ELSEVIER

Age Trajectories of Grip Strength: Cross-Sectional and Longitudinal Data Among 8,342 Danes Aged 46 to 102

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PURPOSE: The purpose is to study the age trajectory of hand-grip strength after the age of 45 years.
METHODS: In this study, we use data from three large nationwide population-based surveys of Danes aged 45 to 102 years with a total of 8342 participants with grip-strength measurements and up to 4 years of follow-up. Grip strength was measured by using a portable hand dynamometer.
RESULTS: Grip strength declines throughout life for both males and females, but among the oldest women, the longitudinal curve reaches a horizontal plateau. The course of the decline is estimated by using full information in the longitudinal data and is found to be almost linear in the age span of 50 to 85 years. In this age span, mean annual grip-strength loss is estimated to be 0.59 (0.02) (SE) kg for men and 0.31 (0.01) kg for women.
CONCLUSION: This study confirms the previously reported grip-strength decline with increasing age. Estimates were obtained by using full-information methods from large population-representative studies. Equations of expected grip strength, as well as tables with sex-, age-, and height-stratified reference data, provide an opportunity to include grip-strength measurement in clinical care in similar populations.
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KEY WORDS: Hand Strength, Aging, Epidemiology, Reference Values.

INTRODUCTION

Cross-sectional and longitudinal studies showed that muscle strength in adults declines with increasing age among both men and women (1–8). Hand-grip strength is an estimate of isometric strength in the upper extremity, but also correlates with strength in other muscle groups (9) and therefore has been taken as an estimate of "overall strength." Measurement of grip strength therefore has been included in many aging studies. Also, grip strength has proved to be a strong predictor of phenotypes of special interest among the elderly, e.g., physical functioning and disability (10–12), morbidity (1, 13), and mortality (14–17). The instrument to measure grip strength, the handheld dynamometer, is inexpensive, easily portable, simple and quick to use, and thus feasible in home-based settings, which is crucial for response rates in studies of the elderly. Because the test does not necessarily require that participants stand up, grip strength can be determined for the elderly with impairments in lower-extremity functioning. Although affected by the physical and cognitive state of the elderly, the possibility of participating in this performance measure is not inherently limited to better-functioning individuals; therefore, it has been used with high participation rates, even among nonagenarians (10). Furthermore, because no ceiling effect has been observed among the younger and/or predisabled elderly, it also can be used for discriminating function among the middle aged (18).

In cross-sectional and longitudinal studies, grip strength has been reported to decline from approximately 30 years of age (3, 8). Based mostly on cross-sectional studies, mean annual loss in grip strength among healthy people from age 30 to 70 years has been estimated to be 0.5% to 1% of the strength at 30 years of age (19). From cross-sectional and longitudinal studies, the course of the decline was reported to accelerate with increasing age (1, 3–5). However, the annual loss may be underestimated in these studies because no attempt was made to take into account the problem of selective dropout caused by mortality and morbidity that is an inherent problem in aging studies. Furthermore, these studies included only a few participants aged 85 years and older, and two studies included only males

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K.C. initiated the surveys with J.W.V. and M.M.; K.C. and H.F. were responsible for conducting major parts of the surveys; H.F., J.H., and J.M. analyzed the results; H.F. and J.H. wrote the first draft; and all authors contributed to writing the report and interpretation of data.

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Selected Abbreviations and Acronyms
MADT = Study of Middle-Aged Danish Twins
LSADT = Longitudinal Study of Aging Danish Twins

(1, 5). In the present study, we describe the course of decline in grip strength from age 45 by using cross-sectional data from three large nationwide surveys of middle-aged, elderly, and oldest-old individuals, as well as 2- and 4-year follow-up data among the elderly and oldest old. Results can be used for studying differences in health and functioning of the elderly across regions and countries, as well as background data if grip-strength measurement is adopted as a routine measure in clinical assessment of the elderly.

METHODS

Study Population

The sample was composed of participants in three nationwide population-based surveys: the Study of Middle-Aged Danish Twins (MADT) (18); the Longitudinal Study of Aging Danish Twins (LSADT), waves 3 (1999), 4 (2001), and 5 (2003) (20); and the Danish 1905 Cohort Study waves 1 (1998), 2 (2000), and 3 (2003) (21), which have been described in detail previously. In brief, participants in the MADT and LSADT were identified in The Danish Twin Register (22), and participants in the 1905 Cohort Study were identified in the Danish civil registration system (23). Eligible participants in the MADT represented a random sample of 120 twin pairs from each of the 22 birth cohorts from 1931 to 1952 (aged 46 to 67 years in 1998). The MADT has not yet had follow-up surveys. Eligible participants in the LSADT were Danish twins aged 70 years and older on January 1, 1999, and 2001, respectively. The LSADT 2001 survey was composed of follow-up on participants from the LSADT 1999, as well as 460 new participants who had turned 70 years since 1999. The LSADT 2003 survey was composed of only follow-up on participants from the LSADT 2001.

