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The normative values of vertical jump and sit-and-reach in a large general Chinese population aged 8–80 years: The China National Health Survey

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ABSTRACT

The normative values of vertical jump (VJ) and sit-and-reach (SR) for Chinese people are still unclear. We aimed to determine these values and their correlations with body composition using data from China National Health Survey which included 19,269 participants aged 8–80 years. Sex-specific smoothed centile tables were generated for the P_1, P_5, P_{25}, P_{50}, P_{75}, P_{95}, and P_{99} centiles of VJ and SR using lambda-mu-sigma method. The median (Interquartile range) values of VJ and SR in males and females were as follows: 20.3 (8.8) cm and 14.1 (5.5) cm for VJ, 1.8 (11.6) cm and 6.8 (10.4) cm for SR, respectively. In males, VJ values increased to a peak around the age of 18, with the 5^{th} and 95^{th} values being 17.7 cm and 41.3 cm, respectively. After reaching the peak, VJ values gradually declined with age. In females, VJ values remained relatively stable from childhood to early adulthood, and then declined after the age of 30. The peak values of SR were observed in early adulthood in both sexes, and remained stable in females but declined with age in males. VJ had a negative association with body composition, particularly in females. SR was found to have a negative association with fat mass indexes in males. However, correlations in females were only marginally statistically significant. The study provides age- and sex-specific percentile reference values for VJ and SR in Chinese people and can aid in the assessment of muscle fitness and facilitate early prediction of neuromuscular disorders.

Introduction

The assessment of health-related fitness is considered useful for identifying motor performance levels, which serves as a fundamental basis for determining health status and measuring the impact of interventions aimed at improving physical capacities associated with health [1].

Muscle fitness, defined as the maximal force or tension that a

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muscle or a group of muscles can generate as a specified velocity, is a key component of health-related fitness. It is believed to be essential for maintaining good health and playing a crucial role in preserving normal movement in humans [2,3]. During the aging process, physical fitness, which includes strength, endurance, agility, and flexibility, tends to diminish. This reduction can lead to challenges in performing daily activities and hinder the normal functioning of older individuals [4,5].

The vertical jump (VJ) and sit-and-reach (SR) tests are important tools for assessing physical fitness and muscle function. VJ, in particular, is considered to be an intuitive and valid test [6]. Unlike other physical tests, VJ is able to accurately measure a wide range of physical capabilities [7]. Over the past few decades, VJ has been utilized to assess muscular power in the lower limbs and is considered as a reliable indicator of functional capacity [8]. Until recently, there have been limited studies investigating the normative value of VJ, with most of the research focused on English and Canadian young adults, and most were athletes [3,9]. In the same context, the existed studies documented the differences in muscle strength, performance, and power between different ethnic groups [10,11].

Unlike VJ, the SR measure is used to assess hamstring and lumbar extensibility [12]. Flexibility is usually determined by the maximum range of motion in a joint or series of joints. Therefore, angular tests that specifically measure hip flexion with the knee extended have been widely used to assess hamstring extensibility [12,13]. Nonetheless, due to the need for sophisticated instruments, qualified technicians, and time limitations, the SR test appears to only be conducted in specific environments and with relatively small sample sizes.

The overall body composition characterizes the size and configuration of the body, which is often described by anthropometric measures [14]. Body composition primarily includes both fat mass (FM) and muscle mass (MM) and is known to vary with age [9]. Motor strength and performance are significantly influenced by anthropometric changes that occur during growth and maturation [15]. Furthermore, as individuals age, there is generally a decrease in muscle mass but an increase in fat mass [16,17]. Muscle mass and strength are two important components of muscle fitness, and both tend to reduce during aging [18]. The loss of muscle mass and loss of muscular power that occur with aging are referred to as sarcopenia and dynapenia. The combined impact of reduced muscle mass and increased fat mass results in sarcopenic obesity, which has been found to be strongly linked to cardiovascular diseases and can increase the risk of mortality among aging individuals [19,20]. Our previous study on the association between hand grip strength (HGS) and body composition indicated that, in ageing, the decrease of muscle strength was faster than that of muscle mass in both sexes [10]. The correlations between muscle mass and HGS were most robust than other correlations. Therefore, in the assessment of muscle fitness and power, it is also important to explore the relationship between body composition, VJ and SR, thus to estimate muscle fitness with aging more comprehensively. It has been shown that genetic, environmental and anthropometric factors could influence biological parameters. Therefore, it is important to understand the normative values of muscle strength and power in different population with variations on genetic background and environments.

Currently, the normative values of VJ and SR, as well as their changing trajectories in relation to body composition, remain unclear for the general Chinese population across a wide range of ages. Therefore, we conducted a secondary analysis using data from the National Health Survey (CNHS) that we conducted from 2012 to 2017. This survey includes a representative sample of the general Chinese population [21]. Our objective was to determine the normative values of muscle fitness and examine their associations with body composition in a sample of unselected Chinese individuals between the ages of 8 and 80. We also aimed to promote the assessment of muscle function growth and development, and further apply it to the early identification of health damage by monitoring abnormal levels of muscle fitness.

