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Title page

How *should* adult handgrip strength be normalized? Allometry reveals new insights and associated reference curves.

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Running title

How should handgrip strength be normalized?

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Abstract

Introduction: Handgrip strength (HGS) is an important indicator of health. Because HGS is strongly associated with body size, most investigators normalize HGS for some measure of body size as a more sensitive indicator of strength within a population. We aimed to (1) identify the optimal body size dimension to remove (normalize) HGS for differences in body size among adults, and (2) generate norm-referenced centiles for HGS using the identified body size dimension.

Methods: Data were from the National Health and Nutrition Examination Survey (NHANES), a representative sample of the U.S. non-institutionalized civilian population. Exclusions resulted in a final sample of 8690 adults aged 20 years and older. HGS was measured using handheld dynamometry. Body size dimensions included body mass, height, and waist circumference. The most appropriate dimension(s) associated with HGS were identified using allometry. We fitted centile curves for normalized HGS using the Generalized Additive Model for Location, Scale, and Shape (GAMLSS).

Results: Findings suggest that neither body mass nor body mass index is appropriate to normalize HGS. Incorporating all three body size dimensions of body mass, height, and waist circumference, or the reduced sub-sets of body mass and height, or height alone, suggest that the most appropriate normalizing (body size) dimension associated with HGS should be a cross-sectional or surface area measure of an individual's body size (i.e., L^2, where L is a linear dimension of body size). Given that height was also identified as the signally best body size dimension associated with HGS, we recommend HGS be normalized by height^2 (i.e., HGS/HT^2). Centile curves for HGS/HT^2 by age group and gender were therefore provided.

Conclusion: Scaling HGS by height^2 may help normalize strength for population-based research.

Key words

Hand strength, body size, adult, nutrition surveys, cross-sectional studies, waist circumference.

Introduction

Muscle strength, assessed by handgrip strength (HGS) using isometric dynamometry, is considered a powerful marker of current and future health (1-5). Low adult HGS is significantly associated with an increased risk of all-cause, cardiovascular, and non-cardiovascular mortality (3, 6), stroke (3), several cancers (including colorectal, lung, and breast cancer) (6), chronic obstructive pulmonary disease (6), type 2 diabetes (7), fractures (8), cognitive declines (including dementia) (8), and functional disability (9). Low HGS is also part of decision algorithms and assessment criteria for determining sarcopenia (10), dynapenia (11), and frailty (12). HGS is easy, affordable and safe to assess (13), has moderate-to-high construct validity with total body and knee extensor strength (14), and high-to-very high test-retest reliability (15). It is for these reasons, why HGS is widely used to determine strength capacity in clinical and epidemiological settings, and for population health surveillance (16).

However, HGS is strongly and positively associated with body size, with taller and/or heavier individuals having greater HGS. For this reason, most investigators report HGS both in absolute units (usually kg) and normalized for some measure of body size, as a more sensitive indication of strength capacity within a population where sub-groups are known to vary in body size (e.g., gender, race). Various normalizing methods have been used to adjust HGS for differences in body size. Most investigators have normalized HGS to body mass (17-24), some have normalized to body mass index (BMI) (23-26), while few have normalized to other measures of body size (e.g., height) (22, 23). The process of normalizing variables such as HGS per body mass (an index known as a ratio standard) has come under strong criticism in the past, a point originally made by Tanner (27) and subsequently by Nevill et al. (28). Indeed, focusing on scaling HGS specifically, Kiilkamp et al. (29) confirmed that HGS should not be normalized by dividing HGS by the entire body mass in both judo athletes and non-athletes. Nevertheless, such ratio standards, using HGS per body mass or HGS per BMI to normalize HGS data, have been used to develop nationally-representative norm-referenced centiles (21, 25) and criterion-referenced health-related cut-points (17, 23). This inconsistency in normalization approaches prompts the obvious research question, “How should HGS be normalized for differences in body size?”

Hence, the purposes of the current study are twofold. Using a nationally representative sample of Americans aged 20 years and older, we aimed to (1) identify, using allometric scaling, which body size dimension is optimal to remove (adjust/normalize) HGS for differences in body size, and (2) to generate norm-referenced centile data for normalized HGS estimated using the generalized additive model for location, scale, and shape (GAMLSS) (30). We hypothesized that the most appropriate body size dimension associated with HGS was likely to be a cross-sectional area of body size such as body mass ($M^{0\ 67}$), see for example, Kiilkamp et al. (29) when normalizing HGS and Nevill et al. (28) when normalizing maximal oxygen uptake for differences in body size.

Methods

Participants

We used data from the 2011-12 and 2013-14 cycles of the National Health and Nutrition Examination Survey (NHANES) dataset, which used a complex multistage probability design to assess the health and nutrition status of a representative sample of the U.S. non-institutionalized civilian population (31). These cycles of the NHANES were selected because they included measures of HGS. Written informed consent was provided by participants and the National Center for Health Statistics Research Ethics Review Board approved NHANES protocols (Protocol #2011-17). We did not seek additional approval because the data used in this study were free from personal identifiers.

While NHANES recruited participants aged 6 years and older, we only used data on adults aged 20 years and older (20-80+ years, with adults aged 80 years and over top-coded in the NHANES at 80 years of age) in this study. Of the initial 19,931 participants, 10,988 were excluded because they: (a) were younger than 20 years (n=8602), (b) were pregnant (n=174), (c) performed the HGS assessment seated (due to physical limitations) 386), (d) were not assessed for HGS with both hands *(n*=1539), or (e) had missing data (e.g., body mass, height, waist circumference) (n=287). In addition, following the procedures of Wang et al. (32) we excluded a further 253 participants as outliers because their bilateral HGS asymmetry was >30%. These exclusions resulted in a final sample of 8690 adults aged 20 years and older.

