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Article

Trends in grip strength: Age, period, and cohort effects on grip strength in older adults from Germany, Sweden, and Spain

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ABSTRACT

Grip strength is seen as an objective indicator of morbidity and disability. However, empirical knowledge about trends in grip strength remains incomplete. As trends can occur due to effects of aging, time periods and birth cohorts, we used hierarchical age-period-cohort models to estimate and disentangle putative changes in grip strength. To do this, we used population-based data of older adults, aged 50 years and older, from Germany, Sweden, and Spain from the SHARE study (N = 22500) that encompassed multiple waves of first-time respondents. We found that there were contrasting changes for different age groups: Grip strength improved over time periods for the oldest old, whereas it stagnated or even decreased in younger older adults. Importantly, we found strong birth cohort effects on grip strength: In German older adults, birth cohorts in the wake of the Second World War exhibited increasingly reduced grip strength, and in Spanish older adults, the last birth cohort born after 1960 experienced a sharp drop in grip strength. Therefore, while grip strength increased in the oldest old aged 80 years and older, grip strength stagnated or decreased in comparatively younger cohorts, who might thus be at risk to experience more morbidity and disability in the future than previous generations. Future studies should investigate factors that contribute to this trend, the robustness of the observed birth cohort effects, and the generalizability of our results to other indicators of functional health.

Grip strength has been shown to be a reliable, objective and powerful predictor of a multitude of health outcomes (Cooper, Kuh, Hardy, & Mortality Review Groupon behalf of the FALCon and HALCyon study teams, 2010; den Ouden, Schuurmans, Arts, & van der Schouw, 2011; Leong et al., 2015; Sayer & Kirkwood, 2015; Vermeulen, Neyens, van Rossum, Spreeuwenberg, & de Witte, 2011), including physical functioning (Taekema, Gussekloo, Maier, Westendorp, & de Craen, 2010), cognitive functioning (Sternäng et al., 2016), cardio-vascular disease (Lawman et al., 2016; Leong et al., 2015), and mortality in younger (Ortega, Silventoinen, Tynelius, & Rasmussen, 2012), middle-aged (Rantanen et al., 2000) and older adults (Gale, Martyn, Cooper, & Sayer, 2007). Grip strength itself seems to be determined to a medium degree genetically with h^2 = 30–65% (Arden & Spector, 1997; Matteini et al., 2010; Reed, Fabsitz, Selby, & Carmelli, 1991). On the other hand, environmental, lifestyle, and morbidity factors, such as societal recession, physical activity, nutrition, and vitamin deficiency were found to be also strongly associated (Antonova, Bucher-Koenen, & Mazzonna, 2017; Girgis et al., 2015; Kuh et al., 2006; Norman, Stobäus, Gonzalez, Schulzke, & Pirlich, 2011). As such, grip strength represents an objective overall indicator of morbidity and disability (Rijk, Roos, Deckx, van den Akker, & Buntinx, 2016; Sayer & Kirkwood, 2015; Syddall, Cooper, Martin, Briggs, & Aihie Sayer, 2003). While many studies using grip strength as an indicator of physical health have been conducted, several issues remain unresolved. It is unclear whether levels of grip strength are increasing, constant, or decreasing.

Reasonable arguments could be made for increasing, decreasing and constant levels of grip strength. Grip strength may have improved due to improved living conditions. Furthermore, quality of medical care may have improved so that most patients are able to live well even with diseases like diabetes (Muschik et al., 2017). However, other factors

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suggest that grip strength may also have declined. Levels of physical activity have diminished on the job (Brownson, Boehmer, & Luke, 2005). Additionally, prevalence rates of mental health like depression and anxiety may have increased, which is likely to affect activity levels and to increase fatigue (Cohen & Janicki-Deverts, 2012; Twenge, 2015). Of course, factors in favour of an increase in grip strength and factors in favour of a decrease are concurrently in effect leading to stable trends. Furthermore, trends in grip strength may also differ by age group. For example, medical progress might have been most beneficial for the oldest old, because they are affected by the highest disease burden, and are thus most likely to benefit from advances in medicine.

Adding to the complexity of the direction of health changes in populations, trends may be caused by age, time period or birth cohort effects (Yang & Land, 2013). Effects of age denote changes in grip strength simply due to aging processes and accompanying changes in physiology, lifestyle and disease risks. Several previous studies have documented age-related differences in grip strength (Dodds et al., 2014; Frederiksen et al., 2006). Also, levels of grip strength might change depending on the time period, corresponding to the calendar years the outcomes of interest were measured. Unobserved factors that affect the outcome and that have changed with time periods, such as changes in lifestyle (e.g., exercise frequency) and advances in medicine, are typically presumed to cause the observed time period effect (e.g., Silverman, 2011). Finally, the birth cohort may also account for changes in grip strength. The birth cohort refers to generational effects that only affect groups born within a particular time period that, because they are born in a similar time, share similar historical and social experiences. For example, food shortages after the Second World War (WW2) might have reduced grip strength of persons born during or after that time. Again, several studies have focused on generational differences in grip strength (Christensen et al., 2013; Jagger et al., 2016; Kingston et al., 2017; Strand et al., 2019; Zeng, Feng, Hesketh, Christensen, & Vaupel, 2017). However, age, period, and cohort effects are likely to influence descriptive changes in grip strength simultaneously. For example, a putative increase in grip strength due to healthier lifestyles might be obfuscated in European older adults because current older adults are also likely to have experienced famines following WW2. Similarly, although cohort effects seem likely, generational differences might be over- or underestimated if one does not account for possible time period changes in variables like physical activity; lastly, age-related differences in grip strength might of course also be confounded with time period and birth cohort effects. Thus, to better understand trends in grip strength one should concurrently account for age, time period, and birth cohort effects. However, to our knowledge, no study to date has done so. All previous studies have analysed only some subset of factors in isolation, but not all three—age, time period, and birth cohort—together.