Methods

Data resource and study population

This is a secondary analysis of data from the CNHS, which is a large, representative survey conducted in mainland China. The protocol of the CNHS has been previously published [22]. Briefly, a multistage stratified cluster sampling method was used to select eleven provinces or autonomous regions (Guizhou, Hainan, Xinjiang, Shaanxi, Inner Mongolia, Qinghai, Heilongjiang, Yunnan, Gansu, Sichuan and Hebei) from mainland China to conduct the health survey. Provinces or autonomous regions were chosen in the initial sampling phase based on their geographical locations. Then, cities and counties were selected from each province in the second stage. In the following stage, districts were chosen from cities, and rural townships were chosen from counties. In the fourth stage, communities were selected from urban districts, while villages were chosen from rural townships. Individuals from the selected communities and villages were invited to participate. The inclusion criteria were individuals aged 20–80 who had been living in the local area for at least one year. The exclusion criteria were individuals with severe mental or physical disorders, pregnant women, individuals on active military duty, or foreigners. In four out of the eleven selected provinces or autonomous regions, children and adolescents over the age of 7 were additionally recruited. The study has been conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Bioethical Committee of the Institute of Basic Medical Sciences, Chinese Academy of Medical Sciences (No. 029–2013). Written informed consent was obtained from the parent/legal guardian of participants younger than 16 and participants above 16.

Vertical jump and sit-and-reach measurement

The vertical jump was assessed using the Squat Jump (SJ) test. Participants were informed of the testing procedures verbally before the beginning of test. They were then instructed to warm up for an at least 2-min with light exercises before performing the VJ tests. During the test, participants were instructed to sink and to hold a squat position on the contact mat for 3 s. On the count of three, they were required to jump as high as they could. A successful test was considered if there was no sinking or countermovement prior to the jump [22]. The sit-and-reach test involved participants assuming a long-sitting position on a board, with their knees fully extended and feet dorsiflexed and flat against the foot platform. They placed their fingertips together and adjacent to a block that was positioned along a scale. The participants pushed the block forward along the scale using their hands, trying to reach the furthest point possible [22]. Both the VJ and SR tests were performed twice, and the maximum values were recorded in centimeters.

Anthropometry and body composition measurements

During the anthropometric measurements, participants wore lightweight clothing and were not wearing any footwear. Height was measured using a fixed stadiometer to the nearest 0.1 cm. Body composition, including weight, body fat percentage, fat mass, fat free mass, muscle mass, was measured using a body composition analyzer (TANITA BC-420, Japan), with decimal-level accuracy. Body mass index (BMI) was calculated by dividing weight in kilograms by the square of height in meters (kg/m^2). Fat mass index (FMI) was calculated by dividing body fat in kilograms by the square of height in meters (kg/m^2), and MMI was calculated by dividing muscle mass in kilograms by the square of height in meters (kg/m^2).

Measurement of other covariates

A standardized questionnaire was administered through face-to-face interviews. Demographic information, such as sex, age, current residence (urban or rural), and educational level, was obtained. Personal disease history including cardiovascular disease, cerebrovascular diseases, respiratory diseases, musculoskeletal disorders, fraction history, neurological disorders, and cancer, was collected. Prior to the survey, all interviewers and technicians underwent a training program to ensure their proficiency in using specific tools and methods.

Statistical analyses

After excluding missing values in VJ and SR, individuals with any diseases, including cardiovascular diseases, respiratory diseases, cerebrovascular disease, musculoskeletal disorders, neurological disorders, had fracture history, or cancer, and individuals who did not reside in the local area, the final analytic sample consisted of 19,269 participants. Descriptive summary statistics were used to present the characteristics of the study population. The mean and standard deviation were used to describe the average value of body composition indexes, VJ and SR. Additionally, the 5th to 9th values of VJ and SR, stratified by sex and age groups, were calculated to display their normative values in the study population. Spearman partial correlations were conducted to examine the age-adjusted correlations among VJ, SR and body composition indexes. The Dixon-Reed method was utilized to identify outliers for each body composition and muscle fitness index [23].

The LMS (lambda, mu, sigma) method was used to construct growth reference charts, which extends regression analysis to include three indexes [24]: the median (mu), which represents the corresponding change when an explanatory variable changes; the coefficient of variation (sigma), which models the spread of values around the mean and adjusts for any nonuniform dispersion; and the skewness (lambda), which models the departure of the variables from normality using a Box-Cox transformation. The LMS models smooth the percentile curves of muscle fitness indexes using cubic natural smoothing spline functions [25].

Since there are significant difference between sexes in terms of both muscle fitness and body composition, the analyses were conducted separately for each sex. Additionally, due to the high correlation between muscle mass (MM) and VJ, and between BFP and SR, the percentiles of MM and SR, as well as the normalized values of VJ and SR divided by MM and SR, respectively, were also included in the LMS procedures.

The descriptive and correlation analyses were conducted using SAS, version 9.4 (SAS Institute Inc., Cary, NC, USA). We utilized GAMLSS package in R (version 4.0) to apply the LMS method. A p-value of less than 0.05 (two-tailed) was considered as statistically significant.

