Sex differences in the level and rate-of-change of physical function and grip strength in the Danish 1905-Cohort Study

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Abstract

Background. Previous research among young-old persons suggests that the rate-of-change in physical and cognitive functioning is associated with longevity. This study examined sex differences in the level and rate-of-change in physical function and grip strength in nonagenarians. We also investigated the associations of growth parameters with lifespan.

Methods. The analysis included all Danes born in 1905 and alive in 1998, when the baseline survey was conducted. A total of 2262 persons (62.8%) aged 92-93 participated at intake. The survivors from previous waves were followed-up in 2000, 2003 and 2005. Hence, we fully used the power of having a cohort with multiple assessments in late life and virtually complete follow-up of survival status (until January 2008). Change in physical function (strength score) and grip strength was analyzed using latent growth curve modeling.

Results. The present study revealed that men had higher initial level and rate-of-change in strength score and grip strength. Lifespan was positively and significantly correlated with intercepts and slopes suggesting that the longest living women and men have higher initial levels of strength score and grip strength and smaller rate-of-change. The initial level of strength score was more predictive of mortality than the rate-of-change, and the predictive effects were similar in men and women.

Conclusion. The Danish data suggests that despite the initial advantage, oldest-old men had a steeper decline in physical function and grip strength. It also indicated that the initial level of physical function was more predictive of mortality than the rate-of-change, similarly in men and women.

Background

The empirical evidence cumulated over the course of the 20th century revealed an apparent contradiction between health and survival of men and women (1-5). Although sex differences has narrowed over the last quarter of the 20th century in many developed countries, women still enjoy longer life than men at all ages (6, 7). Nevertheless, a number of cross-national comparison studies showed that women tend to report poorer self-rated health (8-10) and have higher disability levels compared with men at all ages (11, 12) with the female disadvantage in disability becoming more pronounced at the advanced ages (13, 14). Apparent sex differences favoring men have been indicated in physical performance tests as well (15-17).

It has been suggested that handgrip strength is able to distinguish the frailty of people within the narrow age range better than does chronological age (18). Several studies found that grip strength is predictive of disability among middle-aged men (19), as well as older persons (20, 21). Others demonstrated that grip strength predicts all-cause, cardiovascular (CVD) and cancer mortality among men, but it ceased to predict mortality among elderly women in multivariate analyses (22, 23). Several studies found predictive effects of grip strength for all-cause mortality in both men and women (24, 25) or in the females samples only (26, 27).

Previous research suggest that many physiological functions reach steady levels around 30 years of age and begin to decline around 40 years (28) and that the course of the decline accelerates with increasing age (29-33). Based on the review of cross-sectional and longitudinal studies, the median loss for musculoskeletal system from age 30 to 70 years has been estimated to be 0.3% per year and the mean decline in muscle strength (hand pressure) was 0.7% in men and 0.6% in women (28). It has been also found that the decline is steeper in the individuals with greater levels of muscle strength at baseline (32, 33). A recent study indicated that although the initial level of grip strength was substantially higher in men, but they had also significantly greater linear change (34).

Studies of young-old persons suggest that the rate-of-change in physical and cognitive functioning is associated with longevity (35). However, few data are available on rate-of-change among the oldest-old population due to logistical challenges (high mortality and non-response), but available data suggest that although the level of functioning is predictive of survival, the rate of decline is also important. The decline – mortality association is the central question in the "terminal decline research" that has been done primarily on cognitive abilities. Several studies have found that declining cognitive functioning among elderly individuals is associated with impending death (36-40). Results from the Baltimore Longitudinal Study of Aging (BLSA) suggest that the rates of change in muscle power and isometric strength are stronger predictors of mortality than the power and strength levels (41). However, little is known about sex differences in the rate-of-change in physical function in the oldest population. Most previous studies were restricted to small or specific samples, such as one ethnic or sex group, and were limited in the number of measurement occasions. Although it is well documented that women have lower physical strength, most studies did not specifically focus on sex differences in the decline of physical performance or on the sex differential effect of rate-of-change on survival. It is also unclear to what extent the health-survival paradox is due to sex differences in level and/or rate-of-change in physical functioning.

The present study aimed to determine whether there are sex differences in the initial level and rate-of-change in reported physical function and grip strength, whether it is the level or rate-of-change that is more predictive of mortality, and, finally, whether sex moderates the associations of the level and rate-of-change with lifespan. To address these research questions we used previously collected longitudinal data on a whole national Danish cohort born in 1905 and followed from ages 92-93 to 100 years with almost complete survival status available until January 2008. Hereby we are fully using the power of having a cohort with multiple assessments in late life and virtually complete follow-up.

