acquiring the functionality. The assessment of the vibration sensation can be used to determine the proprioceptive sensory loss and functional loss that may occur due to aging.

When we analysed the sensory threshold, the tactile sense threshold in all the fingers have increased in the negative direction with aging. It has been reported in the literature that SWMT, which is accepted as one of the most objective tests in the evaluation of tactile sensation, should detect 0.0677 grams monofilament as the normal sensory threshold value [24]. In our current study, the mean weight felt in all fingers of the dominant extremity of the geriatric individuals was 3.48 ± 1.00 grams, and the mean weight felt in all fingers of the non-dominant extremity was 3.74 ± 0.85 grams. This results are interpreted as "decreased protective sensation" and "loss of protective sensation" in respect of tactile sensation in both extremities. A study conducted by Bowden et al. in 2013 investigating the age-related changes in the cutaneous sense of the healthy human hand obtained similar results with our study [6]. The age-related negative affection of the sensory threshold may prove that the intensity of receptors required to perceive the tactile sense of the fingers, which is the distal region of the upper extremity, may reduce with aging, or that the perception power of tactile sensory receptors that will affect the daily life may naturally get weaker.

Another sensory parameter we have assessed in our study is the two-point discrimination. It was found in our study that the sense of static two-point discrimination was affected negatively in all fingers in both extremity depending on age. When the literature is reviewed, the most important classification used in the static two-point discrimination is the classification defined by the American Society of Hand Therapists [40]. According to this classification, it is defined as "normal" between 0-5 mm, "decreased" between 6-10 mm, and "anesthesia" for inability of detection [40]. According to the results, all the fingers had a "decreased" sense in our current study when the static two-point discrimination sensation values of dominant and nondominant extremities were examined. A study of Kaneko et al. included healthy participants aged between 20 and 79 years indicated that the static and moving two-point discrimination senses of participants above 60 years of age were affected negatively in the thumb and the little finger [7]. It may be considered that receptors perceiving the two-point discrimination are stimulated by proprioceptive exercises since it is transmitted to the upper centers through proprioceptive pathways, and that the sense of two-point discrimination can also be improved in the geriatric hand.

Limitations

The method of movement repetition, which was measured the joint position sense, grip and pressure sensitivity; it could be considered as one of the limitations of our study because it was influenced by many factors such as intellectual level, memory ability and learning.

Our results are of great importance in terms of demonstrating how healthy aging affects sensory changes in the hand and wrist. In our study, key evidence on many aspects of the hand and wrist sensory parameters has been provided for clinicians, working in the fields of geriatric rehabilitation and hand rehabilitation. This data will also help predict changes in sensory parameters that may occur in hand and wrist with aging and to design protective rehabilitation studies and treatment programs.

References

1 Kalisch T, Wilimzig C, Kleibel N, et al. Age-related attenuation of dominant hand superiority. PloS one 2006;1:e90. https://doi.org/10.1371/journal.pone.0000090

2 Carmeli E, Patish H, Coleman R. The aging hand. J Gerontol A Biol Sci Med Sci 2003;58:146-52.

3 Van de Winckel A, Tseng YT, Chantigian D, et al. Age-related decline of wrist position sense and its relationship to specific physical training. Front Hum Neurosci 2017;11:570. https://doi.org/10.3389/fnhum.2017.00570

4 Kalisch T, Kattenstroth JC, Kowalewski R, et al. Age-related changes in the joint position sense of the human hand. Clin Interv Aging 2012;7:499-507. https://doi.org/10.2147/CIA.S37573

5 Buchman AS, Wilson RS, Leurgans S, et al. Vibratory thresholds and mobility in older persons. Muscle Nerve 2009;39:754-60. https://doi.org/10.1002/mus.21263

6 Bowden JL, McNulty PA. Age-related changes in cutaneous sensation in the healthy human hand. Age 2013;35:1077-89. https://doi.org/10.1007/s11357-012-9429-3