Measures

The HGS and anthropometry protocols are described in detail elsewhere (33-36). HGS was measured using Takei digital handgrip dynamometer (Model T.K.K.5401, Takei Scientific Instruments, Niigata City, Japan). Participants were randomly assigned to start the HGS test with their right or left hand, with the dynamometer adjusted for hand size by ensuring that the middle phalange of each participant's index finger was bent to 90° and rested flat atop of the handle. A sub-maximal effort practice trial was performed to ensure the dynamometer was properly adjusted for hand size and to confirm understanding of the HGS protocol. Participants stood upright (unless they were physically limited), with their feet hip width apart, their arm extended and hanging down away from their body, and squeezed the dynamometer with maximal effort. Three trials were performed for each hand, alternating hands between trials, with 60 seconds of rest between measures on the same hand. The coefficient of variation across the three trials was 8.2%, equivalent to a typical error of 2.8 kg. For this study, HGS was taken as the average of the maximum score attained for each hand.

Standing height was measured using a fixed stadiometer with an adjustable headboard. Body mass was measured using a Mettler Toledo digital weight scale (Mettler-Toledo, Columbus, OH, USA). Waist circumference was measured at end-tidal expiration using a steel measuring tape placed directly on the skin at the level of the superior lateral border of the iliac crests. Participants self-reported their age and gender.

Statistical analyses

To obtain nationally representative estimates, analyses were conducted using NHANES sample weights (survey, strata, and cluster weights), which account for the complex survey design (including oversampling), survey non-response, and post-stratification. To identify the most appropriate body size dimension(s) associated with HGS, we developed the following multiplicative model with allometric body size components, similar to that used to model the physical performance variables of Greek children (37), Peruvian children (38), and older adults (39).

$$HGS = a \cdot M^{k_1} \cdot HT^{k_2} \cdot WC^{k_3} \cdot \varepsilon$$

where ‘a’ is the scaling constant and k_1,k_2, and k_3 are scaling exponents for the body mass (M), height (HT), and waist circumference (WC) respectively, and e is the multiplicative error ratio (28). Note that the multiplicative error ratio ‘s’ assumes that the error will increase in proportion to body size, a characteristic in data known as heteroscedasticity that can be controlled by taking logarithms, as described below. Age and gender were incorporated into the model by allowing ‘a’ to vary for either gender and each age group (age categories 20-29 years, 30-39 years, ..., 80 years and over) to accommodate the likelihood that HGS may rise and then peak sometime during middle age and decline thereafter. The model can be linearized with a log-transformation, and multiple regression/ANCOVA can be used to estimate the body mass and height exponents for HGS having controlled for both age and gender (Eq. 2). In effect, log-transformed HGS becomes the dependent variable, with age and gender incorporated as fixed factors with log(M) and log(HT)entered as the covariates.

$$log(HGS) = log(a) + k_1 \cdot log(M) + k_2 \cdot log(HT) + k_3 \cdot log(WC) + log(\varepsilon) \quad (2)$$

Traditionally, R^2 is used to measure goodness of fit. However, higher R^2 values do not always indicate a better fit. Higher R^2 can indicate overfitting and adding noise variables will also inflate R^2. While R^2 is useful, it is not necessarily the best method of comparing competing models. An alternative method of model comparison is to use the Akaike information criterion (AIC) that can be conceptualized as a “distance” or error between the data and a model, with lower values indicating a better model. Unlike R^2, which rewards models for being more complex (i.e., having more noise variables) with a higher value being better, AIC penalizes models for being more complex with a lower value being better. As a result, model comparison (goodness-of-fit) between the allometric models and the equivalent linear, additive models was assessed using the AIC. The difference between two AIC values was interpreted as negligible (<2), moderate (>2 and <6), strong (>6 and <10), or very strong (>10) evidence for the model with the lower AIC value being better.

Methods for developing the centile curves

Using a group of models called Generalized Additive Model for Location, Scale and Shape (GAMLSS) (30), we fitted centile curves for the most appropriate normalized HGS ratio (to be identified in the results section) by age and gender. Using this approach, we were able to fit different response distributions and different nonparametric smoothing functions (cubic splines, P-splines, and local polynomial regression). The response distributions fitted included the Box- Cox-t, Box-Cox Cole and Green, and Box-Cox Power Exponential. Each model included NHANES sample weights to adjust the dependent variable for oversampling and to better estimate population parameters. We selected the best fitting models using scaled AIC values (40), which ranks models according to their relative importance. The Box-Cox-t (p, o, v, x) power transformation produced the best fit for both males and females. This distribution was defined by Yv having a shifted truncated t distribution with x degrees of freedom, is a four- parameter distribution, which includes location (p) the median of the distribution, scale, sigma (a), approximately the coefficient of variation, *nu* (v) the controls for skewness (the transformation to symmetry), and *tau* (x) the kurtosis of the distribution (30).

The effects and covariates assessed using the ANCOVAs were considered significant at p<0.05. All statistical analyses were conducted in IBM SPSS Statistics (v26, IBM, Chicago, IL, USA), except for the centile curves which were conducted in R (v4.0.2 (41)). We used the GAMLSS package to fit centile curves (30). Post-estimation diagnostics for these models included standard

QQ-plots, de-trended normal QQ-plots (worm plots (42)) and transformed Owen's plots, to check the age-conditional normality of the transformed data (43).