Results

Basic characteristics

The basic characteristics of the study population are presented in Table 1. Out of the total 19,269 participants, 7574 individuals (39.31%) were males, and 1380 were children and adolescents aged 8–18 years. Significant differences were observed between males and females in terms of body composition and muscle fitness profiles (Table 1). To briefly summarize, males displayed higher levels of muscle mass and VJ, but lower levels of fat mass and SR compared to their female counterparts.

The correlations among body composition and muscle fitness indexes

Table 2 displays the age-adjusted correlations between body composition and muscle fitness. VJ was negatively correlated with body composition, particularly among females. Both sexes showed relatively stronger correlations between VJ and muscle mass indexes. In males, the age-adjusted correlation between muscle mass and VJ was 0.102 ($p < 0.001$), while in females, it was not statistically significant (Spearman correlation coefficient: 0.02, $p = 0.062$). MMI showed opposite correlations with VJ in both sexes, with correlation coefficients of 0.045 in males and −0.133 in females. SR was found to be negatively associated with fat mass indexes, including BMI, BFP and FMI, in males. In females, however, these correlations were only marginally statistically significant (Table 2). Supplementary Table S2 shows the stratified analyses based on adulthood status (aged <18 and aged ≥18). In girls, there were negative associations between body composition indexes and VJ, but no statistically significant results was found in boys.

The sex-specific muscle fitness with ageing

There were 16,376 and 18,903 participants who completed the VJ and SR tests, respectively. The age- and sex-specific normative values of VJ and SR are presented in Table 3 and Table 4, respectively. Fig. 1 illustrats the trajectories of absolute VJ, muscle mass, and the normalized values of VJ (VJ divided by muscle mass) from 8 to 80 years of age. The values of upper and lower VJ across ages in males had two periods: an increase to peak values around 18 (with the 5th and 95th values of 17.7 cm and 41.3 cm, respectively), followed by a decline with aging. The trajectory of VJ in females differed from that of males, as it showed preservation from childhood to early adulthood, and then declined after 30 years old. The lowest VJ values in both sexes were observed in the 70–80 years age group, with the 5th and 95th percentile values of 0 cm and 20.6 cm in males, and 0 cm and 15.5 cm in females, respectively (Fig. 1). The age-and sex-specific normative values of SR are shown in Table 4. The peak values of SR in both sexes occurred in early adulthood and then remained stable in females but declined with ageing in males (Table 4 and Fig. 2).

Discussion

To the best of our knowledge, this study is the first to examine the age- and sex-specific percentile reference values for vertical jump and sit-and-reach across a broad age spectrum in a large representative Chinese population. The suggested normative values from this study could provide valuable information for assessing muscle function and serve as a reference for comparing with research from other populations. Our findings indicate that muscle fitness trajectories vary between sexes and change with age. Generally, VJ and SR values declined with age, particularly in males.

Table 1
Body composition and muscle fitness of the study population, stratified by age and sex (N = 19,269). (Median, IQR).