Eligible participants in the 1905 Cohort Study were all Danes born in 1905 and alive in 1998 (age 92 to 93 years), wave 1. The second and third waves were composed of follow-up on participants from previous waves. The MADT survey included 4314 participants (participation rate, 83%). Valid grip-strength measures was obtained from 4148 participants (2123 men and 2025 women) in this cohort. In the LSADT and 1905 cohort surveys, an overview of participation numbers, participation rates, and numbers of grip-strength measures are shown in detail in Figures 1 and 2. All surveys were conducted in periods of 3 to 6 months in 1998 to 2003. A highly comparable structured interview was used in all studies, which were home based and included physical testing (e.g., grip strength and spirometry), cognitive testing, and DNA sampling and were performed by lay interviewers from the Danish National Institute of Social Research. All interviewers had substantial experience in interviewing the elderly, completed a detailed training program by a physician, and were monitored closely during the interview periods. If a person could not participate because of mental or physical weakness, a proxy respondent was encouraged to participate in the interview (LSADT and 1905 cohort surveys only). Thus, proxy participation included no grip-strength measurements (Figs. 1 and 2).

Thirteen twins born in 1905 participated in both the LSADT and 1905 Cohort Study. Grip-strength data for these individuals are used from the LSADT survey only.

Grip Strength

Grip strength in kilograms was measured by using a Smedley dynamometer (TTM; Tokyo, Japan). To measure maximal strength, the width of the handle was adjusted to fit the hand size; the second phalanx should rest against the inner stirrup. Grip strength is influenced by elbow position; strength is greater with a fully extended elbow (24). We required the elbow to be in a 90° position and the upper arm to be tight against the trunk in a series of three measurements, with brief pauses between each, and subsequently used the maximal value as the estimate. We identified the maximum value of three measurements with each hand in the MADT and LSADT and three measurements with the preferred hand in the 1905 Cohort Study. Participants with fewer than three attempts or a difference of 20 kg or more between two measures were excluded (Figs. 1 and 2). In all, grip-strength measures were obtained from 8342 participants at baseline, 2827 participants at 2-year follow-up, and 1539 participants at 4-year follow-up (Figs. 1 and 2). The decreased number of participants at follow-up reflects the large number of MADT intake participants not yet followed up, as well as death and dropout among older participants in the LSADT and 1905 cohort surveys.

Analyses

In the analysis of our longitudinal data, we consider modeling evolution of marginal distributions of grip strength. Our goal is to estimate the evolution of the mean of grip strength over time (defined by age) for each sex based on longitudinal measurements. As expected, follow-up is incomplete for our cohorts because of death and dropout. Participants who drop out do not return later to the study; hence, we possess monotone missing data. We are interested in predicting grip strength in the living and will handle the missing data by imputing values only for dropouts and allow subjects who died to be removed from the study. The analysis therefore

