Age-related differences of extremity joint torque of healthy Japanese

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S. Hisamoto, M. Higuchi, N. Miura. Age-related differences of extremity joint torque of healthy Japanese. Gerontechnology 2005; 4(1): 27-45. Gravity-compensated extremity joint torque (EJT) values were measured in Japanese men and women without disabilities aged 20 to 79 years old to establish reference values for EJT according to age and to identify age-related differences in muscle strength. **Methods** 1008 subjects were recruited for this study. EJT values were obtained by isometric "make" tests in the sagittal plane with a hand-held dynamometer (HHD). **Results** On the whole, the peak age-related changes in each EJT value were in the 30 to 39, 40 to 49, and 50 to 59 years old age groups in both the men and the women. The results revealed significantly lower EJT values in women aged 20 to 29 than in women aged 40 to 49 and/or 50 to 59 ($p < 0.05$, Dunnett *t* test, SPSS for Windows) for five joint motions in the upper limbs, i.e., wrist palmar flexion, wrist dorsiflexion, elbow flexion, elbow extension, and shoulder extension, and lower values in the lower limbs, i.e., hip flexion than in women aged 50 to 59 and 60 to 69. However, the men aged 20 to 29 years old did not have any significantly lower EJT values than the older age groups of men. **Discussion** The results of this study show that younger Japanese women have less muscle strength than older Japanese women, and these results were supported by the age-related differences of grip strength and vertical jump values in the physical fitness standard database of Japanese. This phenomenon is supposed to be attributed to disuse and/or inactivity in Japanese younger women.

Keywords: aging, muscle strength, joint torque, disuse, fitness

Because muscle strength in the limbs has a great impact on activities of daily living (ADL), numerous studies have been carried out on muscle strength in the upper and lower limbs, and some have provided reference values across generations and gender[1-4]. Numerous studies have also been carried out on extremity joint torque (EJT)[5-9], because they are universal values unaffected by moment-arm length or the angle between the limb axis and the gravity axis, because they have a great impact on ADL, and because they are useful when designing a wide variety of products. However, to the authors' knowledge, few studies have provided EJT data for both the upper limbs and lower limbs and across generations and gender in Japan, and there is no open database for both upper-limb and lower-limb EJT values across ages and gender for healthy Japanese. Japan seems to have recently become an over-automated and excessively labor-saving society, and since recent younger generations do not seem to have liked to engage in physical work or strenuous sports, like mountain climbing, soccer, basketball, the muscle strength of the younger generations may have become weaker. The purpose of this study was to obtain EJT values to use as reference values for the muscle strength of healthy Japanese across generations and to identify age-related differences in muscle strength in Japan. The representativeness of the subjects of this study was verified by measuring their grip strength (GS) and vertical jump value (VJ) and comparing the data with the data in the physical fitness standard database (SDB)[10] for Japanese people. Annual measurements for the SDB in Japan have been made out by the MEXT (Ministry of Education, Culture, Sports, Science and Technology) since 1964. There are about 20 measurement parameters in the SDB, including body height and some body size, body weight, and 50-meter run, running long jump, grip strength, and vertical jump data. But the SDB has never included EJT measurements.

Methods

Subjects

1008 Japanese men and women aged 20 to 79 years old were recruited for this study including preliminary measurements. 355 Of them resided in Japan's second largest city, Osaka, and the others resided in 5 other large cities, i.e., Sendai, Tokyo, Kanazawa, Nagoya, Fukuoka, because the measurements were performed at six of the laboratories of the NITE (National Institute of Technology and Evaluation) and the laboratories are located in these six cities. The subjects aged 20 to 59 years old were volunteers and consisted of office workers, factory workers, housewives and students. The subjects aged 60 to 79 years old were paid to participate. None of the subjects were aware of having any neuromuscular, musculoskeletal, or cardiovascular disease. Based on the assumption that the older subjects would have a broader distribution of values, a large number of subjects aged 60 to 79 years old were enrolled. Informed consent was obtained from all subjects before starting the measurements.

Equipment

Characteristics of the subjects

Body height and weight were measured with an automatic digital height-weight measurement system (TBF-210PNS, Yagami Co., Nagoya, Japan). This system uses strain-gauge type road-cell in weight measurement. Accuracy of height value is 1 [mm] and accuracy of weight value is 0.1 [kg]. GS was measured with a digital grip-strength meter (ED-100PNS, Yagami Co., Nagoya, Japan). This system uses strain-gauge type road-cell and accuracy of GS value is 1 [N]. VJ values were measured with a digital vertical-jump measurement system (VT-150PNS, Yagami Co., Nagoya, Japan). Accuracy of VJ value is 1 [cm]. These measurement systems were accurately calibrated every six months.

Torque measurement

Although dynamometers, such as the Primus, Cybex, or Biodex, have been used extensively to make extremity torque measurements in rehabilitation research, their lack of portability, cost, and the stress they impose on subjects as a result of restricting their limbs were obstacles to making measurements in the approximately one thousand subjects, including older persons of this study. Therefore, we used a strain-gauge type compact force sensor (LPR-A-1KNS1, Kyowa Electronic Instruments Co., Tokyo) as a hand-held dynamometer (HHD) instead. Error of measured force value is less than 0.5 [%] of R.O. (rated output). This sensor was accurately calibrated every six months.

However, since whether the strength of

the examiner is sufficient to hold the HHD steady against the force exerted by the subject is important in hand-held dynamometry, preliminary measurements were made in order to confirm the reliability of HDD measurements in the upper limbs[11]. The sensor was attached to the measurement chair to make the lower-limb force measurements, because lower limb force values are high, and it is difficult for the examiner to hold the HHD steady. Signals from the force sensor were processed with a low-pass filter at a cutoff frequency of 20 Hz, and peak values were recorded. Moment-arm length was measured with an anthropometer, and torque values were calculated as the product of the force values and moment-arm values. The chair used was specially designed for making upper and lower limb joint torque measurements (Figure 1). The seat back can be slid along the side rail, and the angle of the seat back is adjustable. The multiple-use arm can be slid along the side rail, and the height of the multiple-use arm can be adjusted. The elbow-joint sustaining plate was attached at the top of the multiple-use arm for the elbow joint torque measurements. The HHD was attached at the bottom of the multiple-use arm for the knee joint and ankle joint torque measurements.

The statistical analysis was performed with SPSS for Windows.

Procedure
The measurements were made in 2001 to 2002 at six of the NITE laboratories. Since the laboratory needed to be comfortable and the atmosphere relaxed enough to prevent exposing the subjects to physical and psychological stress, the temperature and humidity in the laboratory were adjusted to a comfortable level for each subject, and background music was played. All of the measurements were made on the same day for each subject.

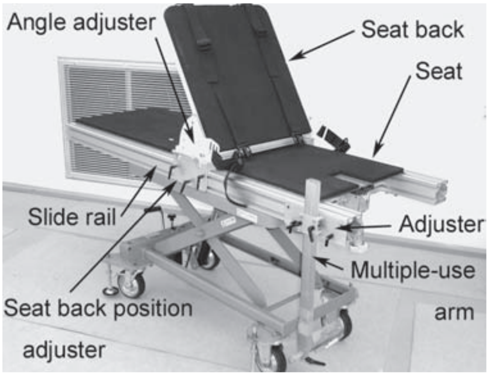

Figure 1. Measurement chair

Characteristics of the subjects
Before starting the measurements, the subject's blood pressure was measured in order to exclude the subjects with high blood pressure for the subject's safety, and the subject was then asked to answer the questions and an investigator filled out a questionnaire to determine the subject's work and leisure activity levels. GS measurements were made on the right and left side, two trials on each side. GS was measured in the standing position, and the subject was free to leave the opposite hand 'open' or to make a 'fist'. GS values were measured during maximal-effort contraction in expiration (maximal voluntary contractions in expiration: EMVC) in order to prevent strokes caused by sudden changes in blood pressure. VJ measurements were made by having the subject perform two trials.