The current study strives to help fill this gap in the literature. In this article, we examine trends in grip strength. Given the likely influence of age, period and cohort effects in the case of changes in grip strength, we strived to disentangle these effects using Hierarchical Age Period Cohort methodology (HAPC; Yang & Land, 2013).

Methods

Sample. Data were drawn from the public release of the Survey of Health, Ageing and Retirement in Europe (SHARE) that aims to provide comparable data on aging across countries (Börsch-Supan, 2018a; 2018b; 2018c). In general, population-based samples of the non-institutionalized population aged 50 and older are provided, mostly collected via multi-stage sampling. As the countries themselves had to obtain funding to finance their national samples, there are differences in sample size and frequency of refreshment across countries and time periods. In order to maximize sample size and number of time points available while curbing complexity, we chose Germany, Sweden and Spain, as all three countries had similar sampling frames and recruited refreshment samples in roughly the same waves. We used data from the 2004 wave (which includes a small number of participants sampled in 2005), the refreshment samples of 2007 (including a small number of participants sampled in 2006) and the 2013 wave as well as an additional refreshment sample in the 2011 wave that was only available for Spain. In total, $N = 22{,}550$ baseline participants were included with $n = 8483$ from Germany, $n = 6198$ from Sweden, and $n = 7869$ from Spain. Analyses were conducted separately for each country.

Only data of first responders was used to control for selective dropout bias, because impaired participants might be less likely to participate in further survey waves (Touloumi, Pocock, Babiker, & Darbyshire, 2002). Additionally, in order to control for response bias (e.g. impaired participants might be less likely to provide grip strength measures) missing values (0%–8% per variable) were imputed using the missForest algorithm (Stekhoven & Buhlmann, 2012), which is a non-parametric imputation method performing especially well with complex data and under minimal distributional assumptions. Ethics board approval was not required, because we only conducted analyses of completely anonymized SHARE-datasets. Further information about SHARE and the sampling strategies applied can be found in Andersen-Andersen-Ranberg, Petersen, Frederiksen, Mackenbach, and Christensen (2009), Börsch-Supan et al. (2013) and Bergman, Kneip, De Luca, and Scherpenzeel (2017).

Measures. Hand-grip strength was measured by trained interviewers using a handheld dynamometer (Smedley, S Dynamometer, TTM, Tokyo, 100 kg). Participants were instructed to preferably stand or sit, with the elbow bent to 90°, keeping the wrist in a neutral position, the upper arm tight against the trunk, and the inner lever of the dynamometer adjusted to suit the hand. Participants were then instructed to squeeze as hard as possible for a few seconds. Two measurements were recorded for each hand. The maximum value of these four measurements was used as the indicator for grip strength.

Several other variables that might be related to grip strength were included to better describe the samples and to improve imputation performance (Gale et al., 2007; Snow-Harter, Whalen, Myburgh, Arnaud, & Marcus, 2009). Physical activity level, obtained via questionnaire, was operationalized as whether participants regularly performed vigorous or moderate physical activities (0 = “no physical activity”, 1 = “physical activity”). Self-rated health was assessed via a five-level Likert scale (from 1 = “Poor” to 5 = “Excellent”) as how participants described their health status themselves. Third, BMI was calculated via self-reported height and weight. Finally, age and gender were included.

Data Analysis. As a first step, descriptive statistics of all variables across countries and time periods are reported. Then, to separate the effects of age, time period, and birth cohort, we performed age period cohort analyses (Yang & Land, 2013). Following the recommendations of Yang and Land (2013), we estimated hierarchical models where individuals are nested within birth cohort groups and time periods, allowing mean levels of grip strength to vary across time periods and birth cohorts. Thus, the model provides first, a fixed intercept that represents the estimated grand mean of grip strength in the sample and a fixed linear and curvilinear effect of age by which estimated changes in grip strength across age can be calculated. Second, the model provides varying intercepts for each birth cohort and each time period, which can be summarized as variance in grip strength due to birth cohorts and

Table 1
Grip strength and background characteristics across countries and time periods.