Male	Height (cm)		Weight (kg)		BMI (kg/m^2)		FM (kg)		BFP (%)		FMI (kg/m^2)		MM (kg)		MMI (kg/m^2)		VJ (cm)		SR (cm)	
8-	128.30	10.10	24.45	5.95	14.53	1.81	1.60	1.95	6.65	5.65	0.98	0.96	21.20	4.40	12.93	0.72	18.40	5.85	2.80	5.90
10-	137.70	7.20	29.30	6.80	15.26	2.28	2.40	2.60	8.30	6.30	1.22	1.20	25.60	3.90	13.32	0.87	19.50	7.00	2.15	8.05
12-	150.90	13.70	37.40	12.00	16.31	2.34	3.00	3.60	8.00	7.00	1.32	1.38	32.60	7.70	14.24	1.14	21.50	7.40	3.30	8.00
14-	162.20	8.50	45.80	10.40	17.44	2.08	3.80	4.50	8.90	7.30	1.51	1.45	39.40	6.00	14.91	0.79	24.25	7.20	6.60	9.20
16-	166.90	7.20	51.70	7.40	18.63	2.64	5.00	3.70	9.60	5.40	1.78	1.16	44.20	5.70	15.83	1.45	27.70	9.00	10.50	9.50
18-	168.00	8.65	54.90	8.60	19.00	3.00	5.40	3.80	10.05	6.40	1.94	1.44	46.55	7.00	16.28	1.69	28.55	9.60	10.10	8.80
20-	170.00	8.30	63.65	17.90	22.10	5.70	11.40	9.30	18.00	9.40	4.00	3.13	50.20	9.30	17.26	2.45	25.40	9.80	4.80	11.40
30-	168.20	8.90	68.20	17.90	24.30	5.30	15.20	8.70	22.20	7.40	5.36	3.01	50.70	9.10	17.93	2.27	22.75	8.30	2.90	11.70
40-	167.10	8.70	68.80	17.10	24.50	5.00	15.70	8.30	22.80	7.00	5.59	2.81	50.40	8.90	18.07	2.20	20.25	7.10	2.00	11.10
50-	166.50	8.90	66.70	17.40	24.10	5.20	15.10	8.80	22.50	7.80	5.43	2.97	49.30	8.70	17.79	2.22	17.70	6.60	0.40	10.90
60-	163.60	9.20	62.00	15.90	23.20	4.70	13.10	8.30	21.40	8.10	4.96	2.92	46.20	8.80	17.29	2.01	15.15	5.30	−1.70	11.10
70–80	162.60	8.50	60.20	15.10	22.45	4.50	12.45	7.50	20.40	7.55	4.63	2.60	44.90	7.65	16.89	1.90	12.70	5.10	−2.95	13.20
Overall	166.50	9.70	64.70	18.90	23.40	5.80	13.50	9.60	21.10	9.10	4.92	3.26	48.60	9.80	17.51	2.45	20.30	8.80	1.80	11.60
Female																				
8-	128.90	10.30	23.60	4.60	14.41	1.67	2.80	1.50	11.90	4.60	1.73	0.82	19.75	3.20	12.03	0.80	16.90	5.10	5.00	7.00
10-	140.90	11.80	30.00	7.80	15.06	2.33	3.90	2.90	13.60	5.30	1.99	1.18	24.70	5.10	12.24	0.96	18.80	6.10	5.00	7.00
12-	150.80	8.30	39.10	9.10	16.73	2.84	7.20	4.60	18.10	8.00	3.08	1.94	29.50	4.70	12.81	1.00	18.30	5.40	8.00	10.30
14-	155.30	8.30	43.80	7.10	17.93	2.70	10.00	4.60	23.50	5.80	4.17	1.62	31.70	3.80	13.04	1.00	18.60	4.95	9.60	8.60
16-	156.75	7.30	45.45	6.05	18.50	2.07	10.60	3.40	23.60	4.70	4.33	1.30	32.60	3.40	13.35	1.00	17.80	5.60	12.80	9.80
18-	156.10	7.30	46.00	6.70	18.70	2.39	10.60	3.60	23.30	5.00	4.33	1.42	33.30	3.60	13.60	1.02	17.85	5.20	11.10	9.70
20-	158.20	8.10	51.40	11.10	20.50	4.00	13.90	6.90	27.20	7.50	5.53	2.72	35.40	4.90	14.11	1.37	16.90	5.60	7.40	11.10
30-	156.30	7.80	54.65	12.10	22.30	4.50	16.75	7.65	30.70	7.80	6.83	3.16	35.70	4.80	14.61	1.37	15.05	5.10	6.40	10.20
40-	156.10	7.80	57.50	12.80	23.60	4.70	19.00	8.40	33.10	7.50	7.82	3.31	36.40	4.90	14.95	1.27	13.40	4.30	6.70	10.40
50-	154.80	8.20	57.55	13.90	23.80	4.80	19.40	8.80	33.90	7.60	8.07	3.44	35.70	5.30	14.89	1.33	12.20	3.60	6.60	10.30
60-	151.60	7.80	53.30	14.50	23.20	5.10	17.80	9.00	33.30	8.40	7.74	3.68	33.80	5.30	14.65	1.31	11.00	3.00	6.40	10.20
70–80	148.60	7.80	49.30	15.20	22.30	5.50	15.85	9.60	32.65	9.50	7.26	3.97	31.50	5.50	14.30	1.49	11.00	2.55	3.90	10.30
Overall	155.20	8.60	54.40	14.20	22.50	5.20	17.00	9.10	31.40	9.20	7.06	3.69	35.30	5.40	14.60	1.50	14.10	5.50	6.80	10.40

BMI: body mass index; FM: fat mass; BFP: body fat percentage; FMI: fat mass index; MM: muscle mass; MMI: muscle mass index; VJ: vertical jump; SR: sit-and-reach.

Table 2
The age-adjusted correlations among muscle fitness and body composition indexes.

Male	BMI	BFP	Muscle	FMI	MMI	VJ	SR
BMI	**1**	**0.940**[a]	**0.789**	**0.974**	**0.960**	**0.026**	**−0.051**
	NA	<0.001[b]	<0.001	<0.001	<0.001	0.038	<0.001
BFP		**1**	**0.659**	**0.992**	**0.817**	**−0.002**	**−0.111**
		NA	<0.001	<0.001	<0.001	0.844	<0.001
Muscle			**1**	**0.712**	**0.834**	**0.102**	**−0.019**
			NA	<0.001	<0.001	<0.001	0.133
FMI				**1**	**0.877**	**0.006**	**−0.091**
				NA	<0.001	0.606	<0.001
MMI					**1**	**0.045**	**0.001**
					NA	<0.001	0.966
VJ						**1**	**0.162**
						NA	<0.001
Female							
BMI	**1**	**0.964**	**0.668**	**0.987**	**0.952**	**−0.149**	**−0.004**
	NA	<0.001	<0.001	<0.001	<0.001	<0.001	0.723
BFP		**1**	**0.573**	**0.994**	**0.842**	**−0.159**	**−0.034**
		NA	<0.001	<0.001	<0.001	<0.001	0.001
Muscle			**1**	**0.617**	**0.702**	**−0.020**	**0.030**
			NA	<0.001	<0.001	0.062	0.041
FMI				**1**	**0.894**	**−0.155**	**−0.021**
				NA	<0.001	<0.001	0.041
MMI					**1**	**−0.133**	**0.031**
					NA	<0.001	0.003
VJ						**1**	**0.141**
						NA	<0.001

a: correlation coefficient, b: *p* value. BMI: body mass index; BFP: body fat percentage; FMI: fat mass index; MM: muscle mass; MMI: muscle mass index; VJ: vertical jump; SR: sit-and-reach.