Torque measurement
Torque measurements of the joints in each extremity were made on the subjects' right side by means of isometric "make" tests in the sagittal plane. After an explanation and a visual demonstration of how the muscle measurements are made, two trials were performed, and the values were averaged. Each trial consisted of a 4- to 6-second EMVC in order to prevent strokes caused by sudden changes in blood pressure. At least one minute of rest was allowed

between successive trials. An investigator asked the subjects if they were tired and the rest period was extended whenever the subjects said that they were tired.

Table 1 lists the postures and joint positions used in EJT measurements. Moment-arm lengths were measured from the axis of the HHD to each joint. The definitions of the "joints" were those specified by JIS Z 8500[12] i.e. wrist joint, elbow joint, shoulder joint, ankle joint, knee joint and hip joint. EJT was measured with the joint flexed at three angles to plot a torque-angle curve in EF, EE, SF, SE, KF, HF and HE, and at four angles to plot a torque-angle curve in KE. The three or four angles consisted of the approximate ends and midpoint of the range of motion (ROM) of the joint. EJT values were measured in 0° flexion in WP, WD, AP and AD. EJT values were calculated as the products of joint force values measured by HHD and the moment arm length measured with the anthropometer.

The torque data of each joint was gravity compensated using the body segment parameters (BSP) in each extremity, i.e. location of center of mass and body segment mass, except the wrist joint and the ankle joint. Errors of the BSP cause errors of the gravity compensation, and so an accurate BSP is needed. Commonly, the BSP obtained by the direct measurements on cadavers are more accurate than the data obtained by the indirect measurements on living subjects, or data obtained by mathematical modeling. But there is no BSP of Japanese obtained by the direct measurements, and so Dempster's BSP[13,14] was used in this study because Dempster's BSP has been obtained by direct measurements on cadavers.

The wrist and the ankle joint torque data were gravity compensated by the segment weight values of each subject's extremity with the subject relaxed, because these two joints are greatly affected not only by the weight of the segment but by the tension of the tendon, making it difficult to compensate for gravity with BSP.

Table 1. Postures and joint positions used to measure joint torque; [a]90° between the trunk and the thigh in every seated posture; [b]shoulder joint 0°, elbow joint 90°; [c]shoulder joint 0°, hammer grip position in forearm; [d]elbow joint 0°, hammer grip position in forearm; [e]hip joint 90°, knee joint 90°; [f]hip joint 0°; [g]hip joint 90°; [h]knee joint 90°

Muscle action	Posture	Joint position as flexion angle
WP: Wrist flexion (palmar flexion)	seated posture [a,b]	0°
WD: Wrist extension (dorsiflexion)	seated posture [a,b]	0°
EF: Elbow flexion	seated posture [a,c]	30, 80, 120°
EE: Elbow extension	seated posture [a,c]	30, 60, 120°
SF: Shoulder flexion (forward elevation)	seated posture [a,d]	35, 80, 130°
SE: Shoulder extension	seated posture [a,d]	35, 80, 130°
AP: Ankle flexion (plantar flexion)	seated posture [a,e]	0°
AD: Ankle extension (dorsiflexion)	seated posture [a,e]	0°
KF: Knee flexion	abdominal posture [f]	15, 50, 90°
KE: Knee extension	seated posture [a,g]	50, 75, 90, 105°
HP: Hip flexion	dorsal posture [h]	15, 45, 90°
HE: Hip extension	dorsal posture [h]	45, 90, 105°

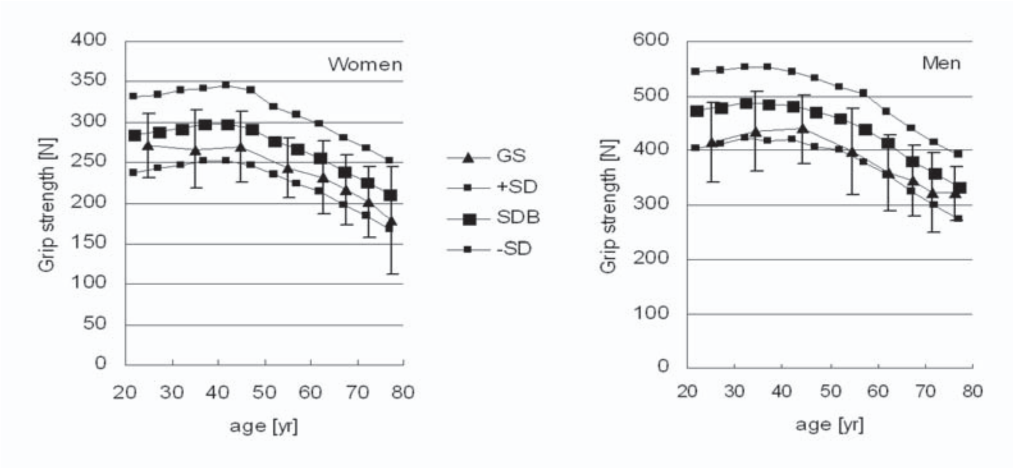

Figure 2. Comparison of grip strength values in SDB[10] and this study; Triangles = mean of grip strength values; Bars = standard deviation; Squares = mean and standard deviation of grip strength values in SDB data

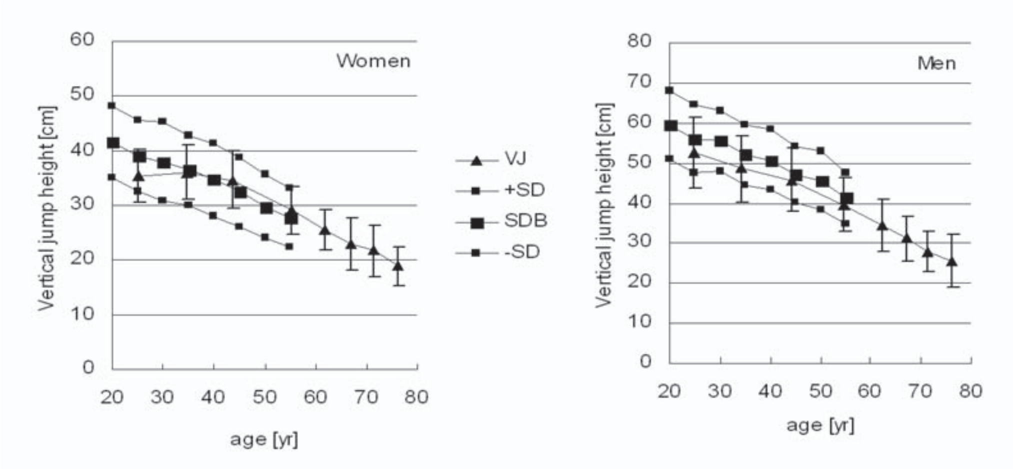

Figure 3. Comparison of vertical jump values in SDB[10] and this study; Triangles = mean of vertical jump values; Bars = standard deviation; Squares = mean and standard deviation of vertical jump values in SDB data

RESULTS

The acronyms for joint actions, e.g., WP (wrist plantar flexion) are spelled out in Table 1. The subjects' work and leisure activity levels determined from the replies to the questionnaires were graded on the four-category ordinal (1-4) scale of Saltin and Grimby[15]. Grade two was most common in median and mode at both work activity level and leisure activity level in the subjects of this study (*Appendix A*). Appendix B shows the characteristics of all 1008 subjects. Figures 2 and 3 show the GS and VJ data obtained in this study and SDB.

Table 2 shows the trend of the joint torque curves and the joint angles at which the largest joint torque value was obtained for each joint. About 500 to 700 subjects were measured in the postures and the joint positions listed in Table 1. Since humans usually shift their posture to the posture that requires the least muscle force to achieve the task, the subsequent analysis was focused on the largest joint torque value for each joint. Table 3 shows the results of the assessment of test-retest reliability in trial 1 and trial 2. Intra-class coefficients for the correlations between the results obtained in the first and the second trials were calculated to provide an indication of test-retest reliability.