Country	Germany			Sweden			Spain			
Time	2004	2007	2013	2004	2007	2013	2004	2007	2011	2013
Grip strength	36.64 (12.36)	37.15 (12.30)	36.12 (12.07)	35.10 (12.26)	36.09 (12.64)	36.19 (11.91)	28.09 (11.10)	30.79 (11.75)	29.79 (11.56)	29.03 (11.18)
Age	63.77 (9.44)	62.89 (10.15)	63.07 (10.17)	64.72 (10.25)	65.44 (10.84)	66.17 (9.37)	66.15 (10.69)	61.12 (11.20)	64.71 (11.06)	66.69 (11.29)
Female (%)	54%	54%	53%	54%	56%	52%	58%	55%	55%	53%
Physical activity (%)	93%	94%	92%	95%	93%	96%	86%	87%	83%	86%
Self-rated health	2.81 (0.98)	2.91 (1.05)	2.80 (1.04)	3.50 (1.02)	3.16 (1.20)	3.38 (1.14)	2.65 (0.99)	2.72 (0.99)	2.69 (1.08)	2.78 (1.00)
BMI	26.55 (4.40)	26.51 (4.20)	27.10 (5.10)	25.79 (3.90)	26.00 (3.91)	25.93 (3.98)	27.38 (4.34)	27.40 (4.80)	27.16 (4.22)	26.57 (4.14)
Men										
Country	Germany			Sweden			Spain			
Time	2004	2007	2013	2004	2007	2013	2004	2007	2011	2013
Grip strength	45.92 (10.52)	46.70 (10.01)	45.30 (9.83)	44.57 (9.99)	46.53 (10.59)	45.37 (9.58)	36.39 (10.14)	38.94 (11.01)	38.44 (10.02)	36.67 (10.26)
Age	63.59 (8.68)	63.18 (9.55)	63.64 (9.82)	65.23 (10.00)	65.49 (10.54)	66.82 (9.43)	66.16 (10.12)	60.62 (10.86)	64.86 (10.55)	66.99 (10.84)
Physical activity (%)	95%	96%	93%	95%	96%	96%	87%	91%	86%	88%
Self-rated health	2.84 (0.98)	2.89 (1.05)	2.76 (1.02)	3.54 (1.01)	3.33 (1.17)	3.40 (1.14)	2.79 (0.99)	2.84 (0.95)	2.79 (1.08)	2.83 (1.00)
BMI	26.99 (3.96)	26.98 (3.76)	27.59 (4.51)	26.14 (3.61)	26.05 (3.43)	26.37 (3.70)	27.28 (3.85)	27.29 (4.15)	27.36 (3.56)	27.03 (3.55)
Women										
Country	Germany			Sweden			Spain			
Time	2004	2007	2013	2004	2007	2013	2004	2007	2011	2013
Grip strength	28.81 (7.37)	29.17 (7.21)	28.08 (7.07)	26.95 (7.10)	27.85 (6.57)	27.78 (6.30)	22.13 (7.28)	23.99 (7.12)	22.27 (7.08)	22.24 (6.66)
Age	63.93 (10.04)	62.66 (10.59)	62.57 (10.45)	64.29 (10.45)	65.41 (11.09)	65.58 (9.28)	66.15 (10.09)	61.55 (11.49)	64.59 (11.45)	66.43 (11.68)
Physical activity (%)	92%	92%	91%	95%	91%	96%	84%	84%	81%	84%
Self-rated health	2.78 (0.97)	2.93 (1.06)	2.83 (1.05)	3.47 (1.03)	3.03 (1.22)	3.36 (1.14)	2.56 (0.98)	2.61 (1.02)	2.61 (1.08)	2.73 (1.01)
BMI	26.17 (4.71)	26.11 (4.51)	26.67 (5.54)	25.49 (4.12)	25.97 (4.25)	25.52 (4.18)	27.45 (4.67)	27.48 (5.29)	27.00 (4.69)	26.17 (4.57)

Notes. Values in cells denote means and (in parentheses) standard deviations, or, where applicable, percentages.

variance in grip strength due to time period (and a residual term containing error variance within cohorts and periods). Thereby, the model estimates changes in grip strength across age, controlling for time period and birth cohort effects, changes in grip strength across time period, controlling for age and birth cohort, and changes in grip strength due to birth cohort, controlling for age and time period. We also conducted partial sub-group-analyses regarding gender and age (younger older adults: age < 65; middle-aged older adults: age ≥ 65 & < 80, oldest old: age ≥ 80). Small sample sizes regarding some subgroups (for example, German women born between 1910 and 1915) and the resulting uncertain effect estimates precluded us from reporting the full gender-separated results in the main text (the full subgroup analyses regarding gender are included in the Appendix). Please also note that even when dropping cohort or period effects from the model the results were similar to those reported. All statistical analyses were performed with R (version 3.5.1).

Results

Overall, participants were on average 64.74 years old ($SD = 10.44$), with 54% being female. We observed a mean grip strength score of 33.63 with a wide variability of $SD = 12.35$ ($M_{Women} = 26.02$, $SD_{Women} = 7.51$; $M_{Men} = 42.58$, $SD_{Men} = 10.83$). Additionally, participants rated their health, on average, as being between fair and good, $M = 2.95$ ($SD = 1.08$). About 91% of the sample reported at least some vigorous or moderate physical activity in a typical week. Participants had a normal-ranged average BMI of $M = 26.62$ ($SD = 4.41$). Detailed sample characteristics are depicted in Table 1.

Descriptive trends of grip strength across time periods. As depicted in Table 1, on a descriptive level, there were only small trends in grip strength. In Germany, the grip strength tended to slightly decrease from 2004 to 2013 ($M_{2013} - M_{2004} = \Delta M = -0.52$), whereas in Sweden and Spain grip strength increased slightly ($\Delta M = 1.09$ and $\Delta M = 0.94$, respectively), with similar descriptive changes in women and men.

Age, period and cohort analyses. Next, we used HAPC analysis (Yang & Land, 2013) to disentangle the observed descriptive changes in grip strength by age, time period, and birth cohort effects. Regarding Germany, the overall intercept was 37.33 [36.56, 38.04], approximately the mean level of grip strength in the German sample. There were strong and statistically significant fixed effects of both linear age ($b = -0.381$ [-0.427, -0.338], $p < .001$) and quadratic age ($b = -0.009$, [-0.012, -0.007], $p < .001$), as can be seen in Fig. 1 (upper row, panel A). Regarding random effects, intercepts varied due to both time period ($SD = 0.30$; Fig. 1, upper row, panel B) and birth cohort ($SD = 0.65$; Fig. 1, upper row, panel C), although the variation due to birth cohort seemed stronger. Fig. 1 depicts the trends of these