Over the years, several methods have been applied to conduct the VJ test, such as the Sargent jump, contact mat, and force plate [26–28]. While the force plate is commonly regarded as the most precise tool for measuring lower limb power, its main drawback is its expensive cost (exceeding10000 USD), the requirement of a specialized laboratory, and the necessity for data processing by a user [8]. On the other hand, the contact mat, which was employed in this study, is a popular device for conducting VJ measurements in large populations due to its considerably lower cost (above 1000 USD) and the convenience of portability outside of a laboratory setting. Bui et al. compared three VJ testing methods and concluded that the contact mat test demonstrated high accuracy, particularly for individuals with elevated VJ values [8].

Both age and sex are strongly associated with physical performance. Differences in motor skills between sexes are likely attributed to interactions between environmental and biological factors [29]. Therefore, it is reasonable to develop sex-specific instrumental tools for the practical interpretation of muscle function. This would help identify probable sarcopenia in clinical practice. Findings of this study indicated the faster decline in muscle strength in males during aging than their female counterparts, which highlights the attention of potential early onset of function impairment in men. Although the fundamental processes underlying aging remains unclear, it is important to have detailed knowledge on muscle tissue-specific mechanisms of aging [17]. Few studies that explored VJ and SR in the general population, with most focusing on selected populations such as elders, children and adolescents, athletes, or special occupational groups [3,7–9,13,30], or having relatively small sample size [6]. This limits our understanding of the growth and change pattern of these indexes in the general population. Jumping mechanography provides an alternative method for assessing muscle function [7]. According to our study, for girls, VJ may be more likely to be influenced by fat mass, while for boys, there may be other determinants that influence VJ aside from body composition. Additionally, there are sex differences in the trajectory of VJ. Males reach their peak values at early adulthood and then experience a rapid decline with ageing, while females show peak values in children and adolescents, reach a platform for years, and then decline with ageing. Previous studies also reported sex differences in drop vertical jump in diverse populations [31,32]. During puberty, girls experience an increase in total body fat mass,

Table 3
Normative values for vertical jump, stratified by sex and age.

Age groups	Male								Female							
	n	Centiles					Mean	SD	n	Centiles					Mean	SD
		5th	25th	50th	75th	95th				5th	25th	50th	75th	95th		
8-	92	12.5	15.55	18.4	21.4	25.2	18.54	3.9	134	11.4	14.6	16.9	19.7	23.9	17.22	3.93
10-	139	12.7	16.3	19.5	23.3	26.8	19.87	4.66	154	12.8	15.3	18.8	21.4	25	18.59	4.01
12-	154	13.6	18.4	21.5	25.8	34.5	22.54	6.34	131	12.1	15.7	18.3	21.1	25.6	18.65	4.36
14-	78	14.5	20.8	24.25	28	34.4	24.24	5.59	108	11.7	16.1	18.6	21.05	24.8	18.62	3.98
16-	107	13.7	22.3	27.7	31.3	39.7	26.97	7.48	207	11.4	15	17.8	20.6	25.1	17.93	4.00
18-	124	17.7	23.8	28.55	33.4	41.3	28.59	7.26	202	12.2	15.4	17.85	20.6	24.5	18.08	3.72
20-	934	15.0	20.8	25.4	30.6	38.7	26.04	7.55	1370	11.1	14.1	16.9	19.7	23.6	17.09	4.08
30-	1320	13.5	18.9	22.75	27.2	34.25	23.23	6.34	2226	10.2	12.6	15.05	17.7	21.7	15.34	3.61
40-	1834	12.4	16.7	20.25	23.8	30.5	20.53	5.48	2868	9.4	11.4	13.4	15.7	19.4	13.69	3.44
50-	1285	10.8	14.2	17.7	20.8	26.7	17.93	5.03	1543	9	10.5	12.2	14.1	17.5	12.33	3.22
60-	662	9.7	12.6	15.15	17.9	23.2	15.5	4.48	487	0	9.7	10.9	12.7	16.4	10.99	3.47
70–80	141	0	10.9	12.7	16	20.6	12.82	4.97	76	0	9.8	11	12.35	15.5	10.76	3.15
Overall	6870	11.4	16.1	20.3	24.9	33.3	20.96	6.83	9506	9.5	11.7	14.1	17.2	21.9	14.62	4.13

SD: standard deviation.

Table 4
Normative values for sit-and-reach, stratified by sex and age.