7 Kaneko A, Asai N, Kanda T. The influence of age on pressure perception of static and moving two-point discrimination in normal subjects. J Hand Ther 2005;18:421-4, quiz 5. https://doi.org/10.1197/j.jht.2005.09.010

8 Incel NA, Sezgin M, As I, et al. The geriatric hand: correlation of hand-muscle function and activity restriction in elderly. Int J Rehabil Res 2009;32:213-8. https://doi.org/10.1097/mrr.0b013e3283298226

9 Neumann DA. Kinesiology of the musculoskeletal system: foundations for rehabilitation. 2nd Ed. USA: Mosby 2011.

10 Vieira AI, Nogueira D, de Azevedo Reis E, et al. Hand tactile discrimination, social touch and frailty criteria in elderly people: a cross sectional observational study. Arch Gerontol Geriatr 2016;66:73-81. https://doi.org/10.1016/j.archger.2016.04.012

11 Kandel ER, Schwartz JH, Jessell TM, et al. Principles of neural science. 5th Ed. USA: McGraw Hill Medical 2013.

12 Krampe RT. Aging, expertise and fine motor movement. Neurosci Biobehav Rev 2002;26:769-76. https://doi.org/10.1016/s0149-7634(02)00064-7

13 Yang Z, Lim PPH, Teo SH, et al. Association of wrist and forearm range of motion measures with self-reported functional scores amongst patients with distal radius fractures: a longitudinal study. BMC Musculoskelet Disord 2018;19:142. https://doi.org/10.1186/s12891-018-2065-z

14 Fasold O, Heinau J, Trenner MU, et al. Proprioceptive head posture-related processing in human polysensory cortical areas. Neuroimage 2008;40:1232-42. https://doi.org/10.1016/j.neuroimage.2007.12.060

15 Pilbeam C, Hood-Moore V. Test–retest reliability of wrist joint position sense in healthy adults in a clinical setting.Hand Ther 2018;23:100-9. https://doi.org/10.1177/1758998318770227

16 Strutton PH, Catley M, Davey NJ. Stability of corticospinal excitability and grip force in intrinsic hand muscles in man over a 24-h period. Physiol Behav 2003;79:679-82. https://doi.org/10.1016/s0031-9384(03)00170-7

17 Chang HY, Chou KY, Lin JJ, et al. Immediate effect of forearm Kinesio taping on maximal grip strength and force sense in healthy collegiate athletes. Phys Ther Sport 2010;11:122-7. https://doi.org/10.1016/j.ptsp.2010.06.007

18 Hosseini SM, Salehi Dehno N, Rezaiian F, et al. Effect of kinesio taping direction on force sense in wrist flexor muscles in healthy persons. Res Sports Med 2019;27:273-82. https://doi.org/10.1080/15438627.2018.1549552

19 Erdem EU. The comparative study on efficiency of different physiotherapeutic approaches in wrist proprioception. PhD Thesis, Hacettepe University 2013.

20 Kito T, Hashimoto T, Yoneda T, et al. Sensory processing during kinesthetic aftereffect following illusory hand movement elicited by tendon vibration. Brain Res 2006;1114:75-84. https://doi.org/10.1016/j.brainres.2006.07.062

21 de Paula Lima PO, de Oliveira RR, Costa LO, et al. Measurement properties of the pressure biofeedback unit in the evaluation of transversus abdominis muscle activity: a systematic review. Physiotherapy 2011;97:100-6. https://doi.org/10.1016/j.physio.2010.08.004

22 Öksüz Ç, Akel BS. Somatik duyular. In: Karaduman AA, Tunca Yılmaz Ö, Eds. Fizyoterapi ve rehabilitasyon. 1. 1 Ed. Ankara: Hipokrat Kitabevi 2016, pp. 299-312.