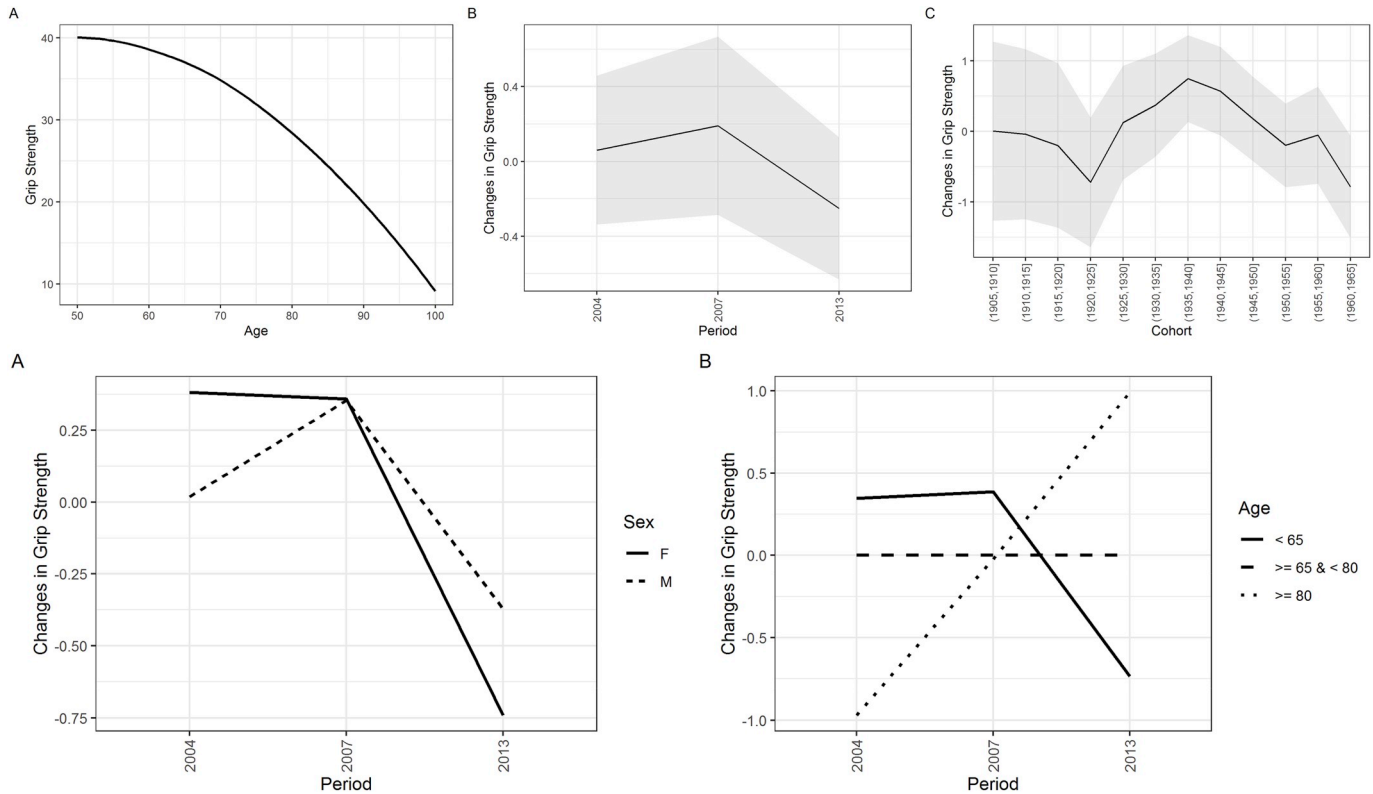

Fig. 1. Age, period, and cohort effects on grip strength in older adults from Germany (N = 8483). In the upper row, panel A depicts the predicted value of grip strength across age; panel B depicts the changes in grip strength due to time period; and panel C depicts the changes in grip strength due to birth cohorts. Shaded areas represent 95% confidence intervals. In the lower row, panel A depicts the changes in grip strength due to time period for men and women separately, and panel B depicts the changes in grip strength due to time period for middle-aged adults, older adults and the oldest old.

effects: On average, no clear pattern emerged regarding time period, but the effects regarding birth cohort showed a hill-shaped pattern, with cohorts born around 1930 until 1945 exhibiting significantly stronger grip strength than cohorts born both earlier and later. Using subgroup analyses regarding gender (Fig. 1, lower row, panel A) and age-group (Fig. 1, lower row, panel B) revealed similar time trends for both sexes, but diametrically opposed trends regarding age groups. Whereas grip strength in the oldest old aged 80 and older strongly increased, there was no change in the grip strength of middle-aged adults aged between 65 and 80 and even a strong decrease across time period in grip strength of younger older adults aged 65 and younger.

In the Swedish sample, the overall intercept was 36.52 [35.48, 37.50], again, approximately the mean level of grip strength in the sample. In the Swedish sample, there were strong and statistically significant fixed effects of both linear age ($b = -0.360$ [-0.394, -0.326], $p < .001$) and quadratic age (b = -0.007, [-0.010, -0.004], $p < .001$), as can be seen in Fig. 2 (predicted grip strength across age: upper row, panel A). Intercepts seemed to vary mostly due to time period ($SD = .80$; Fig. 2, upper row, panel B) and not as much due to birth cohort ($SD = 0.06$; Fig. 2, upper row, panel C). Fig. 2 depicts the trends of these effects: No clear pattern emerged regarding birth cohort, but the effects regarding time period showed an increasing pattern, with participants at later time points exhibiting stronger grip strength. Again, similar time trends for both sexes were found (Fig. 2, lower row, panel A). Regarding age groups (Fig. 2, lower row, panel B), grip strength in the oldest old aged 80 and older strongly increased, whereas there was almost no change in the grip strength of the other, younger age groups.