Appendices C to F show the reference values for extremity joint torque in healthy Japanese subjects, and Figures 4 and 5 show the age-related differences in EJT values in the upper and lower limbs. The subjects of more than 60 years old were divided into age groups at 5-year intervals, because age-related differences in muscular strength were expected to be sharp in this age group.

Appendix G shows the results of the one-way analysis of variance (ANOVA) for comparing age groups, i.e., 20 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 69, and 70 to 79 years old, according to gender. Appendices H & I show the results of the statistical comparisons by the Dunnett *t* test between the data ob-

Table 2. Torque-angle curve; analysis centered on joint angles

Muscle action	n	Torque - angle curve = maximal value at a flexion of:	Joint angle
Elbow flexion	718	80°	80°
Elbow extension	657	120°	120°
Shoulder flexion (forward elevation)	646	80°	80°
Shoulder extension	718	80°	80°
Knee flexion	481	15°	15°
Knee extension	647	75°	75°
Hip flexion	565	15°	15°
Hip extension	550	105°	105°

Table 3. Test-retest reliability; [a]Ratio of the mean torque values between trial 1 and trial 2; [b]Pearson's correlation coefficients between trial 1 and trial 2

Muscle action	Joint angle	n	Torque [N] mean Trial 1	Torque [N] mean Trial 2	(Trial 1)/ (Trial 2)[a]	Correlation Coefficient[b]
Wrist flexion (palmar flexion)	0°	831	7.8	7.9	0.99	0.994
Wrist extension (dorsiflexion)	0°	824	7.5	7.5	1.01	0.982
Elbow flexion	80°	879	32.9	32.7	1.01	0.994
Elbow extension	120°	782	17.8	17.7	1.01	0.996
Shoulder flexion (forward elevation)	80°	749	39.6	39.5	1.00	0.995
Shoulder extension	80°	785	31.4	31.4	1.00	0.950
Ankle flexion (plantar flexion)	0°	857	43.9	44.2	0.99	0.997
Ankle extension (dorsiflexion)	0°	853	23.5	23.5	1.00	0.995
Knee flexion	15°	585	47.3	47.4	1.00	0.995
Knee extension	75°	678	71.0	71.5	0.99	0.996
Hip flexion	15°	614	93.8	94.1	1.00	0.995
Hip extension	105°	622	60.6	61.1	0.99	0.997

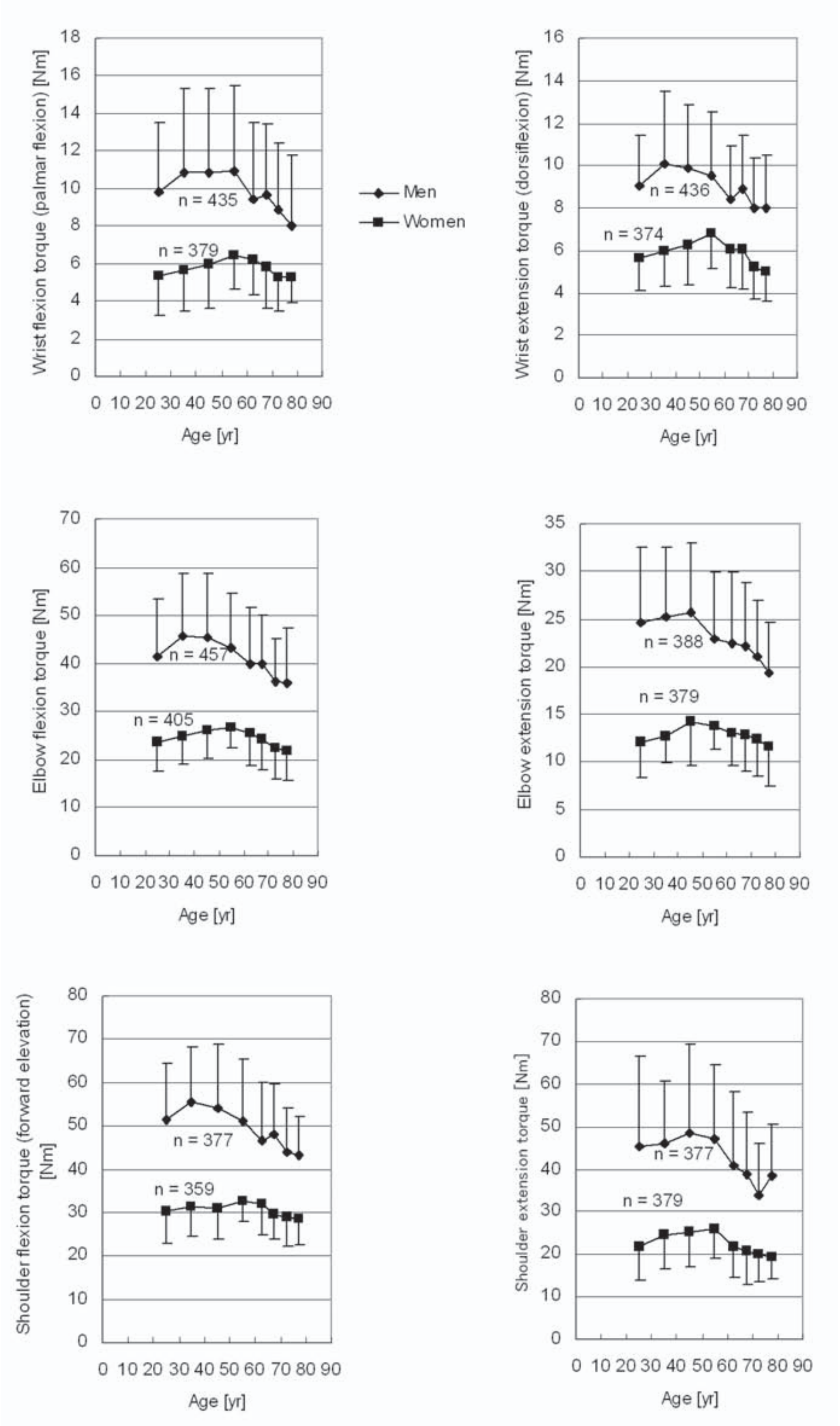

Figure 4: Age-related changes in joint torque values in the upper limbs; Diamonds and squares = mean value; Bars = standard deviation