Material and Methods

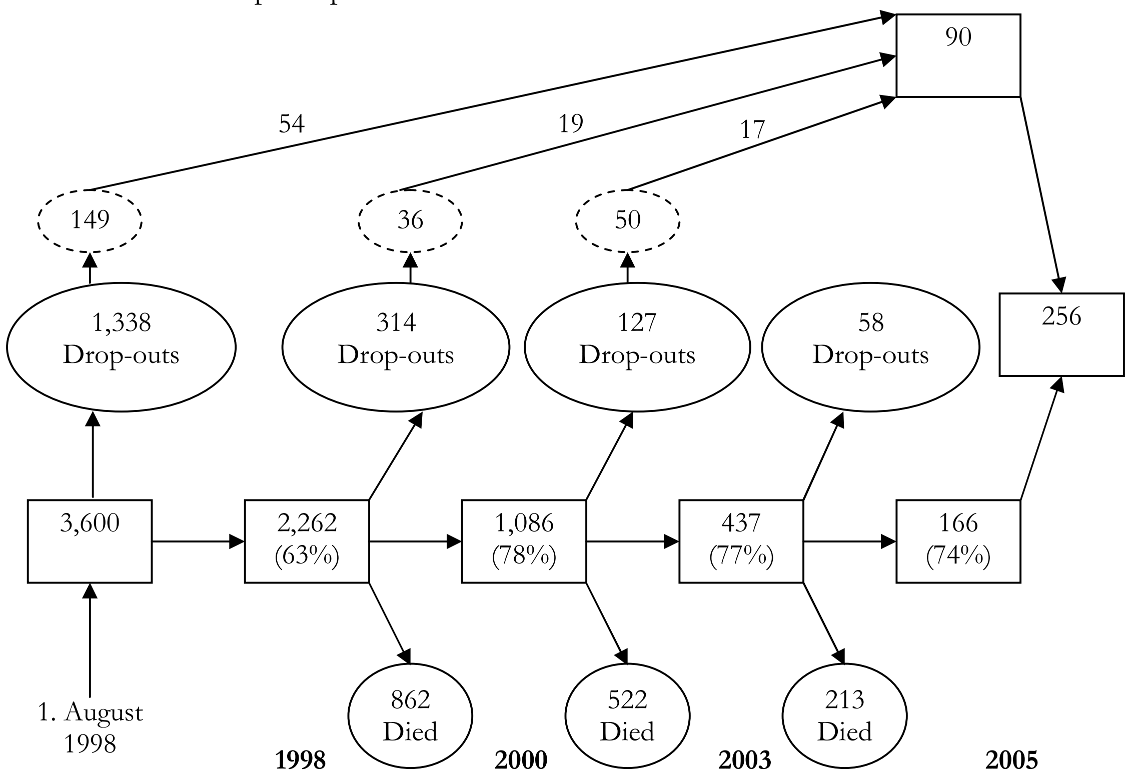
Study population

The study uses the data collected in the Danish 1905-Cohort Study described in detail elsewhere (42). In brief, the individuals eligible to participate in the survey were identified in the Danish civil registration system (43) and included all Danes born in 1905 and alive by August 1, 1998 (aged 92-93 years), when the baseline survey was conducted (Figure 1). A total of 3600 persons were approached irrespective of their residency, physical health or cognitive status. In all surveys the individuals residing in nursing homes or sheltered accommodation were considered eligible to participate in the study. If a person refused or was unable to participate in the face-to-face interview, a proxy respondent, usually a close relative, was sought. A total of 2262 (62.8%) persons participated in the intake survey: 1814 (80.2%) in person and 448 (19.8%) as a proxy-participant. The consecutive waves in 2000, 2003 and 2005 were follow-up assessments of survivors from previous waves with participation rates among survivors between 69% and 78%. In addition, 235 non-respondents at baseline and two follow-up surveys were contacted again and 90 persons agreed to participate in 2005 survey.

Participants and nonparticipants were compared using the extensive registration of the Danish population that made it possible to evaluate thoroughly differences between participants and nonparticipants. No differences were found in housing and marital status, but men and persons living in rural areas were more likely to participate than women and urban dwellers. An analysis of hospitalization patterns from 1973 to 1998 indicated that participants were not healthier than nonparticipants. Nevertheless, in a 6-month period after the start of the survey, nonparticipants had higher mortality, suggesting that terminal illness was one of the reasons for nonparticipation (13, 27, 42).