For Spain the overall intercept was 29.56 [28.61, 30.42], which approximates the mean level of grip strength in the Spanish sample. Seconding the both previous samples, there were strong and statistically significant fixed effects of both linear age ($b = -0.402$ [-0.444, -0.358], $p < .001$) and quadratic age (b = -0.006, [-0.009, -0.004], $p < .001$), as can be seen in Fig. 3 (upper row, panel A). Intercepts, again, seemed to vary due to both time period ($SD = 0.53$; Fig. 3, upper row, panel B) and birth cohort ($SD = 0.77$; Fig. 3, upper row, panel C), although the variation due to birth cohort was stronger. Fig. 3 depicts the trends of these effects: Grip strength increased with later birth cohorts, although the youngest birth cohort exhibited a sharp drop in grip strength. Complementing the Swedish sample, the effects regarding time period showed a linearly increasing pattern, with participants at later time points exhibiting stronger grip strength. Regarding gender, grip strength in men tended to increase, whereas grip strength in women seemed to remain unchanged (Fig. 3, lower row, panel A). Regarding age groups (Fig. 3, lower row, panel B), grip strength in the younger older adults subgroup aged 65 and younger increased only slightly, whereas grip strength in both other older subgroups exhibited strong increases.

Discussion

We found that there were contrasting time period trends for

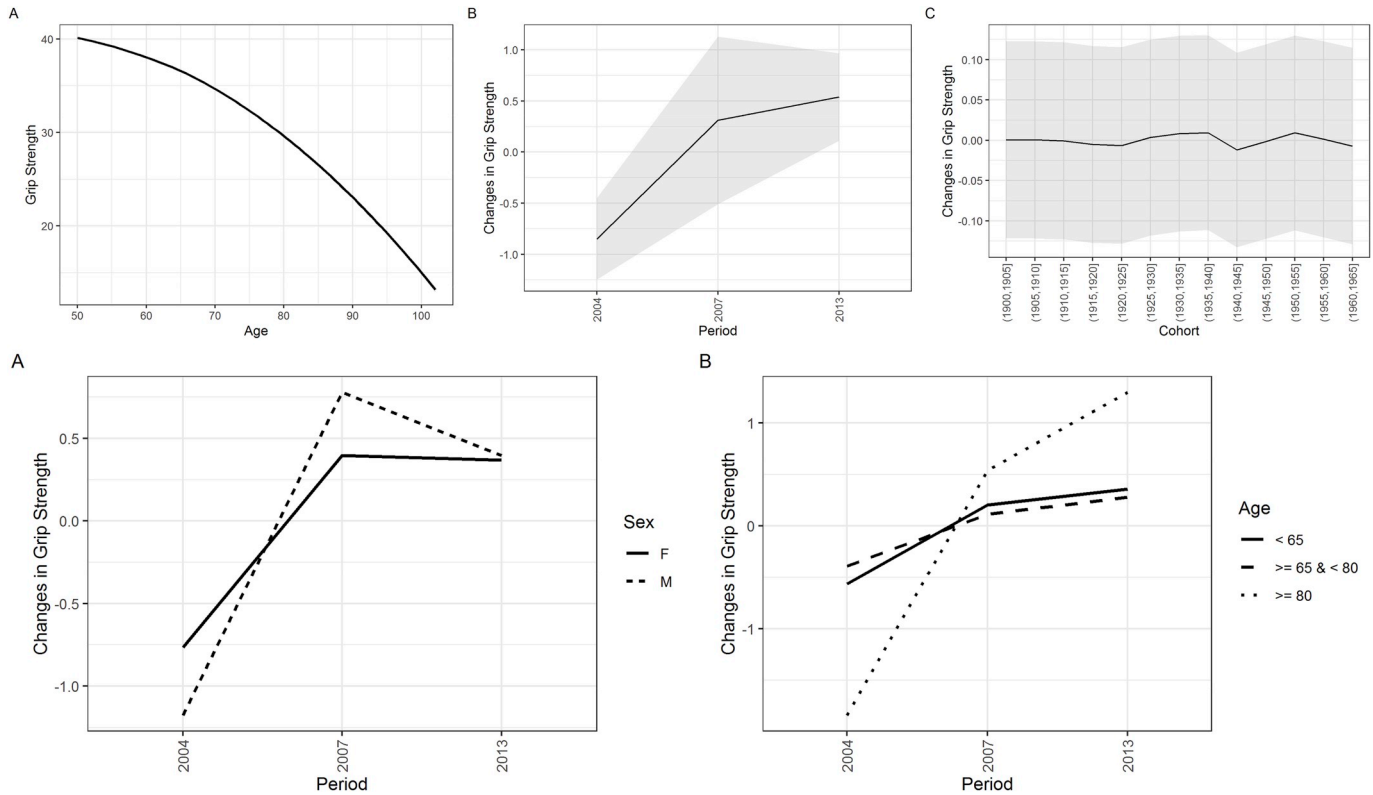

Fig. 2. Age, period, and cohort effects on grip strength in older adults from Sweden (N = 6198). In the upper row, panel A depicts the predicted value of grip strength across age; panel B depicts the changes in grip strength due to time period; and panel C depicts the changes in grip strength due to birth cohorts. Shaded areas represent 95% confidence intervals. In the lower row, panel A depicts the changes in grip strength due to time period for men and women separately, and panel B depicts the changes in grip strength due to time period for middle-aged adults, older adults and the oldest old.

different age groups: Grip strength increased in the oldest old aged 80 years and older, but in adults under 65 years of age it remained relatively constant and even decreased in the case of Germany. These changes in grip strength in the oldest old over 80 years of age were substantial. In concrete terms, the predicted average grip strength score of those aged 80 years and older was generally below 30 kg and reached about 10 kg in centenarians. As the average increase in grip strength over time periods was about 2 kg in this age group, this corresponds to an increase in the average grip strength in the oldest old of 7%–20%. Thus, grip strength, and, perhaps, with it functional health, improved in the oldest old, thus suggesting partial support for Fries' hypothesis of compression of morbidity (1980) in the oldest old. However, we also found that younger cohorts exhibited increasingly weaker levels of grip strength than earlier cohorts. This is in contrast to earlier studies, in which it was generally found that grip strength improved in younger cohorts (Christensen et al., 2013; Jagger et al., 2016; Kingston et al., 2017; Strand et al., 2019; Zeng et al., 2017). Thus, combined with the finding that grip strength in adults aged under 65 years also stagnated or even decreased over time periods, these results concurrently suggest a possible expansion of morbidity in younger older adults.