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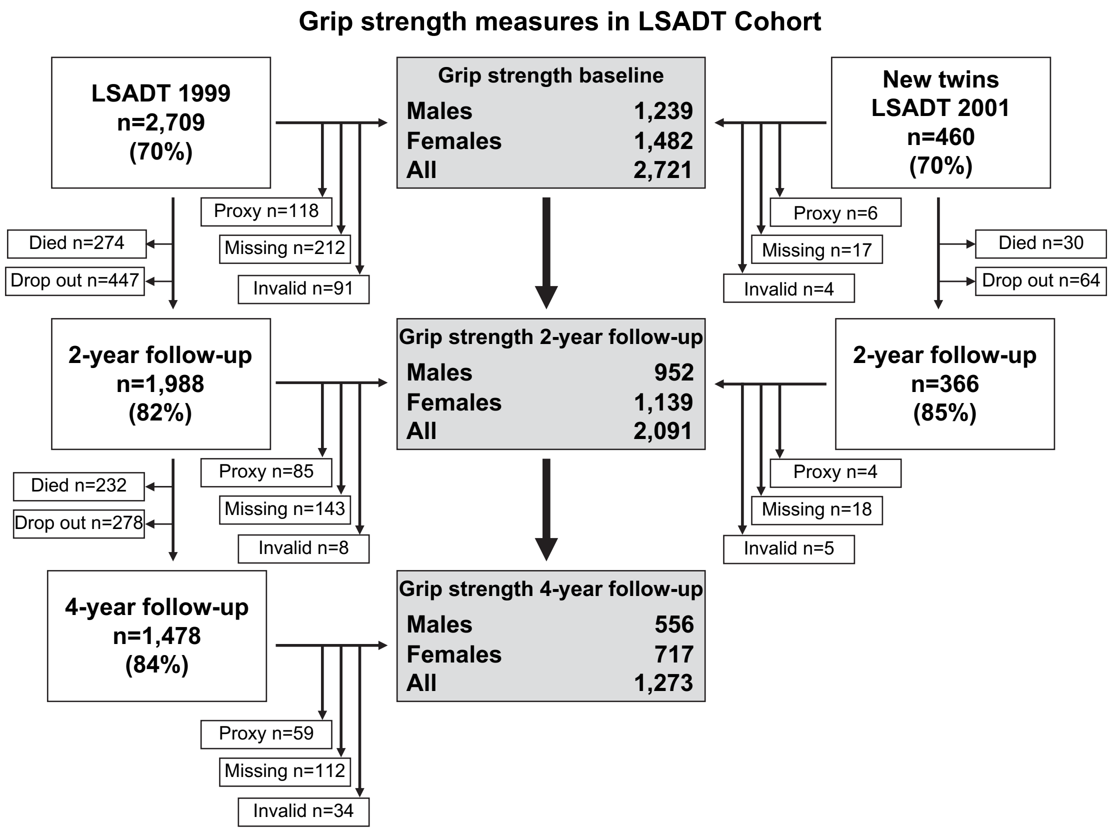

FIGURE 1. Grip-strength measures in the Longitudinal Study of Aging Danish Twins (LSADT) 1999, 2001, and 2003 surveys. Proxy = proxy respondents, missing = no measures, invalid = less than three measures or 20 kg or greater difference between two measures.

assumes that the probability of dropout at wave *t* conditional on being in the study at *t*−*1* and surviving until *t* is independent of grip strength at time *t* (i.e., the "missing at random" assumption (25)). To input missing data, we apply the inverse probability weighting method, as described by Dufouil et al. (26) and Reilly and Pepe (27). Briefly, if individual *i* has probability rho_i(t) of being observed at time *t*, that is, one of 1/rho_i(t) individuals *as individual i* are observed at time *t*, this observation is given the weight 1/rho_i(t). This is equivalent to inputting the observation of individual *i* for the 1/rho_i(t)−1 missing observations. The probabilities rho_i(t) are estimated by using logistic regression with the indicator variable for individual *i* of being observed at time *t* as dependent variable and observed characteristics (in particular, previous grip-strength values) as independent variables. Outcomes from analyses are compared with the case for which missing observations from dropout and death are simply ignored.

To quantify the evolution of the mean of grip strength over time, subjects are classified into 5-year cohorts by age of entry and sex. From ages 70 to 102 years (maximum age), the relationship of mean grip strength with age is estimated wholly from the longitudinal information. Before age 70, estimates follow from cross-sectional observations. We plot estimates of mean grip strength by mean age for each cohort. In case of longitudinal observations, estimates of mean grip strength for subsequent waves are connected by straight lines within each cohort. Finally, the relationship of mean grip strength with age is modeled by smoothed curves using the lowess method (with bandwidth of 0.4).

In this study, participants in the twin cohorts were analyzed as individuals. To account for the nonindependence of observations among intact twin pairs, data were analyzed by using the "robust sandwich estimator" of variance implemented in the statistical software packages STATA (StataCorp, College Station, TX) (28) as the "cluster" option.