The questionnaire included items asking respondents about their socio-demographic characteristics, household composition, family and lifecycle characteristics, self-rated health, health conditions, medication use, sensory impairments, oral health, physical function, lifestyle behavior, and psychosocial factors. Besides, physical, cognitive, and affective functions were assessed and the participants were asked to give a biological sample, blood or cheek swab. Data in each wave were collected within approximately three months. All interviewers had substantial experience in interviewing the elderly, completed a detailed training program by a physician, and were closely monitored during the interview periods.

Figure 1. Flow-chart of the Danish 1905-Cohort Study. The square boxes give the number of participants and participation rates. The dashed circles give the initial number of dropouts that were recontacted later for participation in 2005.



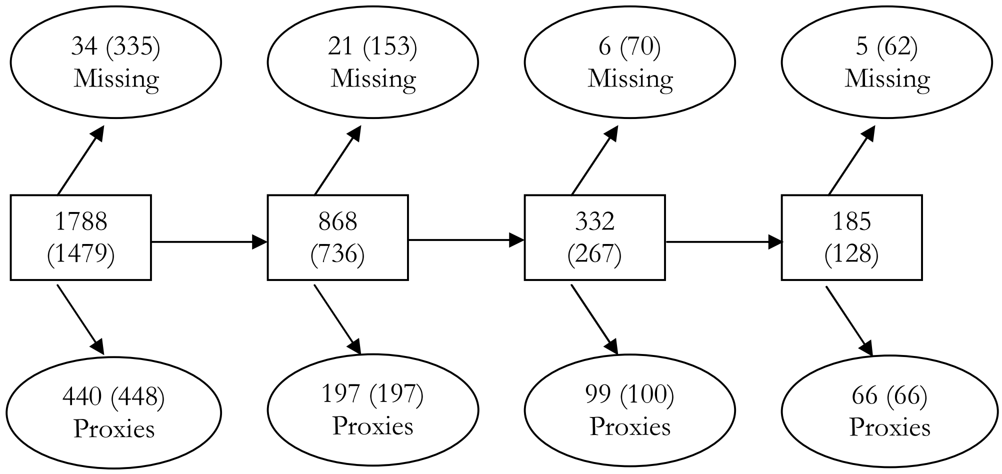
Reported physical function

Physical function was based on self-reports of the activities the participant was able to do on the day of the interview. An 11-item self-reported measure of physical function was administered at each wave of the study. The 11 items ranged broadly, from relatively simple physical tasks such as walking around the house and walking up and down 1 flight of stairs to more demanding activities such as running 100 m and carrying 5 kilos. Each item was answered on a scale ranging from 1 to 4 points (1 = can do the activity without fatigue, 2 = can do activity with fatigue or minor difficulties, 3 = can do the activity with aid or major difficulties, 4 = cannot do the activity). The scale score also ranges from 1 to 4, being an average of 11 items, and it was reversed to make higher scores corresponding to higher levels of physical function (Strength score). If an item was missing or skipped, the mean for that item was substituted. If more than one item was skipped, the scale was coded as missing. This scale has been shown to provide a sensitive quantitative measure of physical ability in our other studies of elderly Danes, to be substantially heritable and have high internal consistency (0.93) for both in-person and proxy interviews (44-46). If a person refused or was unable to participate in the face-to-face interview, a proxy respondent was asked to rate physical function of an elderly (Figure 2). Among 2295 elderly with at least 1 measurement occasion of physical function, 462 (20.1%) were proxy respondents. In total 155 (124 women) had valid measurement of physical function at all 4 waves.

Grip strength

Grip strength in kilograms was measured using a Smedley dynamometer (TTM; Tokyo, Japan) for three performances with brief pauses between each and with the stronger hand (16, 27). 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. Since grip strength is influenced by elbow position, the elbow had to be in a 90 position and the upper arm to be tight against the trunk (47). The grip strength score was set to be missing if one attempt was missing. By definition, proxy respondents had no measurement of grip strength (Figure 2). In total there were 1617 participants with at least 1 measurement of grip strength, 689 - with at least 2 measurements, 240 - had their grip strength assessed at least 3 occasions, and 64 (15 men) - at all 4 waves.

Figure 2. Flow-chart of physical function and grip strength measurements in the Danish 1905-Cohort Study. The square boxes give the number of valid measurements. The numbers in brackets are for grip strength measurements



Lifespan

The update of survival status was available until the end of January 2008. Among baseline participants 862 individuals died before the 1st follow-up survey, 522 persons died between the 1st and 2nd follow-up, and 213 individuals did not survive until the 3rd follow-up assessment. The mean observed lifespan among individuals with available date of death was 95.8 years (SE=0.09) in men and 96.5 years (SE=0.06) in women. A half of male population died between May 1998 and October 2000, whereas 50% of women died between February 1998 and July 2001. Lifespan of 88 individuals (17 men and 71 women) who were still alive by the end of survival follow-up was considered to be their age by 31st of January, 2008.