To our knowledge, this is the first study that simultaneously examined the trajectory of grip strength across age, time period and birth cohorts. As grip strength represents a ubiquitous measure of morbidity and disability, there are several studies on these related constructs' trends to which the current results can be compared. For example, as previously reported, grip strength is strongly associated with subjective indicators of functional limitations such as ADL and IADL (Rijk et al., 2016). In support of our results, Chatterji, Byles, Cutler, Seeman, and Verdes (2015) have reported that functional health improved in their sample of older adults. However, there are other studies that appear to contradict our results (Christensen et al., 2013; Jagger et al., 2016; Kingston et al., 2017; Strand et al., 2019; Zeng et al., 2017). For example, Tetzlaff, Muschik, Epping, Eberhard, and Geyer (2017) analysed temporal trends in multimorbidity and found that multimorbidity generally increased—a finding that remained constant even if other more conservative or less conservative definitions of multimorbidity were used. Additionally, Muschik et al. (2017) found that rates of diabetes were increasing. How can these divergent findings be explained? One possibility is that in more recent years older adults retain more muscle mass and functionality despite their diabetes or even in a state of multimorbidity. This may be explained by improvements of medical care—the burden of disease decreases even when the prevalence of disease increases. An alternative methodological explanation might be that improvements of medical diagnostics enable earlier diagnosis of chronic diseases, what in turn may amplify increasing rates of morbidity (Tetzlaff et al., 2017). Finally, future studies should examine whether different aspects of health show divergent longitudinal trajectories (i.e., rates of diseases increase, but rates of functional impairment decrease) or whether other explanations may be more appropriate. However, in the light of our agreement with the study by Chatterji et al. (2015) in which subjective measures of functional status were used, the combined results strongly suggest that functional health

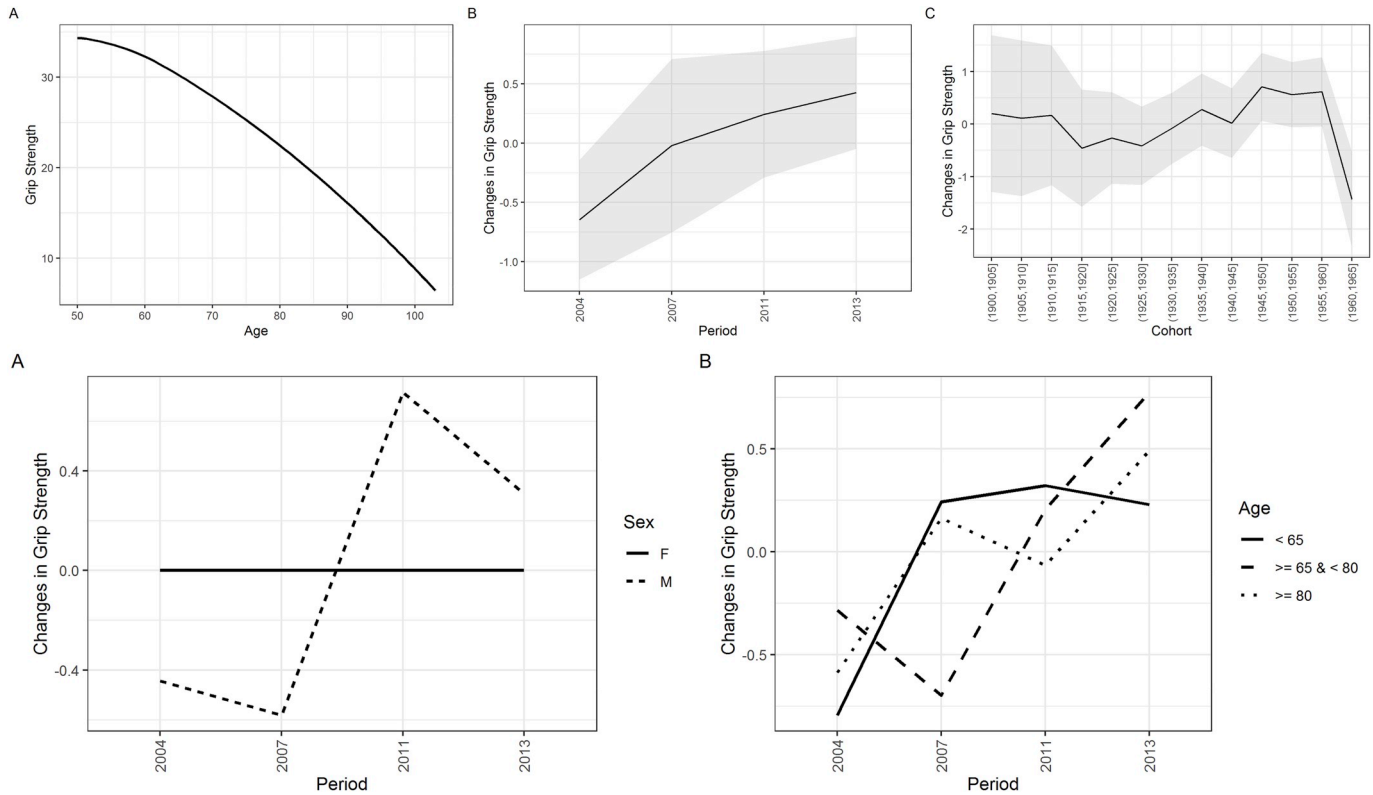

Fig. 3. Age, period, and cohort effects on grip strength in older adults from Spain (N = 7869). In the upper row, panel A depicts the predicted value of grip strength across age; panel B depicts the changes in grip strength due to time period; and panel C depicts the changes in grip strength due to birth cohorts. Shaded areas represent 95% confidence intervals. In the lower row, panel A depicts the changes in grip strength due to time period for men and women separately, and panel B depicts the changes in grip strength due to time period for middle-aged adults, older adults and the oldest old.

of older adults had improved.