Results

To illustrate the strong and positive association between HGS and body size (r=0.73, p<0.001), the HGS of U.S. men and women were plotted against height in Figure 1. This figure provides evidence that the errors increase with height, a characteristic in data known as heteroscedasticity that can be controlled by taking logarithms as described previously in the methods section.

Insert Figure 1 here

The ANCOVA analysis of log-transformed HGS identified the main effects of gender and age as significant (age and gender; both p<0.001) but not the age-by-gender interaction (p>0.05). The main effects of age and gender are shown in Figure 2.

Insert Figure 2 here

The ANCOVA analysis also revealed that all three body size covariates were significant (Table 1). Note that fitted body mass (M) and height (HT) exponents are both positive but waist circumference (WC) is negative, confirming that greater body mass and height benefit HGS but excess waist circumference is detrimental to HGS.

Insert Table 1 here

If waist circumference were unavailable, the reduced body mass and height allometric model covariates for HGS are given in Table 2.

Insert Table 2 here

Finally, examining the log-transformed body size covariates in Table 2, the height covariate log (HT) appears to be the dominant body size dimension associated with HGS $(t$ score is nearly twice as large as that associated with body mass). For this reason, we re-ran the ANCOVA analysis, using a simplified/reduced allometric model (Eq. 2), excluding log(M) and log*{WC)*. The follow-up analysis revealed the height covariate as highly significant (Table 3), but the fitted height (*HT*) exponent was very close to 2 (i.e., HT^2), suggesting that if we were to use height alone, HGS should be normalized by dividing HGS by HT^2.

Insert Table 3 here

Note that the simplified ANCOVA analysis of log-transformed HGS also confirmed very similar age and gender main effects as those reported Figure 2, with main effects for both age and gender significant ($p<0.001$) but not the age-by-gender interaction ($p>0.05$) (Figure 3).

Insert Figure 3 here

To assess the benefit of using allometric scaling to determine the appropriate body size dimension to normalize HGS as independent of body size, we calculated the AIC for the above log model 3 and compared it with the AIC obtained from fitting the equivalent linear, additive models using Height and Height^2 as covariates. The AIC for the allometric (log-linear) model 3 was 57256. When we fitted the equivalent linear additive model to predict HGS (using the fixed factors gender and age group plus the gender-by-age group interaction) but allowing height or height^2 as the covariates, the AICs were 58333 and 58312, respectively. Clearly the AIC associated with allometric Model 3 (AIC=57256) is vastly superior to the equivalent linear, additive models AIC =58333 and 58312 (differences >1000), respectively, evidence for very strong differences.

The centile curves for the HGS/HT^2 by age are given for males and females separately in Figure 4.

Insert Figure 4 here

These curves enable the reader to estimate an individual's normalized HGS (HGS/HT^2) using a nationally-representative sample of American adults for comparative purposes. These centile curves provide a straightforward interpretation and add a valuable level of precision. For example, in the case of an individual's HGS/HT^2 slope and age, if their estimate is on the 75th centile, it means that for every 100 individuals of the same age, 75 would have a lower HGS/HT^2 slope and 25 a higher HGS/HT^2 slope. Point-estimate centile tables by age for males and females are also given in Table 4.

Insert Table 4 here

DISCUSSION

Our initial findings, obtained by fitting the multiplicative allometric model log-transformed (Eq. 2) with all three body size terms, suggest that to obtain a normalized HGS_n independent of body mass, height, and waist circumference, we need to calculate the normalized ratio

$$HGS_n = HGS/(HT^{0.968} \cdot M^{0.577} \cdot WC^{-0.619}) \quad (3)$$

see the exponents reported in Table 1. Physiologically this finding makes perfect sense. Taken together, the body mass and waist circumference terms ($M^{0,577} \cdot WC$~$^{0\ 619}$*)* suggest a body mass divided by WC ratio, where the latter is likely to reflect a measure of adiposity providing a ratio likely to be a proxy for lean body mass. The height term will reflect an advantage that a taller individual will be able to exert on the handheld dynamometer, probably due to the mechanical advantage of having longer levers.

The fitted exponents in the model (Table 1) are also entirely compatible from dimensional considerations, as anticipated by Astrand and Rodahl (44). In their chapter on body dimensions and muscular exercise, Astrand and Rodahl (44) reported that force should scale to the physiological dimension of L^2, where L is a linear dimension of body size. Using L as the common linear body size dimension (e.g., body mass, $M = L^3$), the HGS denominator becomes $(HT^{0.968} \cdot M^{0.577} \cdot WC^{-0.619}) = L^{0.968} \cdot (L^3)^{0.577} \cdot\ L^{-0.619} = L^{0.968} \cdot L^{1.731} \cdot L^{0.619} = L^{2.086}$, or approximately L^2. This is equivalent to a body surface or cross-sectional area, suggesting that HGS is associated with, or proportional to, muscle cross-sectional area. Many muscle physiologists might well have anticipated and approved of this dimensional interpretation.

Based on the reduced body mass and height allometric model (Table 2), to obtain a normalized HGS_n independent of body mass and height, we need to calculate the normalized ratio

$$HGS_n = HGS/(HT^{1.438} \cdot M^{0.164}) \qquad (4)$$

The fitted exponents from the reduced-model covariates can also be interpreted from the above dimensional considerations. The body mass and height exponents are $(HT^{1.438} \cdot M^{0.164}) = L^{1.438} \cdot (L^3)^{0.164} = L^{1.438} \cdot L^{0.492} = L^{1.93}$, again approximately L^2.