Statistical analysis

Latent growth curve models (LGM) were used to investigate sex differences in age--related changes in grip strength and strength score by the method of maximum likelihood using the Mx software (48). The availability of multiple measurements of grip strength and strength score allows estimating the rate-of-change rather than the amount of change, which is commonly examined in the analysis of the traditional difference score. LGM is a special case of multi--level or mixed model analysis in which the first, or within-subject level, is modeled as follows:

$$y_{it} = \pi_{0i} + \pi_{1i}(a_{it}) + \pi_{2i}\,(a^2_{it}) + e_{it}$$

where y_{it} is the observed score for the i^{th} person at time t, a_{it} is the age of the person at time t, π_{0i} is the intercept or level random effect for the i^{th} individual, π_{1i} is the slope score for the i^{th} individual, π_{2i} is the non-linear change score for the i^{th} individual, and e_{it} is the residual term. The second, or between-subject, level models random effects in π_{0i}, π_{1i}, and π_{2i}.

$$\pi_{0i} = \beta_{00} + \sum\beta_{0j}x_{ij} + \mu_{0i}$$

$$\pi_{1i} = \beta_{10} + \sum\beta_{1j}x_{ij} + \mu_{1i}$$

$$\pi_{2i} = \beta_{20} + \sum\beta_{2j}x_{ij} + \mu_{2i}$$

where β_{00}, β_{10} and β_{20} are respectively the fixed (i.e., group-level) intercept, slope and quadratic effects, μ_{0i}, μ_{1i} and μ_{2i} are the respective residual terms, x_{ij} are observations on covariates, and $\beta_{0j,}$ β_{1j} and β_{2j} are the effects of these covariates on individual differences in intercepts and slopes. Since the reliable estimation of random effects on the quadratic component of change requires large number of observations on each individual (49), we estimated the fixed quadratic effect only. Additionally, the analysis was focused on how sex differences in the intercept and slope are associated with lifespan, and how these associations differ in men and women. The mean intercepts and slopes of grip strength and strength score were estimated freely in sex-specific groups. To reveal sex differences in the growth parameters, the initial level and rate-of-change were consecutively constrained to be equal in men and women. The log likelihood ratio test was used to evaluate the model fit.

We expected to find sex differences in both the initial level and rate-of-change with men having an initial advantage over women and also a more rapid age-related decline. Sex differences in the correlations between intercept and slope and lifespan were evaluated by examining the 95% confidence intervals (CI) of the estimated correlations. A sex difference in the correlations between slope and lifespan would indicate that the rate-of-change in strength score and grip strength is differentially predictive of mortality in men and women. In line with "terminal decline" hypothesis, we also expect the rate-of-change to be a stronger predictor of survival than the initial level among the oldest-old, which could partially explain the health – survival paradox. Although the individuals with at least one measurement occasion did not contribute to the estimation of the slope, they were included into the analysis in order to estimate intercepts more precisely.

Results

Change in strength score

In total, there were 2295 (586 men, 25.5%) elderly with at least one reported measure of physical function. In Table 1, Model 1 assumes linear change in strength score, whereas Model 2 additionally includes the fixed quadratic effect. Since the fixed quadratic effect of change in strength score was very small and failed to reach statistical significance in both samples, the reduced linear model was considered in the analysis of change in strength score.

Initially, men aged 93 years had a higher strength score compared with women, 2.07 (95% CI: 2.01, 2.14) versus 1.74 (95% CI: 1.737, 1.775), respectively. However, the linear rate-of-change in strength score among women of -0.13 units (95% CI: -0.15, -0.12) per year was lower than the rate-of-change among men, -0.21 (95% CI: -0.25, -0.18). The models with intercepts (-2LnL=17415 with 6245 df) and slopes (-2LnL=17356 with 6245 df) constrained to be equal in men and women had significantly worse fit than the saturated model. It indicates that the initial level of strength score and rate-of-change were significantly higher in men than among women.