There are several possible explanations for this macro-change in grip strength. One of the major mechanisms might be changes in lifestyle, although not much is known about population-based trends of health-related behaviour. For example, physical activity and nutrition have been reported to be strongly related with grip strength (e.g., Al-Sayegh, Al-Obaidi, & Nadar, 2014; Dodds, Kuh, Aihie Sayer, & Cooper, 2013; Flood, Chung, Parker, Kearns, & O'Sullivan, 2014). Another major mechanism of change might be the experience of critical life events during sensitive periods of development. In our analysis, we found substantive variation over birth cohorts for Germany and Spain. German birth cohorts up to 1940 exhibited an increase in grip strength, but German cohorts born after 1940 experienced a sharp drop in grip strength. One speculative explanation is that experiencing WW2 with worsening living conditions and the famine thereafter may have had long-term effects on health. According to this "survivor effect" interpretation, only the most resilient ones of a certain birth cohort might have survived into old age despite adverse circumstances. Finally, the expansion of the public service sector and an accompanying increase of non-manual work might also have contributed to a decline in grip strength in younger birth cohorts.

Regarding the different age group trajectories, we can only speculate why the oldest old aged 80 years and older in every country have become substantially stronger while in comparatively younger older adults average grip strength has stagnated or decreased. Perhaps improvements of medical care in the recent years may have been to the credit to the oldest old living nowadays. Additionally, economic recessions in the EU (e.g. the European debt crisis beginning in 2009) might have struck primarily adults who are still working instead of the oldest old, who are typically retired (Catalano et al., 2011; Jofre-Bonet, Serra-Sastre, & Vandoros, 2018). Differences in health-related lifestyles between age groups may also apply. For example, while the oldest old might have become more active due to a more active lifestyle, younger older adults might have become more passive, e.g. due to decreasing rates of manual jobs (Autor, 2015). As these are plausible hypotheses, future studies should examine possible reasons for the observed divergent age trajectories of functional health.

Another question refers to differences between countries. While the trends in grip strength between countries appeared surprisingly similar, there are also some idiosyncrasies in each country. For Germany, birth cohort effects were found that were generally not as pronounced as compared with other countries, thus suggesting a WW2 effect. A possible explanation for the lack of a cohort effect in the Swedish data may be the absence of historical ruptures that may have contributed to the strong cohort effects in the German and Spanish samples. For example, Sweden was not directly involved in WW2. Overall, the relatively stable trends in grip strength across the considered birth cohorts could emanate from the countervailing effects of a rapid economic growth, an accelerated urbanisation, and the expansion of the public sector (including the provision of free universal health care, and the launch of extensive housing programmes) since the 1950s. Also the concept of 'folkhemmet' (people's home) that is intertwined with the Swedish

welfare state, effective health policies (e.g. restrictive alcohol policies), and a low degree of social inequality might have had buffering effects (Sundin & Willner, 2007). The same applies to physical activity and in particular the concept of 'friluftsliv' (outdoor life) that are central aspects in Swedish life style. In Spain, there was a sharp drop in grip strength for the last birth cohort born between 1960 and 1965. The birth cohort differences might be due to Spain's historical development: After the end of the 1936–1939 Civil War, Spain entered into a period of stagnation lasting until the 1950's, which corresponds to the comparatively non-variable observed cohort trends in grip strength until the 1950's (del Cura & Huertas, 2009). From 1960 on, Spain experienced an enormous growth of the economy, that in the following years was among the fasted growing ones in the world. This economic development was accompanied by a reduction in infant mortality by 57%, again the largest decline observed in the countries of Western Europe during that time period (Di Vittorio, 2006). Correspondingly, we observed a sharp drop in grip strength in this cohort, possibly due to a survivor effect, in which under favourable life conditions even the less-healthy grow into old age.

From a practical perspective, these results suggest an optimistic perspective at first, because older adults may have been able to improve their functional health. It is likely that recent improvements in living conditions, prevention strategies and intervention efforts have substantially contributed to this positive trend and should thus be continued (Bauer, Briss, Goodman, & Bowman, 2014). However, the current results also raise a cautionary note due to the stagnating or even decreasing functional health of younger older adults. Younger older adults are at risk of becoming substantially frailer and more morbid than previous generations, suggesting that there might also be an expansion of morbidity at the birth cohort level. Therefore, future prevention and intervention efforts should additionally focus on improving lifestyles and health of this age group and of younger cohorts.

There are some limitations to the current study. Firstly, while there was widespread agreement regarding time period effects, it has to be acknowledged that there was also variability in cohort effects over countries. Some substantial arguments can be made on the origin of these differences like WW2 in the case of birth cohort differences in Germany. In other cases, we could only speculate. Similarly, the small sample sizes did not permit us to study gender-specific results, as the algorithms failed to converge. Thus, future studies should replicate our study, potentially using larger samples and/or other approaches, to examine whether our results may be generalizable. Until then, care should be taken in interpreting the birth cohort differences. Secondly, the respective sampling frames included only non-institutionalized older adults, who were able to participate in the comparatively long interview process, and not all older adults participated in the grip strength assessment (Börsch-Supan et al., 2013). Consequently, the "true" mean-level of grip strength across age groups is likely to be lower than reported. However, intensive efforts were undertaken to make our analyses as robust as possible: In our analyses we used only first-time respondents in order to prevent morbidity-related drop-out bias. As a further step, we imputed missing values using a modern non-parametric imputation technique in order to prevent item non-response bias. Finally, although grip strength represents an objective, reliable and valid indicator of functional status of older adults, it is still only a single indicator of objective functional status (Üstün & Kennedy, 2009). There are other objective indicators of functional status such as e.g. the chair stand test, the delayed recall test or peak expiratory flow that should be analysed to obtain a more complete picture of trends in functional health. Going further, the literature is also lacking studies documenting age-period-cohort differences in health-related lifestyles that may be held accountable for the observed changes in grip strength (de Lima, Silva, de Castro, & Christofaro, 2017).