Finally, using the simplified/reduced allometric model (Eq. 2), incorporating only log-transformed height $\log(HT)$ (excluding $\log(M)$ and $\log(WC)$), the fitted height (HT) exponent was 1.752 (see the parameters in Table 3), again close to 2, suggesting that if we were to use height alone, HGS should be normalized to HT^{1752} as follows,

$$HGS_n = HGS/(HT^{1.752} \qquad (5)$$

a finding that is remarkably similar to the result reported by Neto et al. (22) who recommended that HGS of older adults should be normalized using absolute HGS divided by height^{184}.

These results, using allometric models, suggest that the most appropriate body size components that will optimally remove the effect of body size when normalize HGS, should include all three terms body mass, height, and waist circumference, as given by Eq. 3. These results also suggest that investigators who normalize HGS using either body mass (17-24) and/or BMI (23-26) are probably using inappropriate normalizing body size terms. Clearly, if body mass and height are to be used, they should be combined by multiplying the M and terms together ($^{38}M^{0164}$), see Eq. 4, not dividing body mass (M) by height (HT^2) as is the case when using BMI (kg.nT^2) to normalize HGS. Furthermore, if only one body size component were to be used to normalize HGS, height (HT^{1752}) is considerably more successful than body mass (M) at removing the body size/dimensional effect when normalizing HGS.

We recognize that these fitted exponents adopted in the normalizing equations 3, 4, and 5 above are all “sample specific”. That is, they are likely to work well for American adults, and even though they are both physiologically and dimensionally sound, they are unlikely to be equally successful with, and generalizable to, other populations. This was illustrated perfectly when we compare the fitted denominator exponent HT^{1752} reported in Eq. 5, with the same model adopted by Neto et al. (22) for older Brazilian adults, given as HT^{184}.

However, when normalizing HGS, we need a *simple* methodology that is likely to be “generalizable” to all populations. The one consistent and robust finding from the above allometric models, was that the normalizing (body size) dimension associated with HGS was given by L^2 (a cross-sectional or surface area). Furthermore, given that we were able to confirm that height (HT^2) was the single best body size dimension associated with HGS, we recommend, in response to the question posed in the title, that HGS should be normalized by dividing HGS by height (HT^2).

Our findings have several implications. First, several studies investigating the associations between HGS and health have used scaling approaches that are not optimal. There is a need for future research to determine if using HT^2 to normalize HGS impacts these associations. Second, to improve comparability throughout the literature, we also recommend reporting raw HGS values (i.e., in the measured units) in addition to normalized HGS values, when possible. Last, we recommend using a quintile framework to facilitate the interpretation of these HGS centiles, similar to previous studies (e.g., 45). For instance, adults below the 20th centile can be considered as having ‘very low’ HGS; between the 20th and 40th centiles as having Tow’ HGS; between the 40th and 60th centiles as having ‘moderate’ HGS; between the 60th and 80th centiles as having ‘high’ HGS; and above the 80th centile as having ‘very high’ HGS.

Conclusions

HGS is considered an important indicator of health. However, because HGS is strongly associated with body size, most investigators report HGS normalized for some measure of body size as a more sensitive indication of strength capacity of individual within a population. Some investigators choose to normalize HGS per unit of body mass (kg) whilst others normalize per unit BMI (kg.m"^{2}). The current study suggests that neither body mass nor BMI are appropriate to normalize HGS. Incorporating all three body size dimensions of body mass, height and waist circumference, or the reduced sub-sets of body mass and height, or height alone, suggests that the most appropriate normalizing (body size) dimension associated with HGS should be a cross-sectional or surface area measure of body size (i.e., L^2, where is a linear dimension of body size). Given that height was also identified as the signally best body size dimension associated with HGS, we recommend HGS be normalized by dividing HGS by height^2 (HGS/HT^2).For this reason, the centile curves for the HGS/HT^2 by age (20-29 years, 30-39 years, ..., 80 years and over) are given separately for males and females in the study. Future research should confirm these results in other countries, preferably using nationally-representative data.

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Figure captions

Figure 1. The association between handgrip strength (kg; average of the combined maximum score attained for each hand) and height (m) by gender.

Figure 2. The means (±SE) of log-transformed handgrip strength adjusted for $\log(M)$, $\log(HT)$ and $\log(WC)$ by age group and gender.

Figure 3. The means (±SE) of log-transformed handgrip strength adjusted for $\log(HT)$ alone by age group and gender.

Figure 4. The centile curves for normalized handgrip strength (handgrip strength in kilograms divided by height in meters squared) by age and gender.

Table 1. The fitted parameters of the ANCOVA analysis for all three body size covariates.
Parameter Estimates[8]

Dependent Variable: Log(HGS)

Parameter	**B**	**Std. Error**	**t**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Intercept	3.290	0.080	41.028	<0.001	3.132	3.447
Log (M)	0.577	0.024	24.341	<0.001	0.531	0.624
Log (HT)	0.968	0.049	19.672	<0.001	0.871	1.064
Log(VPC)	-0.619	0.034	-18.474	<0.001	-0.685	-0.553
Female	-0.372	0.020	-18.994	<0.001	-0.411	-0.334

Table 2. The fitted parameters of the ANCOVA analysis adopting the log-transformed body mass and height body size covariates.