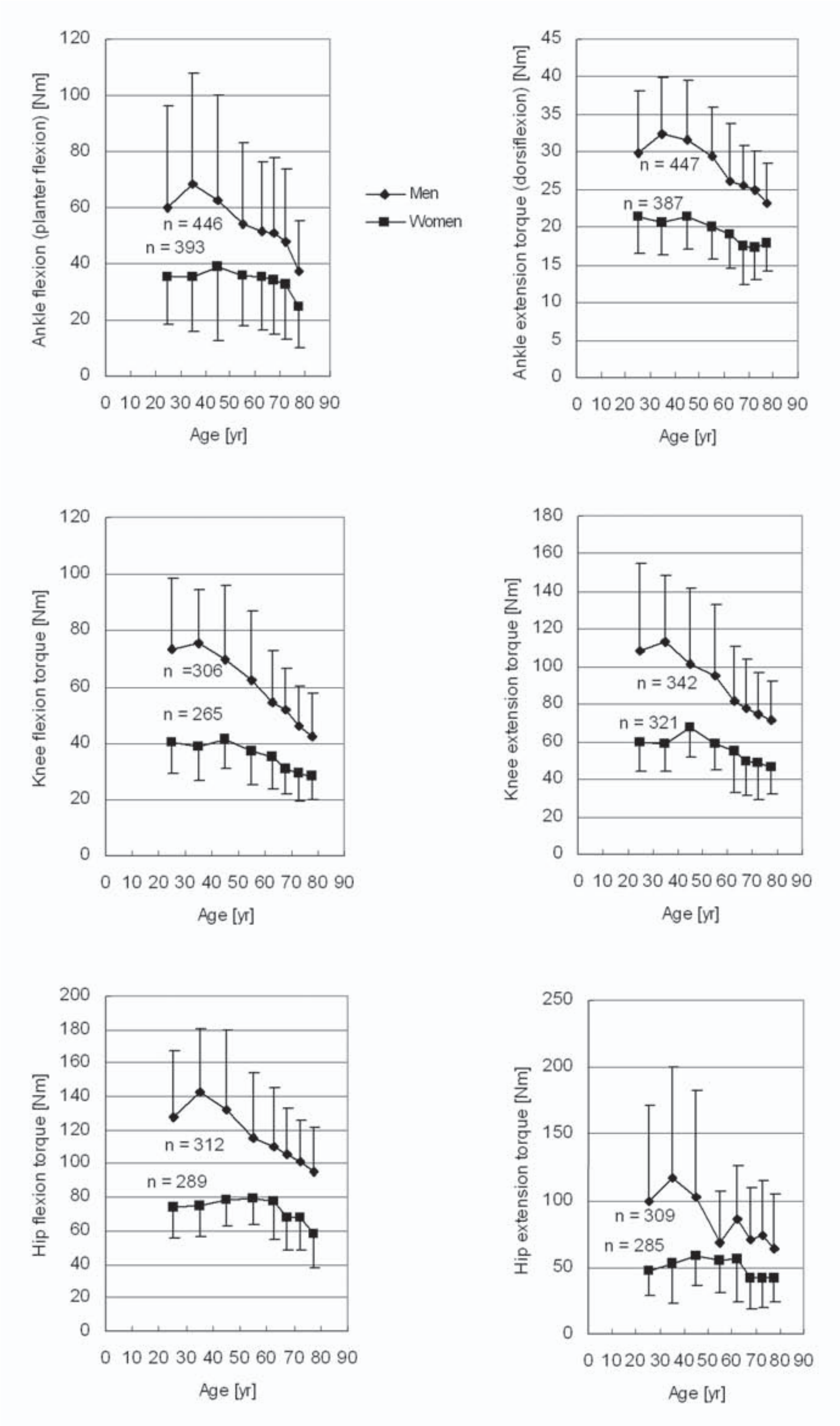

Figure 5: Age-related changes in joint torque values in the lower limbs; Diamonds and squares = mean value; Bars = standard deviation

tained in women and men aged 20 to 29 years old and the other age groups.

DISCUSSION

Characteristics of the subjects

It was essential to determine how representative the study sample was of the Japanese population as a whole. Grade two was most common both for work activity level and leisure activity level. But the women aged 40 to 49 years old and the men aged 30 to 39, 40 to 49, and 50 to 59 years old were grade one. Many workers especially in these age groups, i.e. the women aged 40 to 49 years old and the men aged 30 to 39, 40 to 49, and 50 to 59 years old, now use computers and many of them operate computers for many hours a day and so these age groups may have been grade one.

Age-related differences between GS and VJ data obtained in this study and the data in the SDB were very similar, thereby confirming that the GS and VJ values measured in this study were not excessively biased against SDB data. The GS values in the SDB referred to in this study were obtained in 2002 from 37,878 subjects, and the VJ values in the SDB referred to in this study were obtained in 1997 from 9,536 subjects. The GS values obtained in this study were slightly lower than in the SDB, but the difference may have been attributable to the measurement conditions. More specifically, the SDB measurements were made without giving the subjects any instructions about breathing, and it was the authors' experience almost all of the subjects "have held" their breath, whereas in the present study the subjects were instructed to exert force in "expiration" (EMVC) in order to prevent strokes caused by sudden changes in blood pressure. Needless to say, the muscle strength of the subjects while holding their breaths is greater than during EMVC.

Test-retest reliability of joint torque data

The ratios of the mean torque value in response to each muscle action in trial 1 to the mean value in trial 2 ranged from 0.99 to 1.01, and the coefficients of the intra-class correlations ranged from 0.95 to 0.997, depending on the muscle action (*Table 3*). Most of the values were greater than 0.99, indicating that the measurements made in this study were highly reliable.

Age-related differences in joint torque

In many studies on muscle strength, "women" have usually been regarded as "small men", but the data for men and women obtained in this study were analyzed separately, because of the likelihood of differences in activities of daily living between men and women. On the whole, the peak age-related changes in each EJT value were in the 30 to 39, 40 to 49, and 50 to 59 years old age groups in both the men and the women (*Figures 4 & 5*).

The EJT values of women aged 20 to 29 years old were significantly lower than in the older age groups for six muscle actions (*Appendix H*). The results of the Dunnett *t* test showed that the EJT values of the women aged 20 to 29 years old were significantly lower than those of the women aged 40 to 49 and/or 50 to 59 years old in five of the upper-limb joint torque values (WP, WD, EF, EE, SE) and also lower than those of the women aged 50 to 59, and 60 to 69 years old in one of the lower-limb joint torque values (HF). However, the men aged 20 to 29 years old did not have any significantly lower EJT values than the older age groups of men (*Appendix I*).

Figure 6 is based on the data from the study by R.W. Bohannon in the USA[1] that showed age-related differences in limb muscle strength measured with an HHD. In the study of Bohannon, HHD was held with examiner's hands both in upperlimb's muscle strength measurements and in lower-limb's muscle strength measurements, and the data of strength were neither gravity compensated, nor converted to joint torque. The data reported by Bohannon showed a decreasing trend overall with no significant trend for the muscle strength values of women aged 20 to 29 years old to be lower than in older age groups. The data reported by Bohannon also showed a decreasing trend overall, but no significant trend toward the muscle strength values of men aged 20 to 29 years old being lower than in older age groups. The reason for the differences between the data obtained by Bohannon and the data obtained in this study is not clear.

On the other hand, Metter et al.[3] reported the age-related change of isometric strength in upper limbs based on the data of the Baltimore Longitudinal Study of Aging (BLSA). The subjects consisted of 993 men and 184 women who were the participants of the BLSA, and the isometric muscle strength in upperlimbs was measured as pulling force against the hand-grip in four ways: up, down, forward, and backward along the axis of the forearm. They reported that for men, significant age differences were found in strength with peaking in the 30s and then showing a steady decline, and in women, there was no significant peaking in strength and strength declined with age with the changes beginning in the 50s when examined by age decade.

It is often said that the muscle strength simply decreases with age. If that is true, the EJT values of women aged 20 to 29 in Japan today will be much lower 40 or 50 years from now, and it will be difficult for them to lead an independent life.[16,17] E.J. Metter et al.[3] reported that for men strength declines longitudinally but for women no longitudinal declines were found for strength based on the 25 years of longitudinal data of BLSA.

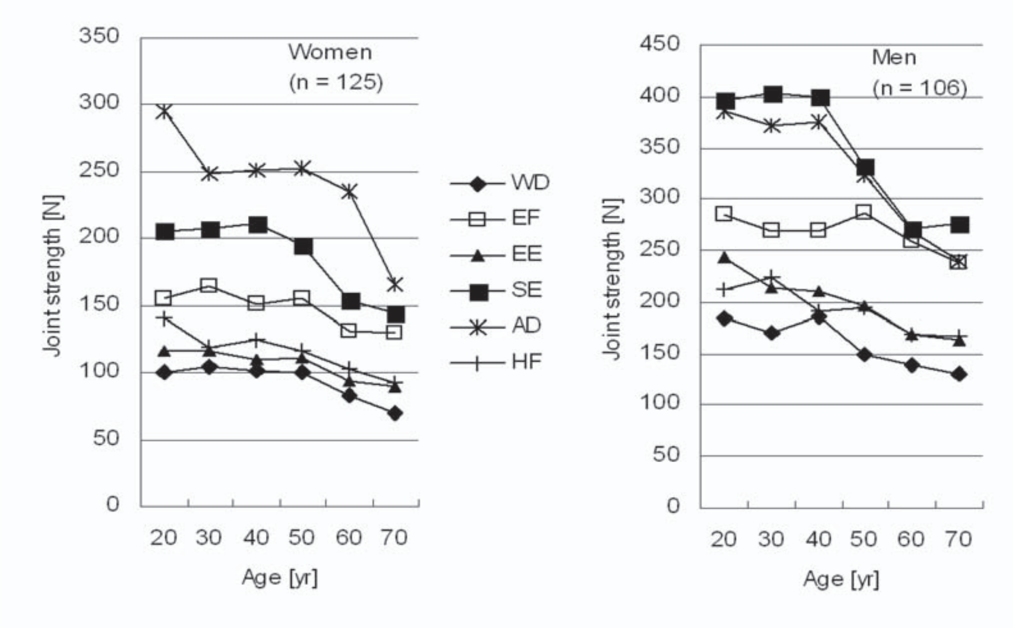

Figure 6: Age-related changes in extremity muscle strength based on the data reported by Bohannon et al.[1]; Mean values of joint strength are indicated