Table 1. Change in strength score from 1998 to 2005 in the Danish 1905-Cohort Study (n=2295)

	Model 1 (linear)		**Model 2 (quadratic)**	
	Men n=586	**Women n=1709**	**Men**	**Women**
Fixed effects				
Intercept	2.07	1.74	2.08	1.74
	(2.01, 2.14)	(1.74, 1.78)	(2.01, 2.15)	(1.71, 1.77)
Slope	-0.21	-0.13	-0.23	-0.13
	(-0.25, -0.18)	(-0.15, -0.12)	(-0.28, -0.19)	(-0.15, -0.11)
Lifespan	95.9	96.7	95.9	96.7
	(95.8, 96.2)	(96.6, 96.9)	(95.8, 96.2)	(96.6, 96.9)
Quadratic effect			0.006	-0.001
			(-0.003, 0.016)	(-0.002, 0.003)
Variance components				
Variance (I)	0.48	0.34	0.49	0.34
	(0.40, 0.58)	(0.31, 0.38)	(0.40, 0.59)	(0.31, 0.38)
Variance (S)	0.007	0.004	0.006	0.0038
	(0.003, 0.012)	(0.002, 0.005)	(0.002, 0.011)	(0.0038, 0.0041)
Covariance (I,S)	-0.03	-0.02	-0.03	-0.017
	(-0.05, -0.01)	(-0.02, -0.01)	(-0.05, -0.01)	(-0.02, -0.01)
Covariance (I,LS)	0.76	0.72	0.78	0.72
	(0.60, 0.94)	(0.63, 0.81)	(0.61, 0.96)	(0.62, 0.81)
Covariance (S,LS)	0.04	0.04	0.02	0.04
	(0.04, 0.09)	(0.02, 0.07)	(0.04, 0.08)	(0.01, 0.07)
2LnL	17340		17338	
AIC	4852		4854	
df	6244		6242	

I – intercept, S – slope, LS – lifespan

Significant variance component of intercept suggests some remaining explainable residual variations in the initial status of strength score in both sexes. All correlation coefficients were in the expected direction (Table 2). Negative correlation coefficients between growth parameters in both male, -0.45 (95% CI: -0.65, -0.17), and female samples, -0.47 (95% CI: -0.58, -0.34), as well as significant covariance between sex-specific intercept and slope, suggest that the elderly individuals with higher levels of strength score decline in their functioning at higher pace (since smaller negative values correspond to larger absolute decline). Further, lifespan and intercept were positively correlated, similarly in men (0.46, 95% CI: 0.37, 0.53) and women (0.46, 95% CI: 0.42, 0.51). Likewise, there were also positive correlations between lifespan and slope in both sex-specific samples, although it was not significant in men (0.23, 95% CI: -0.02, 0.48).

Table 2. Correlations among intercepts, slopes, and lifespan for strength score and grip strength in the Danish 1905-Cohort Study

	Men		**Women**	
	Intercept	**Slope**	**Intercept**	**Slope**
Strength score	n=586		n=1709	
Intercept	1		1	
Slope	-0.45	1	-0.47	1
	(-0.65, -0.17)		(-0.58, -0.34)	
Lifespan	0.46	0.23	0.46	0.25
	(0.37, 0.53)	(-0.02, 0.48)	(0.42, 0.51)	(0.09, 0.40)
Grip strength*	n=450		n=1167	
Intercept	1		1	
Slope	-0.05	1	-0.21	1
	(-0.47, 0.74)		(-0.45, 0.12)	
Lifespan	0.29	0.52	0.31	0.39
	(0.19, 0.39)	(0.14, 1.00)	(0.24, 0.38)	(0.09, 0.77)

* Correlations for grip strength are from the linear model in men and the quadratic model – in women

The test of equality revealed that the correlation coefficient between lifespan and intercept was greater than that between lifespan and slope in both men and women. However, overlapping 95% CIs of the sex-specific correlation coefficients suggest that there was no statistically significant sex difference in the correlation coefficients between growth parameters and lifespan. These findings suggest that the longest living women and men have higher initial levels of physical function and smaller rate-of-change. It suggests also that the initial level of strength score is more important for mortality prediction than the rate-of-change, but its predictive effect is similar in men and women.

Change in grip strength

In total, there were 1617 (450 men, 27.8%) individuals with at least one occasion of handgrip strength measurement. The fixed quadratic effect of change in grip strength was statistically significant in female sample only (Table 3), so that the quadratic effect in the male group was fixed to zero.