Parameter Estimates[8]

Dependent Variable: Log(HGS)

Parameter	**B**	**Std. Error**	**t**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Intercept	1.972	0.037	52.828	<0.001	1.899	2.045
Log(M)	0.164	0.008	20.565	<0.001	0.148	0.179
Log (HT)	1.438	0.043	33.521	<0.001	1.354	1.522
Female	-0.355	0.020	-17.800	<0.001	-0.394	-0.316

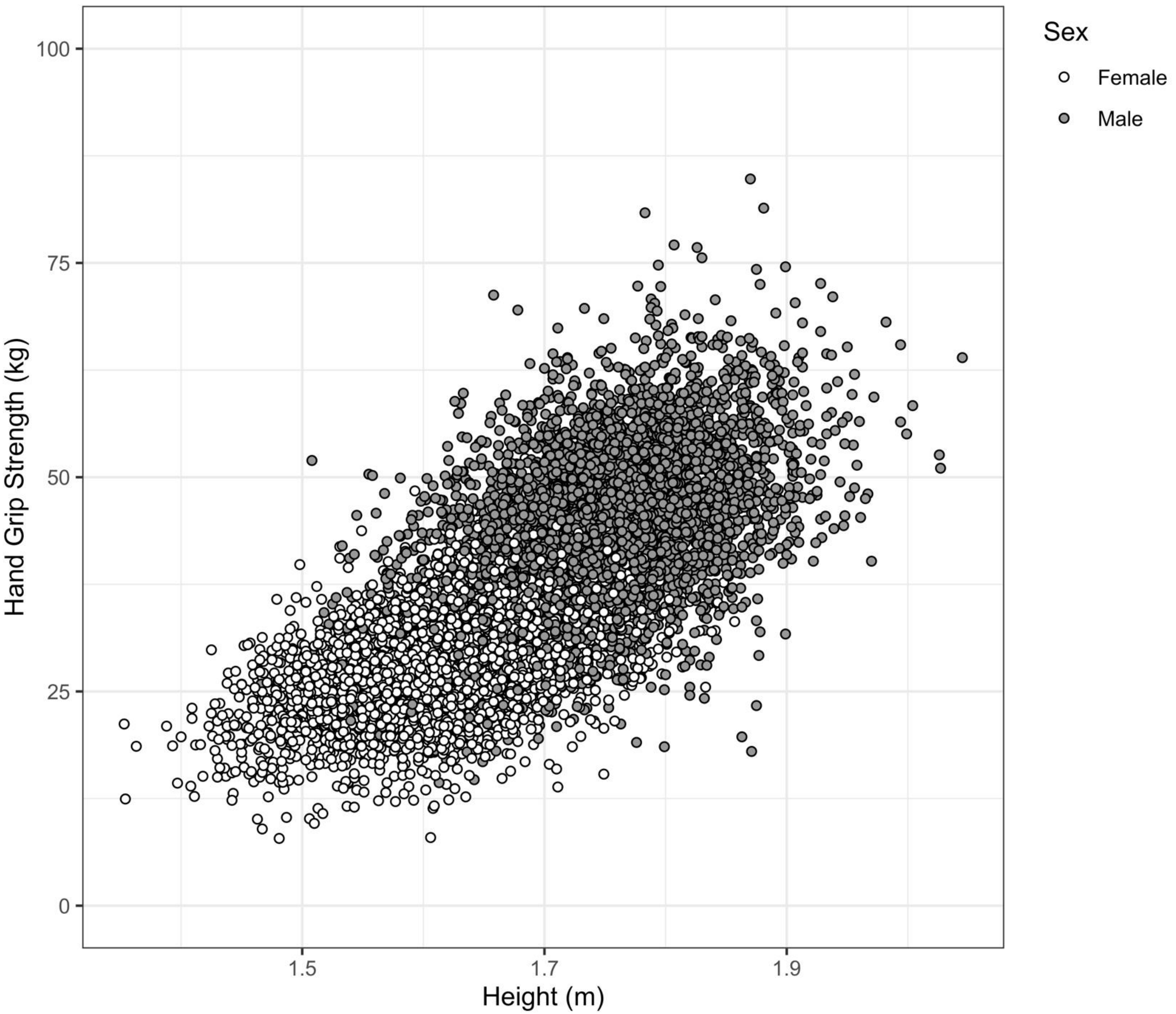
Table 3. The fitted parameters of the ANCOVA analysis adopting the log-transformed height body size covariate alone.