Figures 7 and 8 show the age-related changes in the GS and VJ values of healthy Japanese women based on SDB data from 1967 to 1997. The data in Figures 7 and 8 have been extracted from the data in SDB for four different ages of women, i.e., 25, 35, 45 and 55 years old, and there were about 200 to 500 subjects in each group. The graphs on the left in both figures show the secular changes in GS and VJ in each of the four age groups. A decline in the GS values of women aged 25, 35, and 45 years old started in 1982 or 1987, but the GS values of women aged 55 years old did not show a clear decline, and the VJ values of women aged 25 and 35 years old started declining in 1992. The graphs on the right in both figures show the age-related changes in GS and VJ in each of the four age groups. The changes in GS values are not as clear as the age-related differences in EJT values, but the peaks of the age-related changes in GS are in the 35- or 45-year-old age groups. These findings corroborate the results of this study, which showed that Japanese young women have less muscle strength than older women. In order to confirm that for women in Japan aged 20 to 29 today it will later be difficult to lead an independent life or not, longitudinal studies of EJT values in Japan will be needed.

CONCLUSIONS

The gravity-compensated limb joint torque values of healthy Japanese women aged 20 to 29 years were significantly lower than those of the women aged 40 to 49 and/or 50 to 59 years for all five upper joint torque measurements (WP, WD, EF, EE, SE) and for the single lower joint torque measurement (HE). Overall, the results of this study show that younger Japanese women have less muscle strength than older Japanese women, and this phenomenon is supposed to be attributed to disuse and /or inactivity in younger women. Longitudinal studies will be needed to analyze this phenomenon in detail, and the authors wish to make longitudinal measurements of EJT.

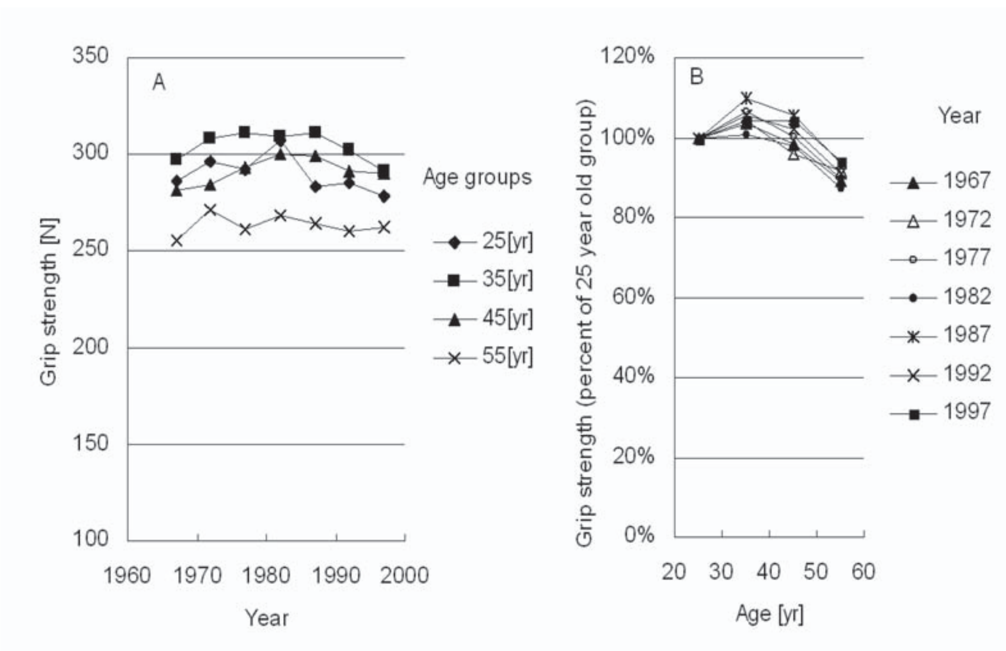

Figure 7: Age-related changes in grip strength of women based on SDB[10] from 1967 to 1997. Graph A: Mean grip strength. Graph B: Percentage of the 25 year old group

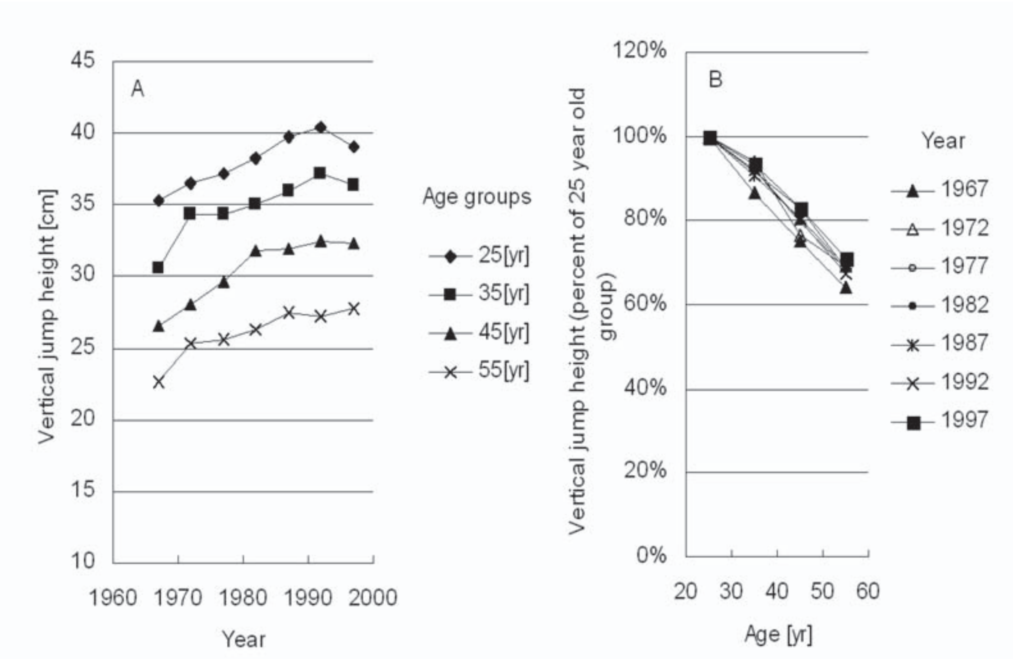

Figure 8: Age-related changes in the vertical jump values of women based on SDB[10] from 1967 to 1997. Graph A: Mean vertical jump height. Graph B: Percentage of the 25 year old group

Many younger women in Japan, such as high-school students or university students, are recently seen sitting or leaning against objects in railway stations, classrooms, etc., and this phenomenon may be attributable to the lower muscle strength of younger women. Many labor-saving devices, such as washing machines, vacuum cleaners, and refrigerators made daily life more comfortable and convenient, but over-automated and excessively labor-saving devices have diminished opportunities for muscle training during housework and daily life. Moreover, younger women in Japan do not like sports, and many of them are on diets. Of course, these labor-saving devices and such concepts as "universal design", "barrier-free design" or "design for all" are essential for aging societies, especially in Japan. However, other choices in the form of "design for fitness", such as "fitness washing machines" (washing machines with manual wringer), "fitness stairs" (buildings should have many accessible stairs and have less elevators), "fitness streets" (pavement with some kind of hurdles), etc., should be provided.

People instinctively seek a more comfortable and easy life, and technology makes it possible. However, a comfortable and easy life is not necessarily good for human health.