RESULTS

Grip strength varied according to age and sex, as expected, i.e., men were stronger than women and strength declined with increasing age (Figure 3). From age 70 onward, 2- and 4-year longitudinal data are included in the figure. Curves show an almost linear course of the decline, with a leveling-off tendency among the oldest women. At

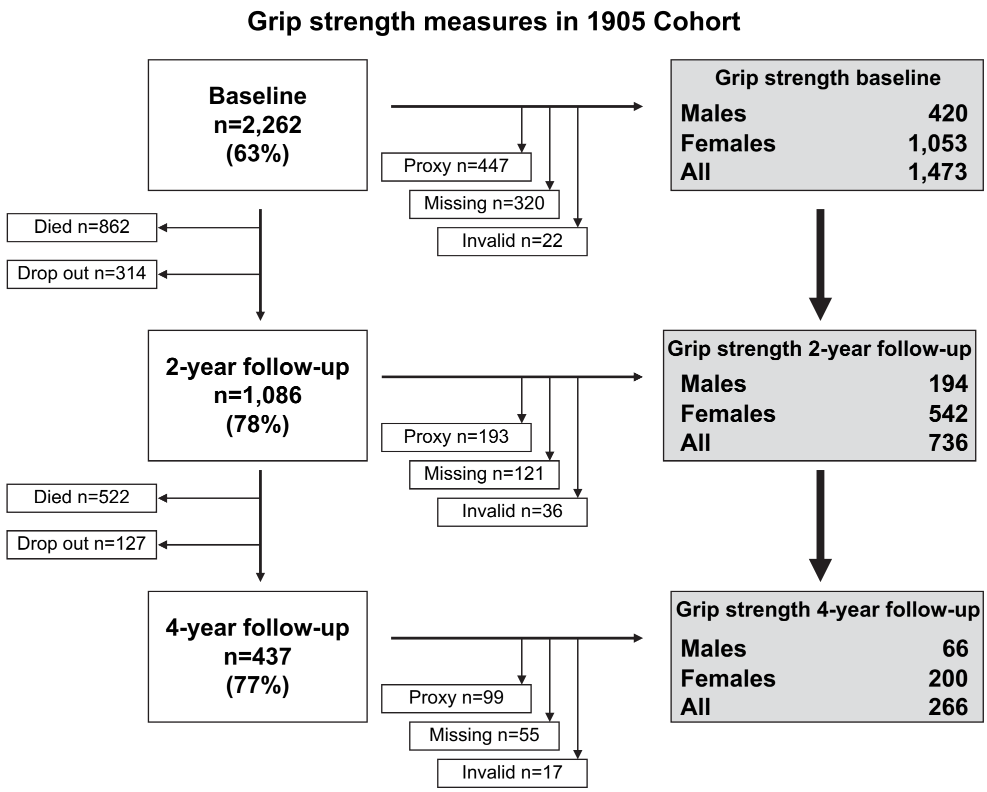

FIGURE 2. Grip-strength measures in the Danish 1905 Cohort Study baseline, first, and second follow-up surveys. Proxy = proxy respondents, missing = no measures, invalid = less than three measures or 20 kg or greater difference between two measures.

baseline, grip strength also varied according to response profile in the successive waves. This is shown by using unadjusted data from the 1905 cohort study in Figure 4 because age adjustment is not needed in this cohort. Participants who completed two follow-ups were stronger than participants who completed only one follow-up, who were stronger than those who participated in only the baseline survey. Furthermore, participants who were nonresponders in next follow-up were stronger than those who died before the next follow-up. The same association is seen across age groups in the LSADT cohort (data not shown). This means that stronger individuals remain in the study, and individual decline therefore is underestimated. If grip-strength decline with increasing age is estimated instead by using full information from the data by application of missing-data methods, curves are adjusted for this selective dropout and consequently shifted modestly downward, as shown in Figure 3. Therefore, using all available information in our data, the population mean decline in grip strength from age 45 to age 98 is described as shown in Figure 5. This figure confirms that decline with age reaches a horizontal plateau among the oldest women.

For possible inclusion in clinical assessment, grip-strength reference values are tabulated across height and age for the two sexes in Tables 1 and 2. Although estimates of sex-, age-, and height-specific grip-strength means are determined with large precision in this study, the SD and range is large, emphasizing the large grip-strength variation among participants. In the age span 50 to 85 years, the course of grip-strength decline is almost linear. In this age span, mean (SE) annual loss in grip strength is estimated to 0.65 kg (0.02) for men and 0.34 kg (0.01) for women. If grip strength is regressed on height and age as independent variables, estimates for mean (SE) annual loss are 0.59 kg (0.02) for men and 0.31 kg (0.01) for women. From this regression, it is found that expected grip strength (GS) in kilograms for any person in the age range 50 to 85 years can be expressed as:

$$GS_{males} = 24.38 + 0.38 \times height(cm) - 0.59 \times age(yr)$$

$$GS_{females} = 11.63 + 0.21 \times height(cm) - 0.31 \times age(yr)$$

DISCUSSION

This study used data from three large nationwide population-based surveys of Danes aged 45 to 102 years, with a total of 8342 participants with grip-strength measurements and