Age groups	Male								Female							
	n	Centiles					Mean	SD	n	Centiles					Mean	SD
		5th	25th	50th	75th	95th				5th	25th	50th	75th	95th		
8-	101	−7.9	−0.5	2.8	5.4	11.5	2.27	5.66	147	−3.2	1.1	5	8.1	12.8	4.81	5.17
10-	144	−8.3	−2.25	2.15	5.8	12.4	1.9	5.86	165	−5.1	1.3	5	8.3	13.8	4.89	5.47
12-	159	−8.3	−1.1	3.3	6.9	13	2.99	6.2	139	−3.5	2.8	8	13.1	19.2	7.99	6.78
14-	79	−3.6	2.1	6.6	11.3	17.7	6.67	6.22	109	−1	6.2	9.6	14.8	20.1	10.13	6.37
16-	109	−1.6	6.4	10.5	15.9	23.2	10.96	7.51	211	0.9	7.2	12.8	17	23.3	12.29	6.68
18-	123	−3.2	5.2	10.1	14	19.8	9.23	7.74	204	0.4	7.3	11.1	17	22.6	11.63	6.96
20-	921	−9.9	−1.2	4.8	10.2	17.8	4.39	8.58	1390	−7.5	1.9	7.4	13	20	7.28	8.23
30-	1326	−11.6	−3.1	2.9	8.6	17.3	2.76	8.66	2337	−6.7	1.4	6.4	11.6	18.2	6.41	7.54
40-	1866	−12	−3.6	2	7.5	16.1	1.97	8.59	3233	−6.7	1.4	6.7	11.8	19.1	6.6	7.88
50-	1414	−13.4	−5.2	0.4	5.7	14.7	0.33	8.36	2139	−6.6	1.4	6.6	11.7	18.8	6.46	7.73
60-	875	−14.8	−7.4	−1.7	3.7	12.7	−1.49	8.31	1110	−6.4	1.2	6.4	11.4	18.8	6.29	7.83
70–80	278	−20	−10.2	−2.95	3	13.7	−3.15	9.52	324	−8.2	−0.55	3.9	9.75	16.4	4.3	7.87
Overall	7395	−12.3	−4	1.8	7.6	16.3	1.83	8.74	11,508	−6.5	1.6	6.8	12	19.1	6.72	7.79

SD: standard deviation.

particularly in their lower limbs, while boys gain more lean body mass [33]. Boys also continue to grow in skeletal length and muscle width, surpassing girls in these aspects [34]. Women have lower muscular volume due to less testosterone production, and a higher percentage of fat mass influenced by estrogen. Therefore, female performance can never reach the same level as that of males [15]. In line with other research among different populations, a decreasing trajectory of jump power with aging in both sexes were observed [6,9]. It revealed that low jump power is associated with a three-fold higher risk of sarcopenia and dysmobility syndrome [6,35]. Jumping ability requires a robust neuromuscular system, coordinated generation of muscle power, intact balance, and stiffness of muscle-tendon system, all of which related to age-related loss of mobility [36]. Although sarcopenia is a common issue among aging individuals, it is important to understand the life-course trajectory of jump power in order to evaluate the optimal intervention time to increase the peak value of muscle fitness and achieve greater clinical benefits. The varied normative values of VJ with regards to sex, in terms of magnitude and rapidity of decline, indicate the necessity for a more focused and gender-specific approach in monitoring muscle power and physical fitness. This is essential for identifying neuromuscular diseases or sarcopenia in the general population as they age.

Several methods have been used to evaluate hamstring extensibility, such as angular tests and lineal tests. Compared to angular tests, lineal tests have a straightforward procedure, are easier to conduct, and require less training to apply [12]. SR is one of the most commonly used measures of flexibility. In our study, females achieved their peak SR values during late adolescence or early adulthood and maintained them consistently as they aged. On the other hand, in males, SR values declined gradually after early adulthood as they aged. The variation in SR trajectory between sexes may indicate differences in hamstring and lumbar extensibility, which are associated with muscle flexibility and overall fitness. Similar with our study, Cai et al. reported sex and age disparities in the associations between combinations of 24-h movement behaviors and physical fitness (including SR) among 135,852 Chinese adolescents [37]; Štefan et al. also reported a higher performance in SR among girls than in boys in Yugoslavia [38]; Tsunoda et al. examined the differences in correlations between physical activity and physical performance based on age and gender in older Japanese adults, and they found a positive connection between leisure time physical activity and physical performance in certain age and sex groups [39].

Unlike jump power, it appears that SR has only a marginal association with body composition and remains stable in female participants, unaffected by advanced age. Furthermore, forward-reach distance in sitting has been suggested to be positively associated with the magnitude of trunk and upper-arm segmental motion, and previous studies have shown that SR can be used as a