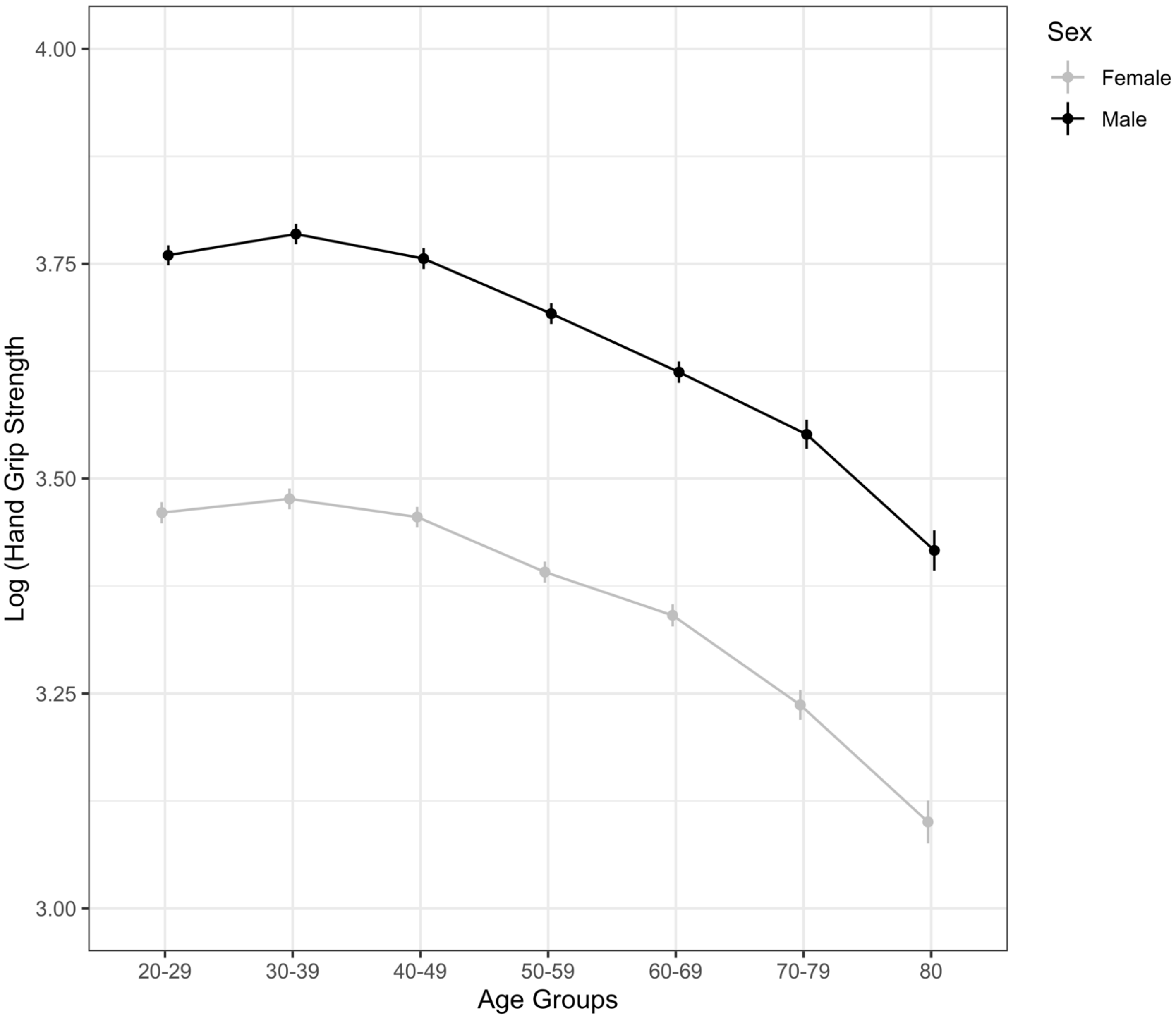
Parameter Estimates[8]
Dependent Variable: log(HGS)

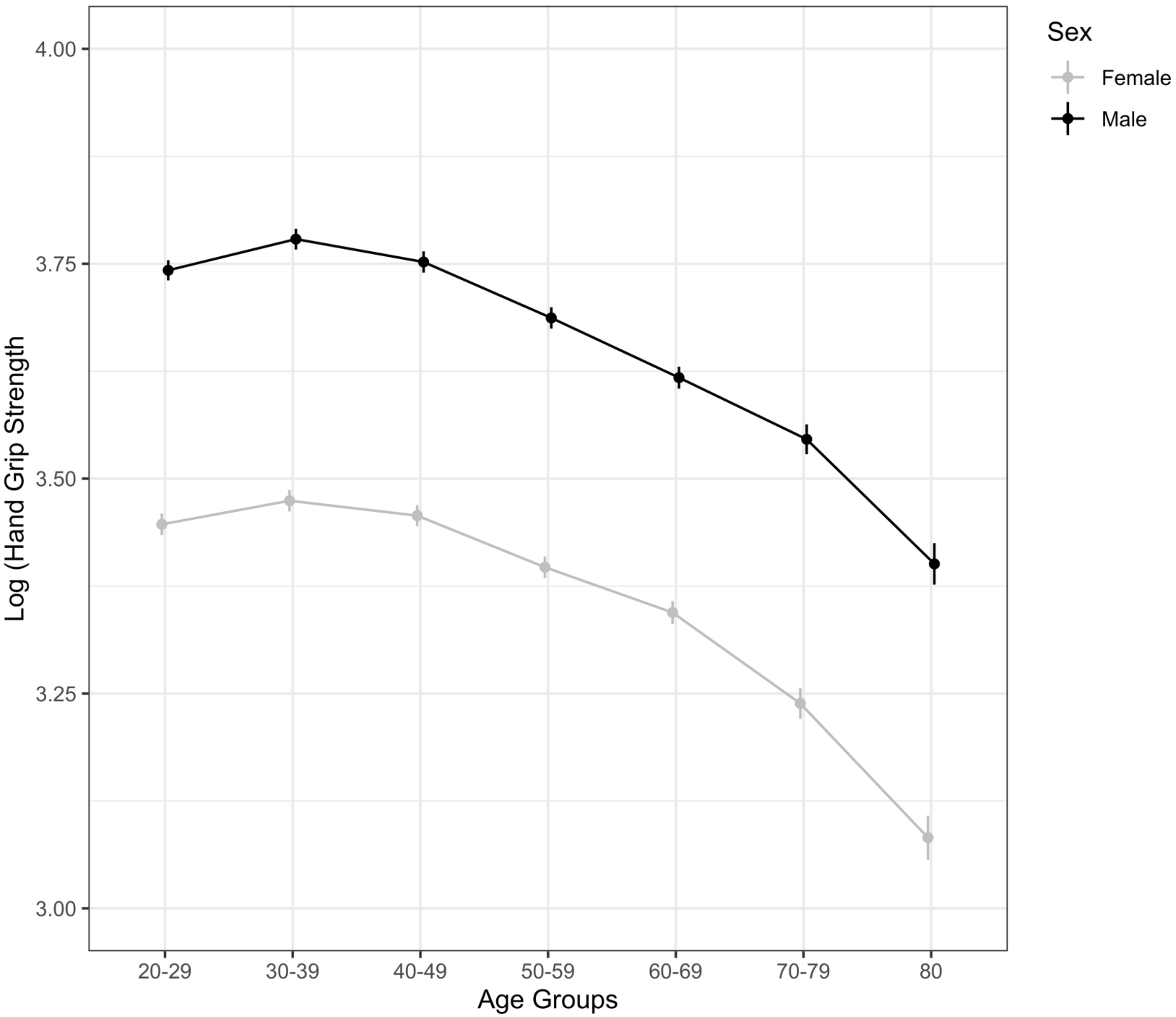
Parameter	**B**	**Std. Error**	**t**	**Sig.**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
Intercept	2.516	0.027	93.261	<0.001	2.463	2.569
Log (HT)	1.752	0.041	42.678	<0.001	1.672	1.833
Female	-0.363	0.020	-17.781	<0.001	-0.403	-0.323