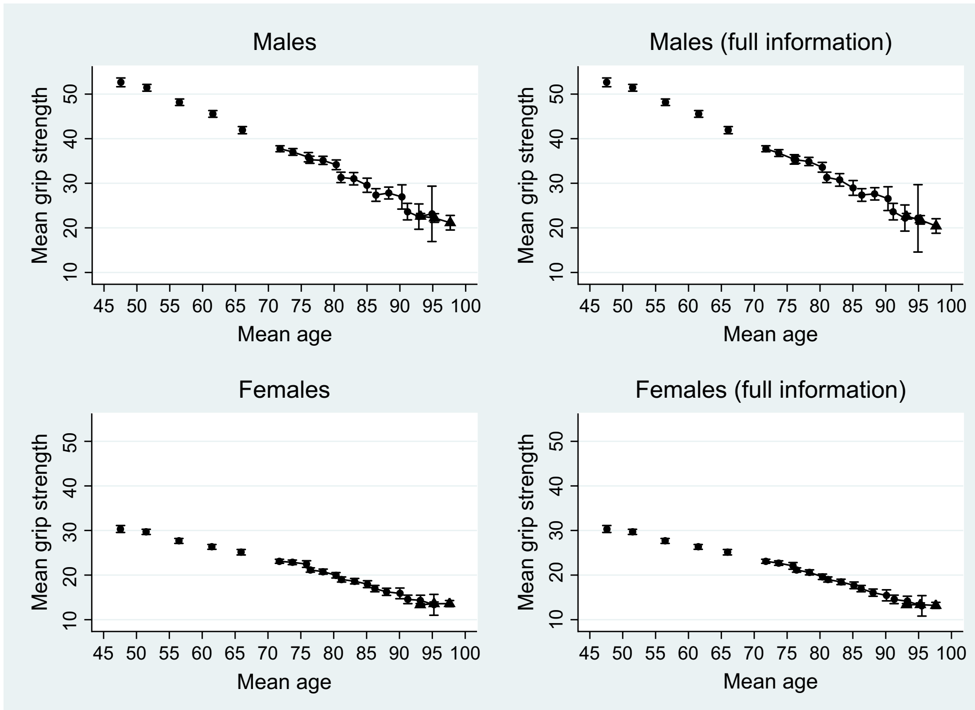

FIGURE 3. Mean grip strength by age. Data come from three surveys: the Middle Aged Danish Twin cohort study, Longitudinal Study of Aging Danish Twins, and Danish 1905 Cohort Study, and are based on 8342 grip-strength values and up to 4 years of follow-up. Full information–labeled curves were adjusted by using growth-curve models.

up to four years of follow-up. It shows that grip strength declines throughout life for both males and females, but among the oldest women, the curve reaches a horizontal plateau. The course of the decline was found to be almost linear in the age span of 50 to 85 years. Analysis of grip-strength longitudinal data was performed by using a full-information method, as previously described. This was done to take into account that nonparticipation, dropout, and mortality are greater among individuals with lower muscle strength, i.e., stronger individuals remain alive and in the study. This is shown in Figure 4 and would lead to underestimation of the age-associated grip-strength decline if not accounted for. Previous studies of age-associated grip-strength decline did not take selective dropout into account, and, as shown in Figure 3, the curves in our study are shifted downward when the full-information method is applied.

It is intriguing that although poor physical functioning is a strong predictor for mortality late in life and although mortality remains greater for males than females at any age, grip strength among men aged 80 years is equal to grip strength among women aged 45 years.

The horizontal plateau in the grip-strength decline observed among the oldest women is in line with previous reports of a decrease in the speed of decline of other aging phenotypes. It thus was reported that mortality in the oldest ages is described by a horizontal or even declining course (29).

Because it well established that low grip strength is associated with imminent functional limitations and disability, mortality, and morbidity, our study provides data (expected grip-strength equations and references tables) that can be used as reference if grip-strength measurement is adapted in routine clinical assessment of the middle-aged and older population. These data also provide opportunities to study differences regarding physical functioning, health, and lifespan of the older population in different regions or countries. However, it is possible that the Danish population is not completely comparable to other similar populations because preliminary results from other studies suggested that mean grip strength may vary across countries, even after adjustment for height. If this is the case, country-specific norms may be needed. Furthermore, it seems likely that the population mean and variance are influenced by the hand dynamometer used.