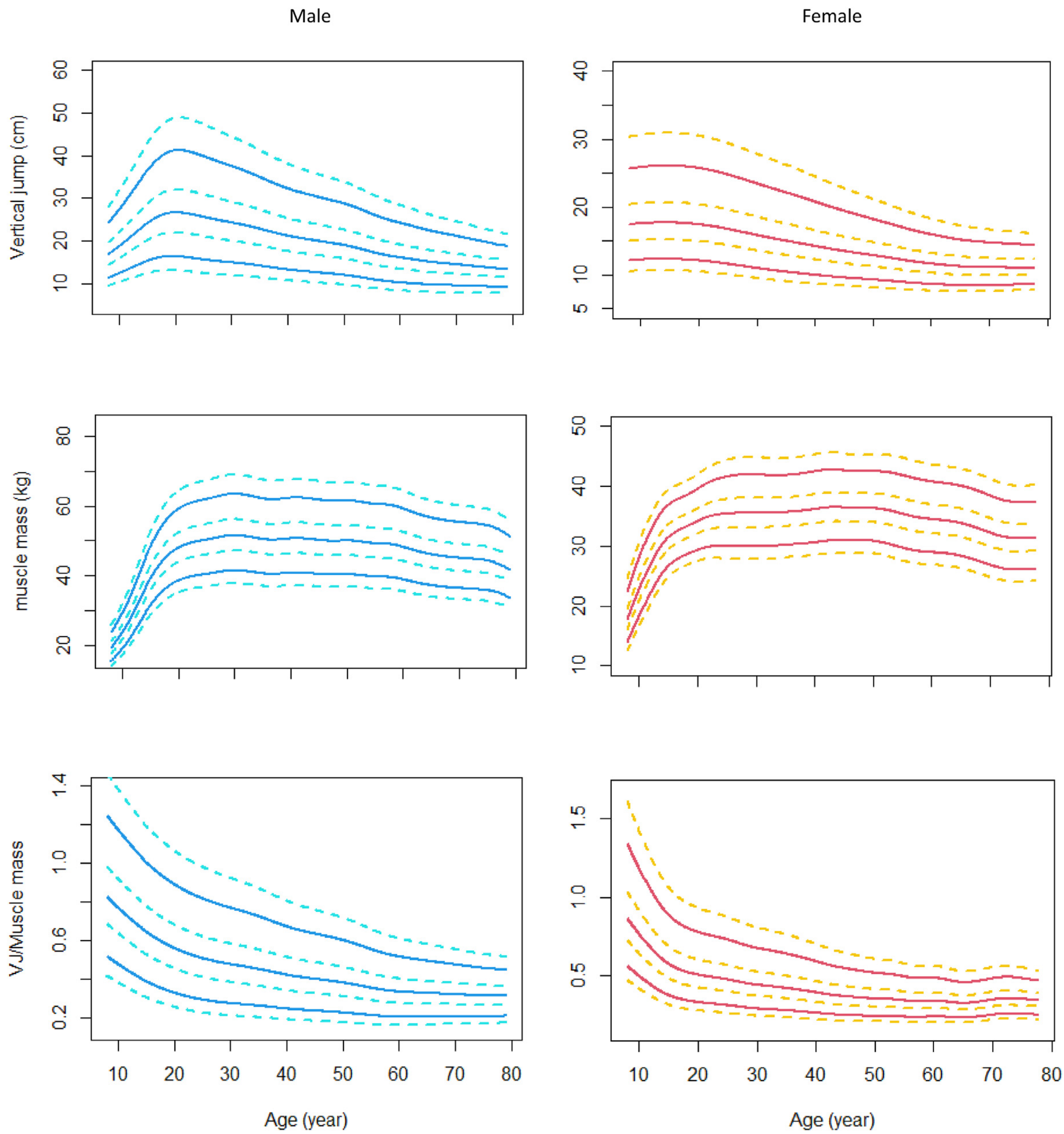

Fig. 1. Vertical jump, muscle mass, and VJ/muscle mass reference percentiles for Chinese people aged 8–80, stratified by sex. The solid lines represented the 5th, 50th, and 95th percentiles, and the dotted lines represented the 1st, 25th, 75th, and 99th percentages. VJ: vertical jump, cm.

predictor of stroke recovery and cardiovascular health [30,40]. This emphasizes the importance of establishing normative values for SR to serve as a reference in assessing these study topics.

Muscle fitness and functional capacity are influenced by a dynamic interaction of various factors, including age, sex, physical activity, nutritional status, genetic backgrounds, and more [9,22,41–44]. With the establishment of sex- and age-specific VJ and SR normative values, this data can provide a precise tool for assessing growth in healthy individuals across a wide range of age. Additionally, it can be used to estimate the potential effects of intervention or make early predictions of sarcopenia.

Our study has several strengths. Firstly, the large sample size of over 19,000 individuals' representative of general population with a wide age range provided comprehensive data on muscle fitness assessment. Secondly, this is the first study to investigate normative values of vertical jump and sit-and-reach in Chinese people. These normative values can be used to assess the growth and development of muscle function, and further applied to early identification of health damage by monitoring abnormal muscle fitness levels. In this regard, our data provides a unique opportunity to evaluate changes in muscle fitness across all ages and genders. However, it is important to acknowledge the limitations of our study. Firstly, the sample size for children and adolescents was relatively small, which may result in unstable estimation in the LMS procedure. Secondly, since the current data from CNHS only covers certain regions in China, further research should be conducted to include a more diverse range of areas in order to make the dataset more representative of the entire country. Nevertheless, during the sampling procedure, we took into consideration the geographic and socio-economic characteristics of the target population, and included subjects based on the local age and sex distribution in order to achieve better representativeness.