Acknowledgement

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Appendices

Appendix A. Activity levels of the subjects as evaluated according to the category scale of Saltin and Grimby[15]

Gender	Age group [yr]	Work activity level median	Work activity level mode	Leisure activity level median	Leisure activity level mode
Female	20-29	2	1	2	2
	30-39	2	2	2	2
	40-49	1	1	2	2
	50-59	2	2	2	2
	60-69	2	2	2	2
Male	70-79	2	2	2	2
	20-29	2	2	2	3
	30-39	1	1	2	2
	40-49	1	1	2	2
	50-59	1	1	2	2
	60-69	2	2	2	2
	70-79	2	2	2	2

Appendix B. Characteristics of the subjects; BMI = Body Mass Index; GS = Grip Strength; VJ = Vertical Jump Value; SD = Standard Deviation

Gender	Age group	n	Age mean [yr]	Age SD [yr]	Height mean [cm]	Height SD [cm]	Weight mean [kg]	Weight SD [kg]	BMI mean [kg/m*m]	BMI SD [kg/m*m]	GS mean [N]	GS SD [N]	VJ mean [cm]	VJ SD [cm]
Female	20-29	36	25.1	2.8	158.5	4.7	50.5	6.9	20.1	2.4	270.8	39.6	35.4	4.8
	30-39	37	34.9	3.2	158.4	4.7	51.7	7.8	20.6	3.0	266.2	47.7	36.0	5.0
	40-49	34	43.7	2.6	156.5	5.0	49.5	6.9	20.2	2.5	269.5	44.1	34.6	5.2
	50-59	46	55.4	3.0	154.1	5.9	52.6	7.1	22.2	2.9	243.3	36.7	29.0	4.3
	60-64	85	61.9	1.3	152.0	5.8	54.4	8.3	23.6	3.4	231.5	45.1	25.5	3.8
	65-69	117	66.9	1.3	151.2	5.2	52.4	7.1	22.9	2.9	216.2	42.9	22.9	4.8
	70-74	94	71.5	1.5	148.1	5.2	51.9	7.0	23.7	3.0	201.5	43.4	21.7	4.6
	75-79	22	76.2	1.3	149.4	5.7	51.5	6.6	23.0	2.1	178.8	66.3	18.9	3.5
	Total	471												
Male	20-29	39	25.0	2.7	171.3	6.3	63.9	16.5	21.6	4.6	414.4	73.3	52.6	9.0
	30-39	54	34.3	2.7	170.7	5.7	68.0	9.2	23.4	3.3	434.3	73.1	48.6	8.3
	40-49	48	44.2	2.7	169.0	6.5	68.0	10.3	23.8	3.0	438.4	63.0	45.8	7.9
	50-59	46	54.5	3.0	166.0	6.3	63.0	10.6	22.8	3.0	397.6	79.1	39.6	6.7
	60-64	79	62.3	1.3	162.7	5.4	61.1	8.6	23.1	2.8	359.1	70.4	34.3	6.6
	65-69	129	67.3	1.3	162.3	5.1	62.0	9.0	23.5	2.7	342.8	64.4	31.2	5.6
	70-74	109	71.5	1.4	161.2	5.8	59.9	8.9	23.0	2.9	321.4	72.1	28.0	5.0
	75-79	33	76.2	1.4	161.4	5.0	58.3	6.5	22.4	2.5	319.8	50.2	25.6	6.5
	Total	537												

Appendix C. Reference values for joint torque in the upper limbs of healthy Japanese women; SD = Standard Deviation

Muscle action	Joint angle	Age group	n	Joint torque [Nm] mean	Joint torque [Nm] SD	Joint torque/weight [Nm/kg] mean	Joint torque/weight [Nm/kg] SD	Grip strength [N] mean	Grip strength [N] SD
Wrist flexion (palmar flexion)	0°	20-29	33	5.38	2.13	0.11	0.040	269.2	38.7
		30-39	33	5.63	2.18	0.11	0.045	263.6	46.4
		40-49	30	6.00	2.36	0.12	0.045	272.5	45.9
		50-59	39	6.45	1.85	0.12	0.039	249.0	33.1
		60-64	66	6.19	1.84	0.11	0.033	231.6	42.1
		65-69	93	5.81	2.16	0.11	0.042	213.1	45.3
		70-74	68	5.24	1.80	0.10	0.034	201.1	44.7
		75-79	17	5.26	1.36	0.10	0.022	174.6	71.2
Wrist extension (dorsiflexion)	0°	20-29	30	5.62	1.54	0.11	0.028	268.2	40.3
		30-39	33	5.98	1.67	0.12	0.037	262.2	46.9
		40-49	30	6.24	1.82	0.13	0.037	272.5	45.9
		50-59	40	6.79	1.63	0.13	0.032	251.1	30.7
		60-64	67	6.07	1.85	0.11	0.032	230.2	43.5
		65-69	89	6.05	1.87	0.12	0.037	218.1	44.5
		70-74	69	5.25	1.59	0.10	0.031	203.1	44.6
		75-79	16	5.04	1.43	0.10	0.029	166.1	78.6
Elbow flexion	80°	20-29	35	23.68	6.23	0.47	0.111	269.2	39.0
		30-39	33	24.77	5.77	0.49	0.111	263.6	46.4
		40-49	29	26.21	5.79	0.54	0.115	273.4	46.4
		50-59	40	26.86	4.31	0.51	0.085	248.9	32.8
		60-64	75	25.56	6.95	0.47	0.122	228.1	44.8
		65-69	95	24.19	6.39	0.47	0.116	219.9	43.6
		70-74	78	22.38	6.33	0.43	0.107	200.2	43.2
		75-79	20	21.67	5.98	0.42	0.100	178.1	65.9
Elbow extension	120°	20-29	33	12.01	3.70	0.24	0.071	267.4	39.3
		30-39	32	12.72	2.87	0.25	0.060	265.3	46.0
		40-49	28	14.17	4.52	0.29	0.078	272.9	47.0
		50-59	39	13.83	2.54	0.26	0.050	250.0	32.5
		60-64	66	13.03	3.37	0.24	0.059	228.4	43.4
		65-69	94	12.83	3.88	0.25	0.076	215.8	44.8
		70-74	68	12.36	3.82	0.24	0.067	202.2	42.5
		75-79	19	11.63	4.17	0.23	0.073	171.6	68.2
Shoulder flexion (forward elevation)	80°	20-29	34	30.21	7.38	0.60	0.132	267.9	38.8
		30-39	31	31.16	6.52	0.61	0.105	262.4	46.7
		40-49	29	30.95	7.12	0.63	0.124	276.5	44.4
		50-59	40	32.60	4.58	0.62	0.093	248.9	32.8
		60-64	66	31.84	6.85	0.59	0.103	231.9	46.0
		65-69	82	29.79	6.05	0.58	0.112	216.5	45.7
		70-74	62	28.80	6.57	0.56	0.111	203.1	44.0
		75-79	15	28.58	6.18	0.54	0.113	179.7	73.5
Shoulder extension	80°	20-29	34	21.98	8.09	0.44	0.164	267.9	38.8
		30-39	32	24.74	8.09	0.49	0.151	260.8	46.0
		40-49	29	25.37	8.52	0.52	0.162	276.5	44.4
		50-59	40	26.15	7.16	0.50	0.161	248.9	32.8
		60-64	70	21.74	7.35	0.41	0.135	230.1	46.3
		65-69	93	20.66	7.98	0.40	0.159	216.7	44.7
		70-74	65	20.05	6.65	0.39	0.113	201.7	43.6
		75-79	16	19.34	5.16	0.38	0.092	176.7	71.7

Appendix D. Reference values for joint torque in the upper limbs of healthy Japanese men; SD = Standard Deviation