Some issues in our study deserve consideration. Grip-strength measurements were performed by different lay interviewers, which could introduce a measurement bias attributable to interviewers (interviewer effects). However, interviewer effects are very unlikely to be associated with the other contrasts in this study, age of participants, because

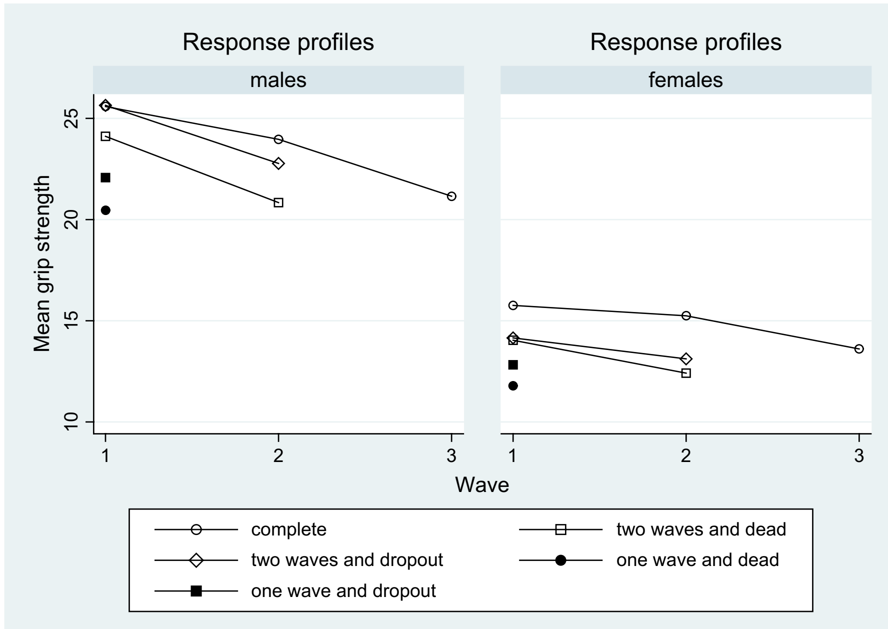

FIGURE 4. Mean grip strength across response profile in the successive follow-ups in the Danish 1905 Cohort Study.

interviewers were distributed according to region. A large proportion of interviewers participated in all surveys and therefore in different age groups of participants. We previously showed that only a negligible proportion of the variability in another functional ability measure could be attributed to interviewer effects (30). In line with this result, differences attributable to interviewer effects accounted for only 1% to 2% of the population variation in grip strength in all three cohorts (data not shown).

The mechanism by which grip strength impacts on disability, morbidity, and mortality is not known. Studies of associations between grip strength and factors that are possible intermediate steps, modifiers, or confounders between grip strength and other aging phenotypes have been reported.

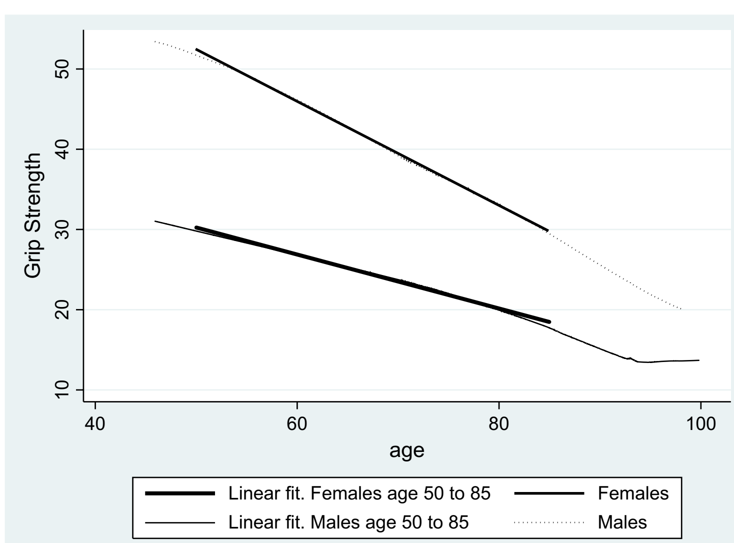

FIGURE 5. Mean grip strength by age. Data come from three surveys: the Middle Aged Danish Twin cohort study, Longitudinal Study of Aging Danish Twins, and Danish 1905 Cohort Study, and are based on 8342 grip-strength values and up to 4 years of follow-up. Curves are smoothed by using the lowess method with bandwidth of 0.4. Linear fit curves are based on linear regression in the age span of 50 to 85 years.