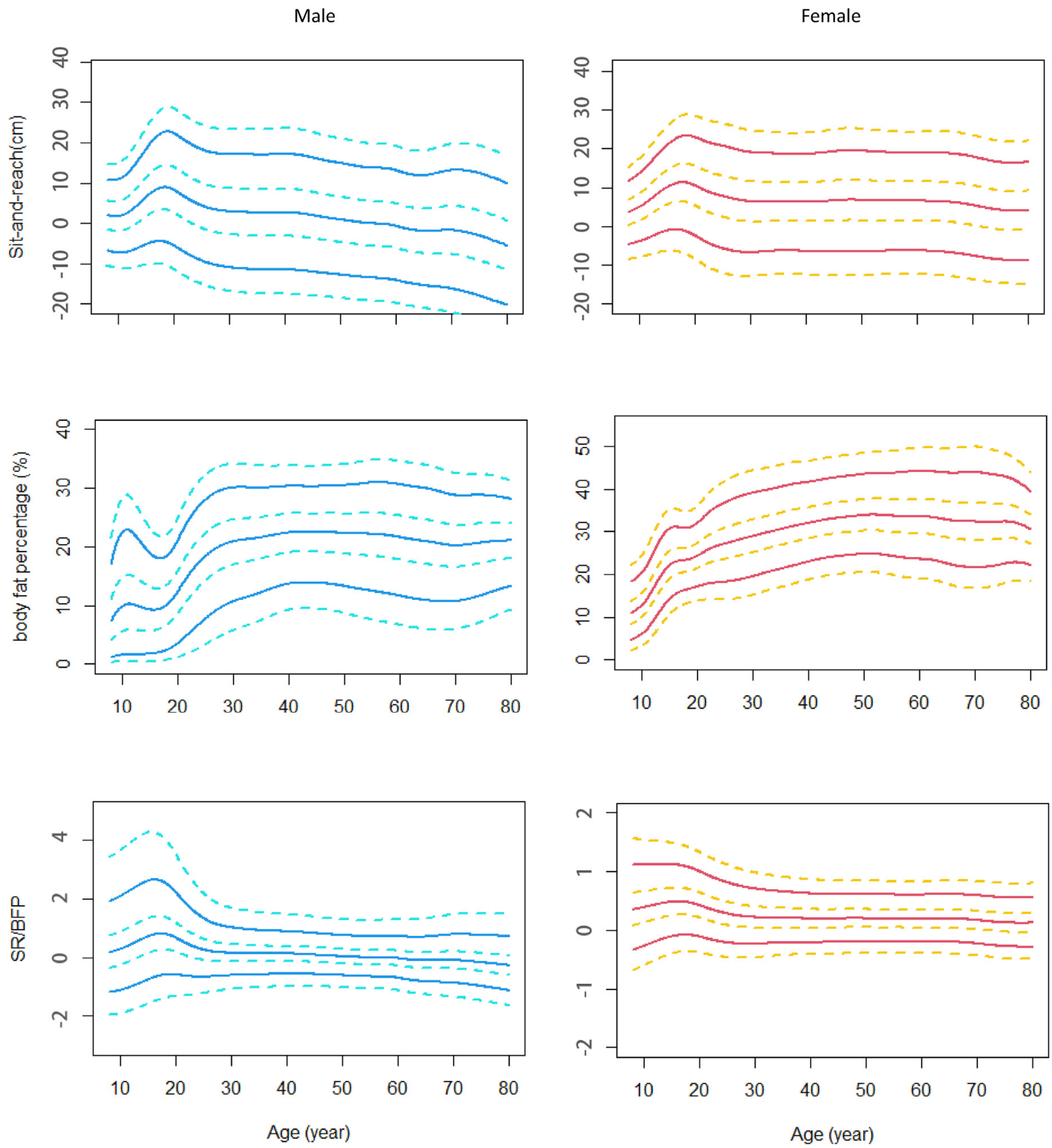

Fig. 2. Sit-and-reach, body fat percentage, and SR/BFP reference percentiles for Chinese people aged 8–80, stratified by sex. The solid lines represented the 5th, 50th, and 95th percentiles, and the dotted lines represented the 1st, 25th, 75th, and 99th percentages. SR: sit-and-reach, cm; BFP: body fat percentage, %.

Conclusions and implications

Our study investigated for the first time the age- and sex-specific percentile reference values for VJ and SR in an unselected Chinese population spanning a wide range of ages. The extensive data obtained can assist in the practical assessment of muscle strength and promote the early detection of sarcopenia and other impairments related to neuromuscular disorders.

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Ethics approval

The study has been carried out in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Bioethical Committee of the Institute of Basic Medical Sciences, Chinese Academy of Medical Sciences (No. 029–2013). Written informed consent was obtained from the parent/legal guardian of participants younger than 16 and participants above 16.

CRediT authorship contribution statement

Huijing He: Conceptualization, Investigation, Methodology, Data curation, Validation, Formal analysis, Writing – original draft, preparation. **Li Pan:** Conceptualization, Investigation, Data curation. **Dingming Wang:** Investigation, Resources. **Jianwei Du:** Investigation, Resources. **Lize Pa:** Investigation, Resources. **Hailing Wang:** Investigation, Resources. **Jingbo Zhao:** Investigation, Resources. **Xia Peng:** Investigation, Resources. **Guangliang Shan:** Conceptualization, Methodology, Validation, Data curation, Supervision, Writing – review & editing, All authors read and approved the final version of the manuscript.

Conflict of interest

Guangliang Shan and Huijing He are editorial board members for Global Transitions and were not involved in the editorial review or the decision to publish this article. All authors declare that there are no competing interests.

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Appendix A. Supplementary data

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