Summing up, we investigated age-period-cohort effects in grip strength as a commonly used indicator of functional health and morbidity in older adults in Germany, Spain and Sweden between 2004 and 2013. We found that the oldest old, aged 80 years and older, strongly improved, while comparatively younger older adults stagnated or even decreased—a finding that was consistently found in the three countries considered. Additionally, we found strong birth cohort effects in Germany and in part in Spain such as that grip strength progressively deteriorated in younger cohorts.

Ethics

Ethics board approval was not required, because we only conducted analyses of completely anonymized SHARE-datasets.Acknowledgements

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Conflicts of interest

There are no conflicts of interest to disclose.

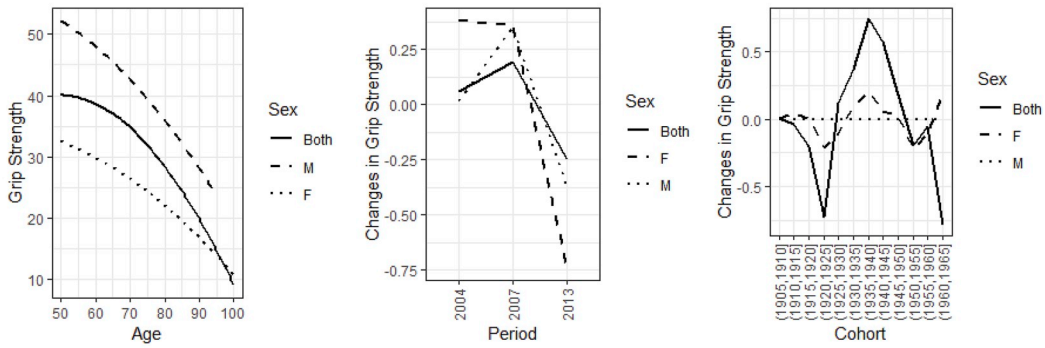
Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2019.100456.

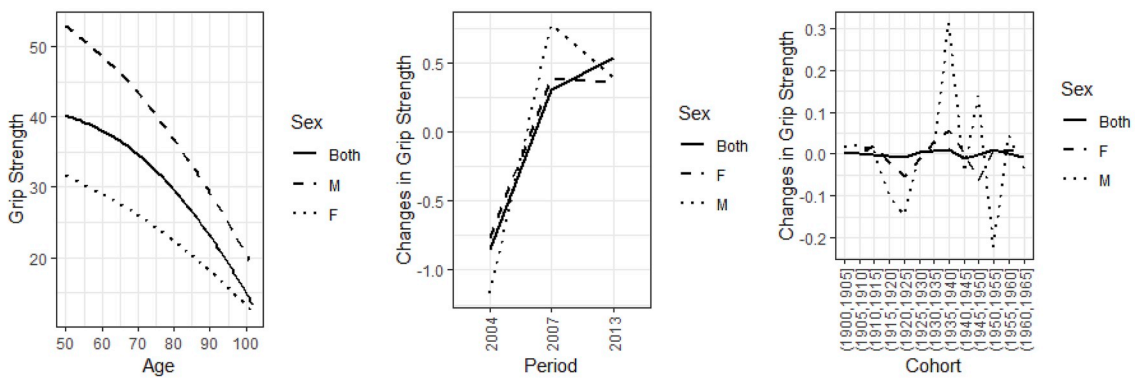
Appendix

Age-Period-Cohort effects reported separately for women and men. Please note that due to small sample sizes the estimated gender-separate effects vary widely and should thus be interpreted with care.

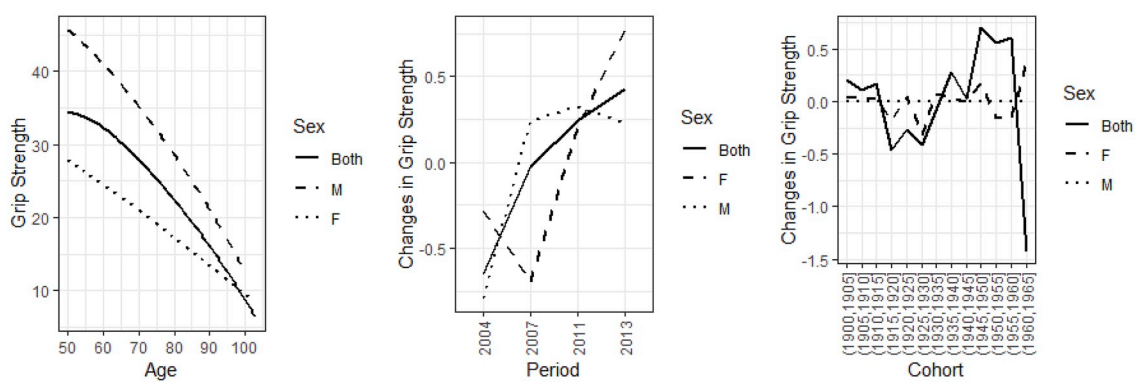
Germany



Sweden



Spain



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