Muscle action	Joint angle	Age group	n	Joint torque [Nm]		Joint torque/weight [Nm/kg]		Grip strength [N]	
				mean	SD	mean	SD	mean	SD
Wrist flexion (palmar flexion)	0°	20-29	36	9.86	3.64	0.16	0.063	411.2	73.3
		30-39	43	10.88	4.43	0.16	0.059	436.9	69.9
		40-49	39	10.88	4.42	0.16	0.072	435.6	68.7
		50-59	39	10.89	4.58	0.17	0.060	389.6	75.7
		60-64	68	9.46	4.02	0.16	0.066	357.4	73.0
		65-69	103	9.66	3.80	0.16	0.056	340.2	63.8
		70-74	84	8.90	3.53	0.15	0.053	322.2	75.3
		75-79	23	8.04	3.72	0.14	0.058	325.6	51.0
Wrist extension (dorsiflexion)	0°	20-29	36	9.06	2.38	0.15	0.041	411.2	73.3
		30-39	43	10.07	3.43	0.15	0.051	436.1	68.8
		40-49	40	9.90	2.99	0.15	0.048	434.4	68.2
		50-59	40	9.54	3.00	0.15	0.041	390.6	75.4
		60-64	70	8.40	2.51	0.14	0.042	359.3	69.8
		65-69	101	8.89	2.49	0.15	0.039	339.8	65.7
		70-74	87	7.97	2.37	0.13	0.037	321.2	72.9
		75-79	19	7.99	2.48	0.14	0.043	322.2	54.5
Elbow flexion	80°	20-29	37	41.36	11.93	0.68	0.195	414.0	74.3
		30-39	45	45.70	12.91	0.67	0.187	435.5	69.6
		40-49	44	45.55	12.97	0.68	0.205	437.6	64.0
		50-59	39	43.32	11.43	0.70	0.150	395.0	82.4
		60-64	72	40.01	11.64	0.66	0.186	357.2	71.3
		65-69	109	39.93	10.23	0.65	0.154	340.6	66.3
		70-74	86	36.12	9.06	0.61	0.133	318.5	72.1
		75-79	25	35.87	11.30	0.61	0.169	323.6	54.4
Elbow extension	120°	20-29	34	24.61	7.93	0.40	0.132	421.4	69.7
		30-39	35	25.30	7.20	0.37	0.104	436.8	71.8
		40-49	33	25.77	7.18	0.39	0.114	434.7	68.5
		50-59	33	22.94	6.87	0.37	0.095	402.1	85.8
		60-64	62	22.52	7.44	0.37	0.121	360.4	73.6
		65-69	96	22.20	6.55	0.36	0.100	339.0	64.6
		70-74	74	21.11	5.91	0.35	0.093	323.0	75.7
		75-79	21	19.36	5.31	0.33	0.089	331.6	53.1
Shoulder flexion (forward elevation)	80°	20-29	34	51.44	12.84	0.84	0.189	415.6	75.7
		30-39	35	55.35	12.60	0.79	0.157	436.8	71.8
		40-49	33	54.15	14.53	0.81	0.202	434.7	68.5
		50-59	31	51.02	14.18	0.81	0.160	399.1	88.5
		60-64	64	46.68	13.20	0.77	0.191	359.4	72.9
		65-69	89	47.95	11.72	0.78	0.165	340.8	69.9
		70-74	72	43.90	10.12	0.74	0.155	318.5	78.7
		75-79	19	43.07	9.05	0.74	0.138	330.6	50.1
Shoulder extension	80°	20-29	34	51.44	12.84	0.84	0.189	416.4	74.8
		30-39	35	55.35	12.60	0.79	0.157	436.8	71.8
		40-49	33	54.15	14.53	0.81	0.202	434.7	68.5
		50-59	31	51.02	14.18	0.81	0.160	395.7	87.0
		60-64	64	46.68	13.20	0.77	0.191	358.3	74.0
		65-69	89	47.95	11.72	0.78	0.165	340.9	69.2
		70-74	72	43.90	10.12	0.74	0.155	322.2	75.9
		75-79	19	43.07	9.05	0.74	0.138	334.6	49.0

Appendix E. Reference values for joint torque in the lower limbs of healthy Japanese women; SD = Standard Deviation

Muscle action	Joint angle	Age group	n	Joint torque [Nm]		Joint torque/weight [Nm/kg]		Vertical jump [cm]	
				mean	SD	mean	SD	mean	SD
Ankle flexion (plantar flexion)	0°	20-29	32	35.34	16.789	0.71	0.327	35.3	5.0
		30-39	31	35.13	19.406	0.70	0.387	35.8	5.1
		40-49	30	38.81	26.28	0.78	0.501	34.6	5.4
		50-59	40	35.97	18.174	0.68	0.329	29.0	4.4
		60-64	67	35.41	18.853	0.66	0.332	25.5	3.5
		65-69	101	34.22	19.314	0.66	0.357	23.2	4.4
		70-74	75	32.70	19.455	0.62	0.354	21.6	4.5
		75-79	17	24.99	15.083	0.50	0.284	18.6	3.7
Ankle extension (dorsiflexion)	0°	20-29	31	21.45	4.9608	0.43	0.090	35.4	5.0
		30-39	32	20.60	4.3088	0.41	0.090	35.8	5.0
		40-49	30	21.32	4.2713	0.44	0.091	34.6	5.4
		50-59	40	20.08	4.2809	0.38	0.081	29.0	4.4
		60-64	73	19.15	4.5728	0.36	0.093	25.8	3.5
		65-69	93	17.47	5.0458	0.34	0.085	23.2	4.4
		70-74	75	17.39	4.4603	0.34	0.082	21.4	4.6
		75-79	13	17.95	3.7943	0.36	0.075	18.9	3.9
Knee flexion	15°	20-29	34	40.32	10.879	0.80	0.204	35.3	4.9
		30-39	28	38.54	11.896	0.76	0.261	36.0	4.4
		40-49	26	41.30	10.562	0.83	0.171	34.7	5.5
		50-59	36	37.39	12.358	0.71	0.261	29.1	4.4
		60-64	40	35.24	11.761	0.65	0.202	25.8	3.2
		65-69	57	31.01	8.9889	0.60	0.162	23.6	4.7
		70-74	33	29.43	9.8999	0.56	0.164	22.0	4.2
		75-79	11	28.12	8.2467	0.58	0.167	19.1	4.3
Knee extension	75°	20-29	33	59.61	15.910	1.19	0.321	35.3	5.0
		30-39	32	59.20	15.569	1.19	0.395	36.1	5.3
		40-49	29	67.40	15.702	1.38	0.279	34.7	5.5
		50-59	39	58.93	14.111	1.12	0.319	29.0	4.5
		60-64	51	55.06	21.775	1.03	0.352	25.7	3.2
		65-69	71	49.13	17.322	0.95	0.331	23.4	4.5
		70-74	51	48.55	19.627	0.93	0.321	22.2	5.2
		75-79	15	46.09	14.172	0.90	0.235	19.5	3.9
Hip flexion	15°	20-29	32	73.67	18.129	1.46	0.334	35.3	4.8
		30-39	29	74.88	18.718	1.48	0.355	35.2	4.5
		40-49	29	78.46	16.142	1.60	0.286	34.7	5.5
		50-59	38	79.71	15.891	1.52	0.355	29.1	4.5
		60-64	42	77.34	22.404	1.43	0.368	26.1	3.2
		65-69	63	67.74	19.700	1.32	0.390	23.2	4.6
		70-74	41	68.26	19.547	1.31	0.295	22.4	4.2
		75-79	15	58.17	19.937	1.17	0.366	18.8	3.9
Hip extension	105°	20-29	33	47.74	18.955	0.96	0.401	35.2	4.9
		30-39	30	53.46	29.902	1.05	0.578	35.1	4.5
		40-49	29	58.86	22.124	1.20	0.416	34.7	5.5
		50-59	37	55.58	25.071	1.06	0.514	29.2	4.5
		60-64	43	56.43	32.236	1.03	0.533	26.1	3.1
		65-69	60	41.92	23.422	0.82	0.447	23.4	4.6
		70-74	41	41.51	21.484	0.80	0.407	22.2	4.1
		75-79	12	42.46	17.687	0.88	0.419	19.3	4.1

Appendix F. Reference values for joint torque in the lower limbs of healthy Japanese men; SD = Standard Deviation