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TABLE 1. Grip-strength normal values for males across height in centimeters and age in years

Height	Grip strength				Height	Grip strength			
<160 cm	Mean	SE	SD	Range	175 cm	Mean	SE	SD	Range
45	—	—	—	—	45	51.8	0.8	6.3	39–69
50	—	—	—	—	50	51.0	0.6	7.0	29–70
55	—	—	—	—	55	48.0	0.7	7.5	23–66
60	—	—	—	—	60	47.2	0.6	6.1	25–62
65	—	—	—	—	65	41.4	0.8	6.9	22–57
70	32.2	2.8	8.5	17–51	70	40.2	0.7	7.5	15–60
75	30.3	3.0	8.0	16–43	75	37.3	0.7	7.7	3–55
80	24.0	3.7	5.2	16–30	80	33.8	0.9	7.0	19–58
85	19.2	2.7	4.6	8–27	85	29.9	1.1	6.0	15–42
90	19.0	2.0	6.2	6–30	90	23.5	0.8	6.8	3–40
95	19.4	3.0	5.3	11–25	95	23.2	1.3	6.4	14–37
160 cm					180 cm				
45	47.3	3.7	6.4	38–55	45	53.6	0.8	6.6	21–68
50	44.0	2.0	5.2	34–51	50	52.6	0.7	7.2	33–71
55	41.4	1.1	4.2	31–47	55	51.2	0.8	6.9	33–67
60	37.8	2.0	8.4	11–49	60	47.7	0.9	8.2	15–65
65	36.1	1.5	5.5	24–43	65	44.7	0.9	5.9	27–60
70	32.4	1.4	7.1	15–51	70	40.0	1.0	8.1	17–63
75	32.3	1.1	6.8	9–45	75	37.7	1.0	7.6	14–60
80	29.3	1.4	6.0	18–41	80	35.0	1.8	8.1	23–57
85	25.2	1.5	4.6	14–34	85	28.8	1.0	2.9	22–37
90	21.6	0.8	6.1	3–35	90	23.2	1.1	7.1	11–39
95	20.5	1.9	7.5	6–34	95	21.6	2.1	7.8	9–39
165 cm					185 cm				
45	49.6	1.7	7.0	40–65	45	57.2	1.0	6.8	36–74
50	47.7	1.3	7.0	25–61	50	56.2	1.0	7.5	40–74
55	47.5	0.9	6.4	34–68	55	51.8	1.0	7.4	32–69
60	43.3	0.7	5.0	30–54	60	48.0	1.8	9.8	22–62
65	40.5	0.9	6.7	20–54	65	44.9	1.1	6.1	25–59
70	35.7	0.7	6.9	15–52	70	42.0	1.5	7.4	23–62
75	33.1	0.7	7.1	10–49	75	37.0	1.4	6.3	23–50
80	31.7	0.9	7.6	12–48	80	38.1	3.4	8.4	29–53
85	27.2	1.0	6.5	13–45	85	—	—	—	—
90	22.8	0.5	6.2	9–42	90	22.3	1.3	5.6	12–33
95	21.5	0.9	6.4	9–38	95	22.9	3.6	7.3	12–33
170 cm									
45	49.5	1.2	7.9	45–55					
50	49.7	0.7	7.3	45–54					
55	45.8	0.6	6.6	41–50					
60	44.0	0.6	6.4	40–48					
65	41.9	0.7	6.9	37–47					
70	37.0	0.5	6.7	33–42					
75	35.3	0.4	6.2	31–40					
80	32.9	0.6	6.4	29–38					
85	30.9	0.7	5.0	27–35					
90	24.0	0.6	7.1	20–29					
95	22.4	0.7	5.8	19–26					

TABLE 2. Grip-strength normal values for women across height in centimeters and age in years