Table 3. Change in grip strength from 1998 to 2005 in the Danish 1905-Cohort Study (n=1617)

	Model 1 (linear)		**Model 2 (quadratic)**	
	Men n=450	**Women n=1167**	**Men**	**Women**
Fixed effects				
Intercept	22.7	13.5	22.7	13.4
	(22.1, 23.3)	(13.2, 13.7)	(22.1, 23.3)	(13.2, 13.7)
Slope	-1.32	-0.52	-1.43	-0.31
	(-1.59, -0.99)	(-0.66, -0.39)	(-1.84, -1.02)	(-0.51, -0.10)
Lifespan	96.4	97.3	96.4	97.3
	(96.2, 96.6)	(97.2, 97.5)	(96.2, 96.6)	(97.2, 97.5)
Quadratic effect			0.04	-0.06
			(-0.05, 0.12)	(-0.09, -0.02)
Variance components				
Variance (I)	34.8	13.8	32.9	13.5
	(28.6, 39.9)	(11.8, 15.9)	(26.9, 40.0)	(11.5, 15.7)
Variance (S)	0.23	0.13	0.18	0.15
	(0.01, 0.61)	(0.02, 0.25)	(0.00, 0.57)	(0.04, 0.28)
Covariance (I,S)	-0.13	-0.45	-0.16	-0.31
	(-1.69, 1.18)	(-0.92, -0.02)	(-1.69, 1.13)	(-0.78, 0.13)
Covariance (I,LS)	4.04	3.18	4.16	2.99
	(2.58, 5.63)	(2.47, 3.92)	(2.67, 5.79)	(2.29, 3.75)
Covariance (S,LS)	0.61	0.16	0.44	0.41
	(0.16, 1.08)	(-0.10, 0.42)	(-0.13, 1.05)	(0.09, 0.73)
2LnL	22595		22588	
AIC	14193		14189	
df	4201		4199	

I – intercept, S – slope, LS – lifespan

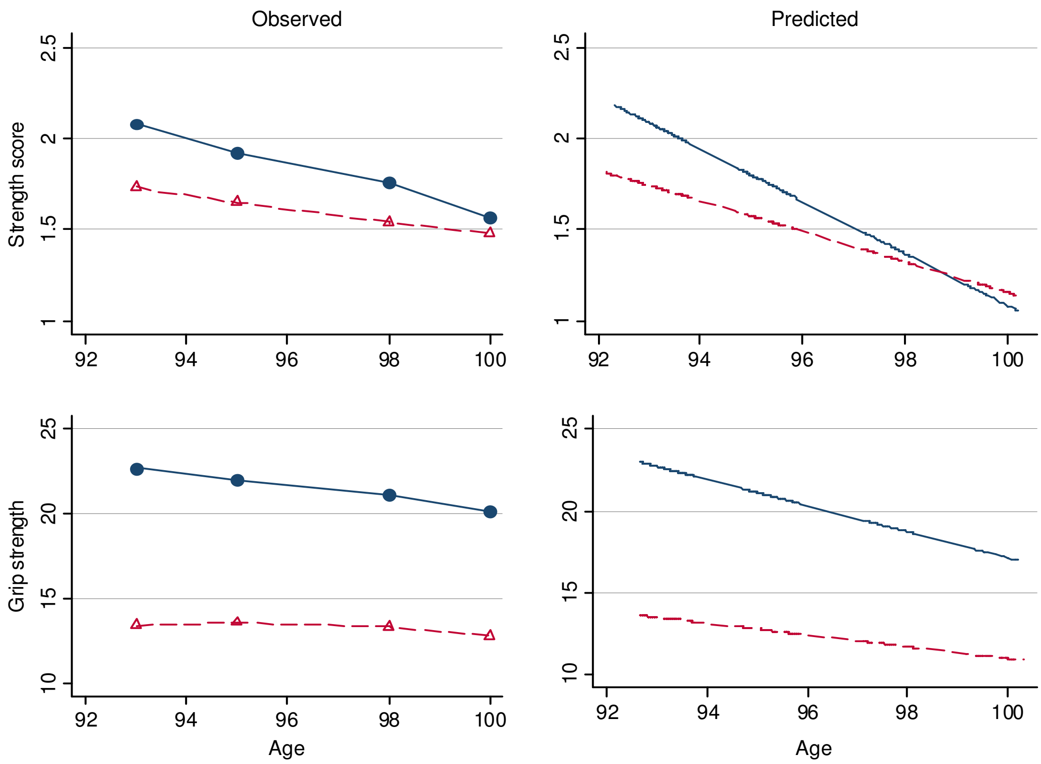
The initial level of grip strength was higher in men than in women, 22.7 kg (95% CI: 22.1, 23.3) and 13.4 kg (95% CI: 13.2, 13.7), respectively. Men declined in grip strength by -1.32 kg (95% CI: -1.59, -0.99) per year, whereas the decline was -0.31 (95% CI: -0.51, -0.10) in women at the baseline. The negative fixed quadratic effect of -0.006 (95% CI: -0.09, -0.02) indicates that in women the rate-of-change increases with advanced age. Because the pace at which women decline in grip strength changes with age, its overall annual drop is difficult to summarize by a single number. The Figure 3 illustrates observed (left panel) and predicted (right panel) trajectories of change in strength score and grip strength in the Danish 1905-Cohort study from 1998 to 2005. Both the observed and predicted trajectories point toward more rapid decline in strength score and grip strength among men than women.