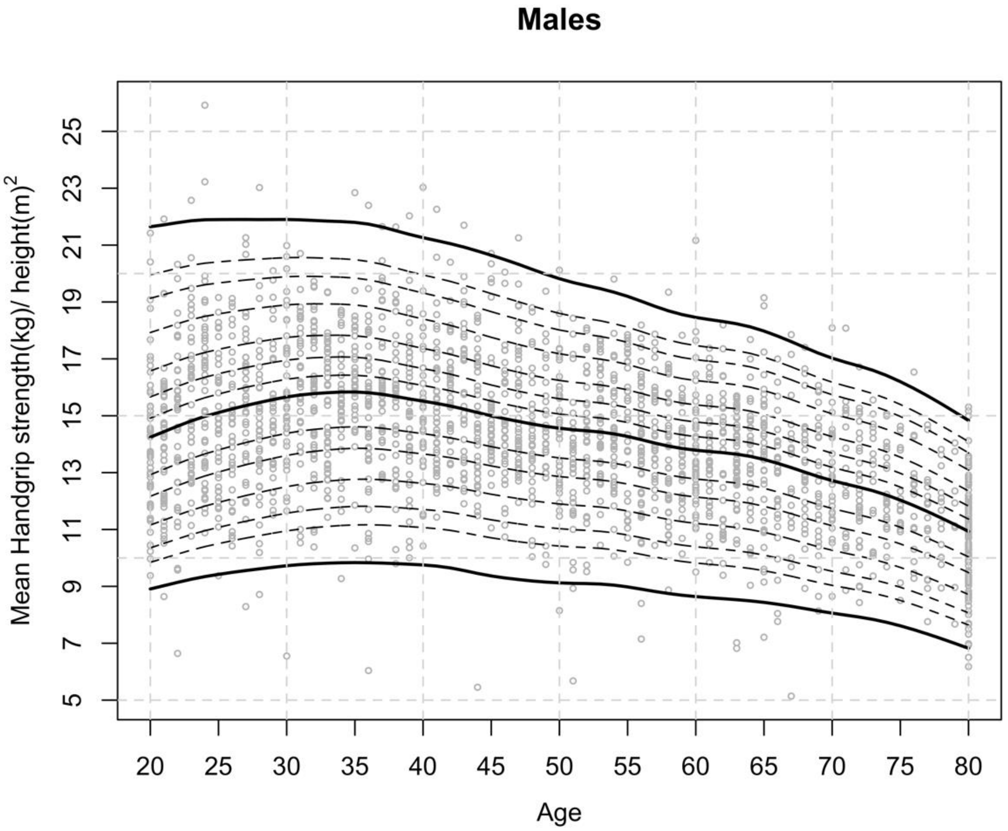
Table 4. Normalized handgrip strength (handgrip strength in kilograms divided by height in meters squared) centiles by age group and gender for a national sample of Americans aged 20 years and older.