Muscle action	Joint angle	Age group	n	Joint torque [Nm]		Joint torque/weight [Nm/kg]		Vertical jump [cm]	
				mean	SD	mean	SD	mean	SD
Ankle flexion (plantar flexion)	0°	20-29	35	59.97	36.414	0.98	0.561	52.3	9.1
		30-39	41	68.59	39.347	1.00	0.568	48.1	6.9
		40-49	41	62.74	37.436	0.95	0.592	45.6	8.3
		50-59	39	54.10	29.184	0.84	0.385	39.8	6.7
		60-64	70	51.34	24.731	0.86	0.421	34.5	6.8
		65-69	108	50.95	27.058	0.82	0.417	31.0	5.6
		70-74	86	47.67	26.105	0.80	0.432	28.2	5.0
		75-79	26	37.53	17.867	0.65	0.311	26.0	5.6
Ankle extension (dorsiflexion)	0°	20-29	36	29.88	8.1763	0.49	0.124	52.7	9.3
		30-39	43	32.49	7.428	0.48	0.119	48.3	6.8
		40-49	42	31.72	7.676	0.47	0.119	45.9	8.3
		50-59	38	29.47	6.4988	0.48	0.095	39.8	6.9
		60-64	67	26.17	7.6256	0.43	0.117	34.6	6.7
		65-69	109	25.53	5.3688	0.42	0.090	31.1	5.6
		70-74	88	24.90	5.0875	0.42	0.089	28.0	5.0
		75-79	24	23.16	5.2406	0.40	0.088	25.7	5.4
Knee flexion	15°	20-29	34	73.51	24.834	1.18	0.376	53.3	7.7
		30-39	33	75.24	18.909	1.08	0.242	48.1	7.5
		40-49	33	69.68	26.472	1.04	0.421	45.2	8.7
		50-59	32	62.22	24.601	1.00	0.344	39.8	6.8
		60-64	47	54.71	18.321	0.89	0.271	34.8	7.1
		65-69	66	51.91	14.707	0.84	0.222	30.9	6.3
		70-74	47	46.18	14.288	0.76	0.198	28.8	5.4
		75-79	14	42.19	15.411	0.73	0.258	27.1	4.9
Knee extension	75°	20-29	34	108.33	46.279	1.72	0.650	53.3	7.7
		30-39	34	113.16	35.139	1.64	0.497	48.1	7.4
		40-49	31	101.20	39.927	1.49	0.539	44.7	8.8
		50-59	33	95.38	37.588	1.52	0.547	39.8	6.7
		60-64	54	81.68	29.098	1.36	0.434	35.0	6.9
		65-69	81	78.14	25.809	1.27	0.393	31.0	6.1
		70-74	58	74.95	21.408	1.22	0.334	28.3	5.1
		75-79	17	71.17	21.146	1.24	0.293	26.6	6.1
Hip flexion	15°	20-29	34	127.53	39.524	2.08	0.689	53.3	7.7
		30-39	33	142.73	37.58	2.07	0.552	48.1	7.5
		40-49	32	132.29	47.024	1.98	0.741	44.9	8.7
		50-59	31	115.67	38.183	1.86	0.493	39.4	6.5
		60-64	44	110.02	35.586	1.80	0.462	34.9	7.5
		65-69	72	105.75	26.925	1.74	0.430	31.2	6.2
		70-74	53	101.04	25.031	1.64	0.364	28.7	5.2
		75-79	13	94.95	26.722	1.64	0.460	27.5	4.9
Hip extension	105°	20-29	34	99.88	71.264	1.65	1.180	53.3	7.7
		30-39	33	116.99	83.542	1.72	1.232	48.1	7.5
		40-49	31	103.31	79.454	1.58	1.267	44.6	8.7
		50-59	31	68.51	39.23	1.09	0.546	39.4	6.5
		60-64	41	86.72	39.496	1.44	0.650	35.2	7.4
		65-69	72	71.18	38.473	1.15	0.562	30.9	6.0
		70-74	53	74.58	40.064	1.22	0.670	28.7	5.1
		75-79	14	64.49	40.817	1.10	0.702	26.9	5.2

Appendix G. Comparison of extremity joint torque (EJT) values in each joint with ANOVA

Joints and motion	Women		Men	
	F	P	F	P
Wrist flexion (palmar flexion)	2.744	0.019	3.532	0.004
Wrist extension (dorsiflexion)	5.517	0.000	6.036	0.000
Elbow flexion	4.406	0.001	7.962	0.000
Elbow extension	2.260	0.048	4.644	0.000
Shoulder flexion (forward elevation)	2.104	0.064	7.259	0.000
Shoulder extension	6.124	0.000	6.758	0.000
Ankle flexion (plantar flexion)	0.868	0.502	5.230	0.000
Ankle extension (dorsiflexion)	7.312	0.000	17.439	0.000
Knee flexion	7.863	0.000	18.440	0.000
Knee extension	7.051	0.000	13.362	0.000
Hip flexion	3.211	0.008	10.671	0.000
Hip extension	2.499	0.031	5.222	0.000

Appendix H. Comparison of extremity joint torque (EJT) values in each joint for women; [a] Dunett *t* tests p<0.05; WP = Wrist flexion (palmar flexion); WD = Wrist extension (dorsiflexion); EF = Elbow flexion; EE = Elbow extension; SF = Shoulder flexion (forward elevation); SE = Shoulder extension; AP = Ankle flexion (plantar flexion); AD = Ankle extension (dorsiflexion); KF = Knee flexion; KE = Knee extension; HF = Hip flexion; HE = Hip extension

Comparison of age groups	WP	WD	EF	EE	SF	SE
30-39 <> 20-29	0.596	0.451	0.503	0.473	0.569	0.195
40-49 <> 20-29	0.282	0.224	0.156	0.037a	0.632	0.117
50-59 <> 20-29	0.041a	0.010a	0.047a	0.059a	0.171	0.033a
60-69 <> 20-29	0.179	0.264	0.393	0.259	0.653	0.938
70-79 <> 20-29	0.883	0.982	0.986	0.707	0.983	0.992
Comparison of age groups	AP	AD	KF	KE	HF	HE
30-39 <> 20-29	0.808	0.951	0.954	0.833	0.113	0.438
40-49 <> 20-29	0.507	0.823	0.695	0.132	0.072	0.134
50-59 <> 20-29	0.746	0.987	0.988	0.853	0.009a	0.270
60-69 <> 20-29	0.845	1.000	1.000	1.000	0.001a	0.797
70-79 <> 20-29	0.977	1.000	1.000	1.000	0.114	0.984

Appendix I. Comparison of extremity joint torque (EJT) values in each joint for men; No significant differences were found in the Dunett *t* test ; WP = Wrist flexion (palmar flexion); WD = Wrist extension (dorsiflexion); EF = Elbow flexion; EE = Elbow extension; SF = Shoulder flexion (forward elevation); SE = Shoulder extension; AP = Ankle flexion (plantar flexion); AD = Ankle extension (dorsiflexion); KF = Knee flexion; KE = Knee extension; HF = Hip flexion; HE = Hip extension

Comparison of age groups	WP	WD	EF	EE	SF	SE
30-39 <> 20-29	0.313	0.137	0.119	0.635	0.252	0.727
40-49 <> 20-29	0.324	0.223	0.134	0.512	0.424	0.468
50-59 <> 20-29	0.319	0.465	0.472	0.977	0.842	0.646
60-69 <> 20-29	0.893	0.951	0.944	0.998	0.998	0.999
70-79 <> 20-29	0.994	0.999	1.000	1.000	1.000	1.000
Comparison of age groups	AP	AD	KF	KE	HF	HE
30-39 <> 20-29	0.262	0.113	0.676	0.553	0.113	0.275
40-49 <> 20-29	0.629	0.266	0.965	0.972	0.588	0.720
50-59 <> 20-29	0.961	0.861	1.000	0.998	0.994	1.000
60-69 <> 20-29	0.996	1.000	1.000	1.000	1.000	1.000
70-79 <> 20-29	1.000	1.000	1.000	1.000	1.000	1.000