According to the log-likelihood ratio test, the saturated model had better fit than the models with either intercepts (-2LnL=23050 with 4201 df) or slopes (-2LnL=22614 with 4201 df) constrained to be equal in two groups ($p<0.05$). It indicates that the initial level and rate-of-change in grip strength are significantly higher in men than in their female counterparts.

Variance components of intercepts and slopes were significant in both groups suggesting that potentially explainable residual variations in the initial status and rate-of-change still remain. The covariance between the intercept and slope in men (-0.13, 95% CI: -1.69, 1.18) and women (-0.31, 95% CI: -0.78, 0.13) were negative, but they failed to reach statistically significant level. The correlation coefficients between intercept and slope in both groups were also small and insignificant (Table 2). It may imply that oldest old Danes grip strength decline at a similar pace regardless of its initial level.

Lifespan was significantly and positively correlated with intercept in men, 0.29 (95% CI: 0.19, 0.39) and women, 0.31 (95% CI: 0.24, 0.38), indicating that within both sexes the individuals with higher grip strength have longer lifespan (Table 2). Lifespan significantly correlated also with slope in both groups, suggesting that grip strength declines at a smaller pace among longest living individuals. The correlation coefficient between lifespan and slope was higher in men, 0.52 (95% CI: 0.14, 1.00), compared with that in the female group, 0.39 (95% CI: 0.09, 0.77). However, the overlapping 95% CIs of sex-specific correlation coefficients suggest that the correlation between lifespan and slope was similar in men and women. Likewise, there was no sex difference in the correlation coefficients between lifespan and intercept.

Figure 3. Observed and predicted trajectories of change in physical function and grip strength in the Danish 1905-Cohort Study (1998-2005)



Discussion

Sex differences in the initial level and rate-of-change

Consistent with previous research reports, the present study revealed that in the Danish 1905-cohort men had higher strength score and grip strength compared with women (16, 22, 23, 50, 51). Although oldest-old men had the initial advantage, they have also experienced steeper decline in strength score and grip strength compared with the same-aged women. The data analysis showed that strength score declined linearly in both sexes, whereas the decline in grip strength was non-linear. It appears that among women the decline in grip strength accelerates with increasing age. Non-significant quadratic effect among men is possibly due to a small number of male participants (n=15) with valid measurements at all four surveys necessary to estimate non-linear quadratic effect. The present study suggests that in absolute terms elderly men declined more rapidly than their female counterparts in the physical function and grip strength.

Our results are in agreement with some previous research studies. A longitudinal study among Swedish twins revealed significantly greater change for grip strength in men compared with women (34). Hughes at al found that although men had higher isokinetic strength in all muscle groups, the absolute 10-year decline in strength of each muscle group was greater in men compared with women (52). Forrest et al showed that over 10-year follow-up period women declined in grip strength, on average, by 5.1 kg, equivalent to 2.4% decline per year, whereas men declined by 19.9% over 7-year period, corresponding to 2.8% annual drop (32, 33). The analysis of the Women's Health and Aging (WHA) by means of growth curve models demonstrated that the women aged 65-79 years declined by 0.50 kg per year and the 80 years and over old women declined by 0.60 kg annually (53). Besides, consistently with other research findings, our study suggest that the decline in physical performance increases with advancing age (29-33). The 59-year longitudinal Terman study pointed out that the decline in self-rated health accelerated after age 50 for both men and women, but the mean rate of linear change in men was slightly albeit significantly higher than in women (54).

Several studies, however, found that longitudinal changes in handgrip strength were similar in men and women (31) or even greater in women than among men (55, 56). A greater rate-of-change in physical function was found among 65 years and older women than among same-aged men (50, 51, 57). These studies involved younger individuals compared with the Danish 1905-Cohort Study participants and used different measures of reported physical function and/or analytical methods. Research reports on the trajectories of age-related decline in grip strength are also controversial (34, 58).

Our analysis of change in strength score revealed statistically significant negative correlations between intercept and slope, suggesting that the oldest-old individuals with higher initial levels of strength score have higher rate-of-change. However, we could not detect a similar pattern in the analysis of change in grip strength suggesting that a decline in grip strength among oldest-old Danish men and women occurs at a similar pace regardless of the initial level of muscular strength.