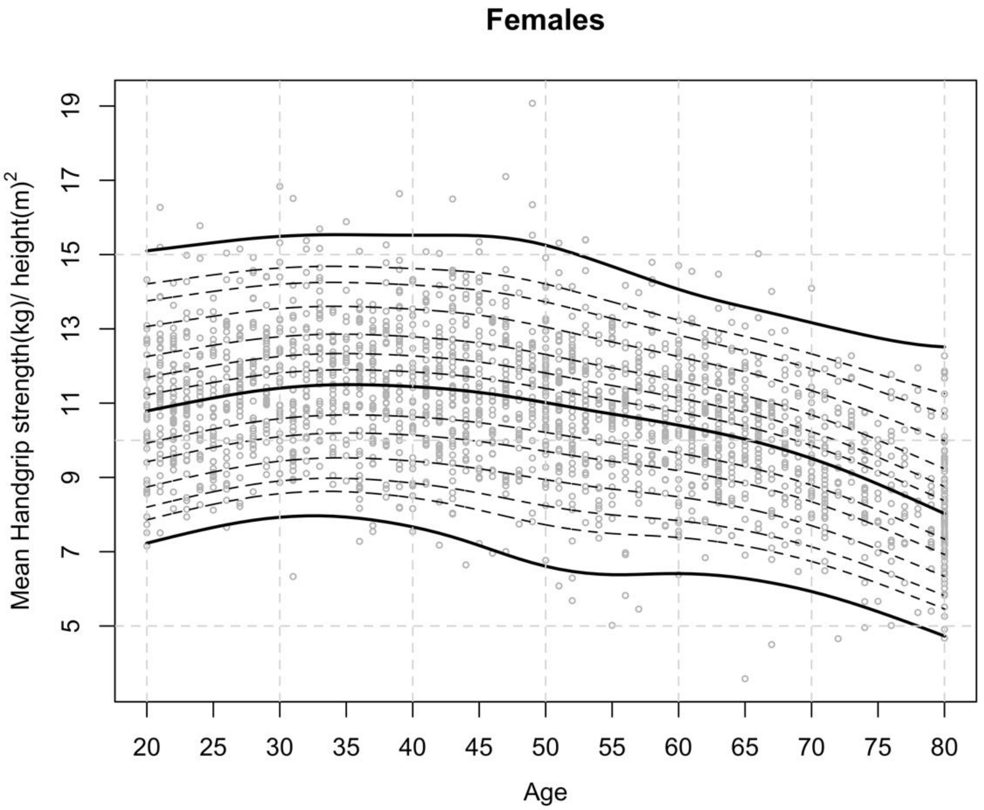
Age	Cl	C3	C5	CIO	C20	C30	C50	C60	C70	C80	C90	C95	C97	C99
Males														
20	8.4	9.5	10.0	10.9	12.0	12.7	14.1	14.7	15.5	16.4	18.3	19.0	19.8	21.6
25	8.9	10.2	10.8	11.7	12.9	13.7	15.0	15.7	16.4	17.3	18.5	19.6	20.4	21.9
30	9.2	10.6	11.2	12.2	13.4	14.2	15.5	16.1	16.8	17.6	18.6	19.7	20.4	21.8
35	9.4	10.8	11.5	12.5	13.6	14.4	15.6	16.2	16.9	17.6	18.6	19.7	20.4	21.7
40	9.5	10.8	11.5	12.4	13.5	14.2	15.4	16.0	16.6	17.3	18.4	19.4	20.0	21.5
45	9.3	10.6	11.2	12.1	13.2	13.9	15.0	15.5	16.1	16.8	17.9	18.8	19.5	20.9
50	8.9	10.2	10.8	11.7	12.7	13.4	14.5	15.0	15.5	16.2	17.4	18.1	18.7	20.0
55	8.7	10.0	10.6	11.5	12.5	13.2	14.3	14.8	15.4	16.0	16.9	17.8	18.4	19.6
60	8.0	9.4	10.1	11.0	12.0	12.7	13.8	14.3	14.8	15.5	16.5	17.3	17.8	19.0
65	6.7	8.5	9.3	10.4	11.5	12.3	13.4	13.9	14.4	15.1	16.0	17.0	17.7	19.1
70	5.7	7.7	8.6	9.8	11.0	11.7	12.9	13.4	14.0	14.7	15.3	16.8	17.6	19.4
75	4.8	6.9	7.8	9.0	10.2	11.0	12.1	12.6	13.1	13.8	14.3	16.1	16.9	19.1
80	3.8	5.8	6.8	8.0	9.1	9.8	10.9	11.3	11.9	12.6	13.3	14.8	15.7	18.1
Females														
20	7.4	8.0	8.4	8.9	9.5	10.0	10.8	11.2	11.7	12.2	13.0	13.7	14.2	15.1
20	7.4	8.0	8.4	8.9	9.5	10.0	10.8	11.2	11.7	12.2	13.0	13.7	14.2	15.1
25	7.7	8.3	8.6	9.2	9.8	10.3	11.2	11.6	12.0	12.6	13.4	14.1	14.5	15.4
30	7.8	8.5	8.8	9.4	10.1	10.6	11.4	11.9	12.3	12.9	13.7	14.4	14.8	15.8
35	7.7	8.5	8.9	9.5	10.2	10.7	11.5	12.0	12.4	13.0	13.8	14.5	14.9	15.9
40	7.4	8.3	8.7	9.4	10.1	10.6	11.5	11.9	12.4	12.9	13.7	14.4	14.9	15.9
45	7.0	8.0	8.5	9.2	10.0	10.5	11.4	11.8	12.2	12.8	13.6	14.3	14.8	15.9
50	6.5	7.7	8.2	8.9	9.7	10.3	11.1	11.5	12.0	12.5	13.3	14.1	14.6	15.8
55	6.2	7.4	7.9	8.7	9.5	10.0	10.9	11.3	11.7	12.2	13.0	13.7	14.3	15.4
60	6.0	7.2	7.7	8.4	9.2	9.7	10.6	11.0	11.4	11.9	12.6	13.3	13.8	14.9
65	5.8	6.9	7.4	8.1	8.8	9.4	10.2	10.6	11.0	11.5	12.2	12.9	13.4	14.5
70	5.4	6.4	6.9	7.6	8.3	8.8	9.6	10.0	10.4	10.9	11.6	12.3	12.8	13.9
75	5.0	5.9	6.3	6.9	7.6	8.1	8.9	9.2	9.6	10.1	10.9	11.6	12.2	13.3
80	4.5	5.3	5.7	6.2	6.9	7.3	8.0	8.4	8.8	9.3	10.1	10.9	11.5	12.8


Hand Grip Strength (kg)
100
75
50
25
0
1.5
1.7
1.9
Height (m)
Sex
Female
Male


Log (Hand Grip Strength
4.00
3.75
3.50
3.25
3.00
20-29
30-39
40-49
50-59
60-69
70-79
80
Age Groups
Sex
Female
Male


Sex
Female
Male
Log (Hand Grip Strength
4.00
3.75
3.50
3.25
3.00
20-29
30-39
40-49
50-59
60-69
70-79
80
Age Groups


Males
Mean Handgrip strength(kg)/ height(m)^2
5
7
9
11
13
15
17
19
21
23
25
20
25
30
35
40
45
50
55
60
65
70
75
80
Age


Females
Mean Handgrip strength(kg)/ height(m)^2
5
7
9
11
13
15
17
19
20
25
30
35
40
45
50
55
60
65
70
75
80
Age