23 Temlett JA. An assessment of vibration threshold using a biothesiometer compared to a C128-Hz tuning fork. J Clin Neurosci 2009;16:1435-8. https://doi.org/10.1016/j.jocn.2009.03.010

24 Massy-Westropp N. The effects of normal human variability and hand activity on sensory testing with the full Semmes-Weinstein monofilaments kit. J Hand Ther 2002;15:48-52. https://doi.org/10.1053/hanthe.2002.v15.01548

25 Dellon AL, Mackinnon SE, Crosby PM. Reliability of two-point discrimination measurements. J Hand Surg Am 1987;12:693-6. https://doi.org/10.1016/s0363-5023(87)80049-7

26 Maenhout AG, Palmans T, De Muynck M, et al. The impact of rotator cuff tendinopathy on proprioception, measuring force sensation. J Shoulder Elbow Surg 2012;21:1080-6. https://doi.org/10.1016/j.jse.2011.07.006

27 Akseki D, Erduran M, Özarslan S, et al. Parallelism of vibration sense with proprioception sense in patients with patellofemoral pain syndrome: a pilot study. Eklem Hastalik Cerrahisi 2010;21:23-30.

28 Karagiannopoulos C, Watson J, Kahan S, et al. The effect of muscle fatigue on wrist joint position sense in healthy adults. J Hand Ther 2019. https://doi.org/10.1016/j.jht.2019.03.004

29 Sadeghi H, Hakim MN, Hamid TA, et al. The effect of exergaming on knee proprioception in older men: a randomized controlled trial. Arch Gerontol Geriatr 2017;69:144-50. https://doi.org/10.1016/j.archger.2016.11.009

30 Mohammadi R, Abdollahi Khorasgani M, Tabatabaei M, et al. Effects of elastic therapeutic taping on joint position sense of the ankle in stroke survivors. Am J Phys Med Rehabil 2019;98:830-4. https://doi.org/10.1097/phm.0000000000001191

31 Strimpakos N. The assessment of the cervical spine. Part 1: range of motion and proprioception. J Bodyw Mov Ther 2011;15:114-24. https://doi.org/10.1016/j.jbmt.2009.06.003

32 Ribeiro F, Oliveira J. Aging effects on joint proprioception: the role of physical activity in proprioception preservation. Eur Rev Aging Phys Act 2007;4:71-6. https://doi.org/10.1007/s11556-007-0026-x

33 Verdu E, Ceballos D, Vilches JJ, et al. Influence of aging on peripheral nerve function and regeneration. J Peripher Nerv Syst 2000;5:191-208. https://doi.org/10.1111/j.1529-8027.2000.00026.x

34 You SH. Joint position sense in elderly fallers: a preliminary investigation of the validity and reliability of the SENSERite measure. Arch Phys Med Rehabil 2005;86:346-52. https://doi.org/10.1016/j.apmr.2004.01.035

35 Negyesi J, Galamb K, Szilagyi B, et al. Age-specific modifications in healthy adults' knee joint position sense. Somatosens Mot Res 2019;36:262-9. https://doi.org/10.1080/08990220.2019.1684888

36 Strong R. Neurochemical changes in the aging human brain: implications for behavioral impairment and neurodegenerative disease. Geriatrics 1998;53(Suppl 1):S9-12.

37 Doty RL, Gandhi SS, Osman A, et al. Point pressure sensitivity in early stage Parkinson's disease. Physiol Behav 2015;138:21-7. https://doi.org/10.1016/j.physbeh.2014.09.015

38 Ünver B. Effects of plantar sensitivity and pressure distribution changes to balance and falling in elderly subjects. PhD Thesis, Hacettepe University 2017.

39 Özay Z, Malkoç M, Angın S, et al. Effect of balance training on postural stability and walking in type 2 diabetic neuropathy. Turk J Physiother Rehabil 2012;23:55-64.

40 Stone JH. Clinical assessment recommendations. 2nd Ed. USA: American Society of Hand Therapists 19