Correlations with lifespan

The analysis of change in strength score within sex-specific samples revealed a consistently greater correlation between lifespan and intercept than the correlation between lifespan and slope. It suggests that the initial level of strength score is more predictive of mortality than the rate-of-change, but its predictive effect is similar in men and women. Similarly, the analysis of change in grip strength demonstrated that the correlation between intercept and lifespan was similar in male and female samples, indicating that the initial level of grip strength is predictive of mortality in both sexes. About twice larger correlation coefficient between slope and lifespan compared with that between intercept and lifespan in the male sample is likely to be due to a small sample size. Only 182 men had ≥2 measurements of grip strength versus 507 women, whereas only 60 men and 179 women had ≥3 measurements of grip strength that are necessary to fit the linear growth model. It is also possible that the initial selection of individuals, who were sufficiently strong at the baseline to have several follow-up measurements of grip strength, also explain a more rapid drop in grip strength.

At present, existing knowledge about decline – mortality association based on measures of physical health is limited. It is especially sparse in the oldest-old individuals due to high mortality and loss to follow-up. Metter et al found that changes in physical strength had a greater effect on the mortality risk than the actual levels in younger men, but higher levels of grip strength were more predictive of a reduced risk of death among 60 years and older men (59). A later analysis of the BLSA data indicated that the decline in the muscle power and isometric strength were stronger predictors of mortality than the strength and power levels (41). Another study among Medicare recipients revealed that the individuals with rapid rates of decline in physical abilities had a substantially higher risk of death compared with persons with preserved functions or slower rates of loss, but the association between rate-of-change and risk of death was stronger in ≥75 years old individuals (60). The older age of the 1905-Cohort Study participants than the BLSA participants and Medicare recipients may explain why the level rather than the rate-of-change in strength score and grip strength was more important to predict mortality in our study.

Although a variety of studies provide compelling evidence that lower levels of cognitive function increase the risk of mortality (37), the literature regarding decline – mortality association based on cognitive function is also contradictory. Several studies demonstrated that cognitive change predicts subsequent survival (35, 36, 61), whereas others found that the level but not the decline is predictive of mortality (62, 63). Some researchers suggested that the effect of cognitive (64, 65) or functional decline (60) on mortality levels off at very old age. Diminishing decline – mortality association at the very advanced age may also partially explain the fact that the rate-of-change in our study failed to be more predictive of mortality than the initial levels of strength score and grip strength.

Methodological considerations

Some issues in our study deserve consideration. The paper highlights difficulties of estimating the rate-of-change in the oldest-old individuals due to high mortality and loss to follow-up. Despite an initially large sample size with almost complete follow-up of survival status, we still had limited power to estimate more precisely the rate-of-change in those health measures, where the proxy interviews cannot be used. Second, grip strength measurements were performed by different lay interviewers, which could have introduced a measurement bias attributable to interviewers. However, previous studies in Denmark reported that differences attributable to interviewer effects accounted for only 1% to 2% of the population variation in grip strength (16). Further, because censoring cannot be easily accommodated in growth curve analysis, lifespan of individuals still alive by the end of survival follow-up was estimated to be their age by January 31, 2008. Therefore, our method may restrict the variance of the lifespan variable and, thus, correlations between lifespan and growth parameters may be biased towards zero. However, this bias is likely to be small and insignificant because only 88 individuals were affected. Finally, the analysis was based exclusively on the observed data without accounting for selective loss to follow-up due to non-response or mortality. Recent studies in Denmark showed that correcting disability score for missing data because of nonparticipation (but not because of death) using inverse probability weights (66) gave results very similar to the unadjusted score (67). Even though the curves of the age-related decline in grip strength were shifted downwards when selective dropout due to non-participation was taken into consideration (16), it would not affect male-female differences in the initial level and rate-of-change in strength score and grip strength, as well as sex difference in the correlation of lifespan and with growth parameters.

Conclusion

The present study revealed that despite their initial advantage the oldest-old Danish men have more rapid age-related decline in reported physical function and grip strength compared with women. Our findings suggest that the initial levels are more important in predicting mortality than the rate-of-change, but the predictive effect is similar in women and men. This study found little support for the hypothesis that the rate-of-change in physical function is more predictive of survival than the initial levels, and consequently, contributed little to the explanations of the male – female health – survival paradox. Decline-mortality association based on grip strength requires further investigation with a sufficiently larger number of male participants.

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