Height	Grip strength				Height	Grip strength			
<150 cm	Mean	SE	SD	Range	165 cm	Mean	SE	SD	Range
45	—	—	—	—	45	31.2	0.5	4.7	20–45
50	—	—	—	—	50	29.7	0.5	6.0	6–48
55	—	—	—	—	55	28.1	0.4	5.3	8–43
60	—	—	—	—	60	27.7	0.4	4.7	10–41
65	—	—	—	—	65	25.8	0.5	5.0	13–41
70	18.6	0.9	3.0	14–25	70	23.8	0.4	5.0	11–39
75	18.1	0.8	2.9	12–26	75	22.6	0.4	5.0	9–34
80	16.9	1.0	2.8	10–21	80	20.1	0.4	4.2	9–32
85	14.5	1.7	2.9	7–17	85	17.9	0.6	4.7	7–35
90	12.6	0.4	3.0	3–18	90	14.1	0.3	4.1	2–25
95	11.7	1.0	4.2	3–18	95	14.4	0.5	4.5	4–25
150 cm					170 cm				
45	25.9	1.0	3.3	15–33	45	32.1	0.9	5.6	17–43
50	28.2	1.4	4.3	24–40	50	31.6	0.6	5.3	19–43
55	25.2	1.2	3.8	15–32	55	29.9	0.7	5.0	17–42
60	21.3	1.1	4.0	15–35	60	28.4	0.8	5.1	5–41
65	21.2	0.9	4.0	10–26	65	26.8	1.2	5.5	16–40
70	21.2	0.7	4.3	12–33	70	25.1	0.7	4.8	12–42
75	19.5	0.7	4.6	3–32	75	23.1	0.6	4.3	12–37
80	17.5	0.6	4.0	4–27	80	20.7	0.8	5.0	9–32
85	17.3	0.7	4.4	7–27	85	18.7	0.8	2.8	10–23
90	12.9	0.3	4.4	2–25	90	14.9	0.7	5.6	4–29
95	13.5	0.5	4.5	2–25	95	13.8	0.7	3.4	8–20
155 cm					175 cm				
45	28.3	1.3	6.1	16–42	45	34.2	1.5	5.6	22–44
50	27.5	0.6	4.1	14–34	50	31.7	1.0	5.6	18–42
55	26.2	0.7	5.1	8–40	55	31.5	1.5	5.8	19–41
60	24.7	0.6	5.0	11–35	60	27.5	1.4	5.8	10–36
65	24.1	0.6	4.8	13–38	65	28.3	1.4	3.4	22–33
70	22.0	0.5	4.8	8–35	70	24.2	1.4	3.3	13–34
75	21.1	0.4	4.7	6–36	75	27.4	1.7	5.5	20–37
80	18.8	0.5	4.8	7–34	80	22.9	1.3	3.9	16–28
85	16.2	0.5	3.7	7–27	85	—	—	—	—
90	12.9	0.3	4.4	3–29	90	12.3	1.0	3.9	6–22
95	13.4	0.4	4.6	2–28	95	13.0	1.9	4.5	6–23
160 cm									
45	28.5	0.7	5.4	15–49					
50	28.8	0.5	5.6	10–41					
55	26.7	0.5	5.1	6–38					
60	25.7	0.4	4.8	13–40					
65	25.4	0.5	4.9	13–39					
70	23.2	0.4	5.3	10–37					
75	21.1	0.3	4.8	5–37					
80	19.5	0.3	3.9	9–33					
85	17.7	0.5	4.5	5–30					
90	13.9	0.2	4.5	2–27					
95	13.5	0.3	4.3	3–28					

Low grip-strength levels or a steep decline thus has associated with recently diagnosed rheumatoid arthritis (31), depressed mood (32), high insulin levels (33), and high levels of serologic markers for inflammation (interleukin 6, tumor necrosis factor α, and C-reactive protein) (34, 35). Another potential confounder for the association between grip strength and aging phenotypes is physical activity. It is well documented that grip strength is associated with physical activity (i.e., more active individuals have a stronger grip) (2, 36, 37), which in itself predicts better survival (38, 39), less disability (40), and less morbidity (41, 42). However, a conceivable explanation for the positive association between grip strength and aging phenotypes is that grip strength serves as a marker of reserve muscular capacity (3, 9) and nutritional status, and grip strength and hand function in themselves are important for the studied phenotypes (43, 44).

In conclusion, we report the course of the age-associated decline in grip strength from age 45 and onward. Because grip strength, in addition to being inexpensive and easy to measure, is associated with current and future physical functioning, morbidity, and mortality, grip-strength assessment in clinical care is facilitated by the present reference data. Furthermore, the data possibly can be used for studying differences in aging across regions and countries.

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