An International Perspective on Aging and Cognitive Decline

A DISSERTATION by

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Es ist nicht genug, zu wissen,
man muß auch anwenden;
es ist nicht genug, zu wollen,
man muß auch tun.

Wilhelm Meisters Wanderjahre
JOHANN WOLFGANG VON GOETHE, 1821.

Abstract

Worldwide populations are growing older. Thus, many countries fear economic and societal burden, but population aging can also be seen as an opportunity for a society. Which view prevails is very much dependent on the chosen measures of aging that are so far mainly based on chronological age.

In the first part of this thesis measures of population aging are analyzed and new measures are proposed. The novel cognition adjusted dependency ratio (CADR) is introduced as an alternative to the old-age dependency ratio (OADR), which only considers a chronological age threshold. A CADR based ranking of certain countries across the world shows a completely different picture compared to an OADR based ranking of the same countries. Northern European countries and the United States are listed at the top according to their CADR, while they are at the bottom end considering their OADR. This difference is discussed in detail within this thesis. On the micro level, a characteristics based approach is proposed to measure and compare individual aging. More specifically, differences in aging are converted into single years of age, which highlights the magnitude of differences between groups such as socioeconomic subpopulations.

The second part of this thesis addresses the huge variability in cognitive functioning, a dimension of healthy aging, between and within countries. The relationship between cognition and education (e.g. individual and national level) is investigated across countries that vary substantially in terms of their demography and level of economic and social

development. The results indicate that increasing the national educational level is assigned with better individual cognitive performance in addition to the positive individual education effect. In the subsequent study, determinants associated with the differences in cognitive functioning across countries, cohorts, and gender are examined. Improvements in living conditions and education support better cognitive performance. Moreover, better living conditions and higher education will increase gender differences in some cognitive functions and decrease or eliminate the gender differences in other cognitive abilities.

Kurzfassung

Die Überalterung der Gesellschaft ist ein Trend der in vielen Staaten weltweit zu beobachten ist. In vielen Ländern wächst daher die Sorge vor den daraus resultierenden ökonomischen und sozialen Problemen. Die steigende Zahl älterer Menschen kann aber auch als Chance betrachtet werden. Auf die Auswirkungen einer überalternden Gesellschaft wird in dieser Arbeit nicht eingegangen, vielmehr aber warum manche Gesellschaften besser altern als andere und wie man das Alter einer Gesellschaft überhaupt messen kann.

Traditionell wird das chronologische Alter als Maß herangezogen, mit einigen daraus resultierenden Schwächen. Der erste Teil dieser Arbeit stellt daher bewährte Indikatoren zur Messung der Bevölkerungsalterung wie den Altenquotienten (OADR) in Frage und präsentiert einen neuen adaptierten Altenquotienten, der die kognitiven Fähigkeiten der über 50 Jährigen berücksichtigt. So werden über 50 Jährige mit guten kognitiven Fähigkeiten auch als Potential gesehen. Beispielsweise erscheinen Länder wie die Vereinigten Staaten oder auch nordeuropäische Länder mit einem hohen Anteil an älteren Menschen unter Berücksichtigung der kognitiven Fitness jünger als zum Beispiel China oder Indien. Auf der Mikroebene werden Unterschiede beim individuellen Altern zwischen sozioökonomischer Gruppen untersucht, wobei hier der Fokus auf physischer Kapazität liegt. Zu diesem Zweck wird der Unterschied in Mobilität (gemessen durch Schrittgeschwindigkeit) zwischen unterschiedlich gebildeten Menschen höheren Alters in eine äquivalente Altersdifferenz umgerechnet. Mit dieser Methode kann gezeigt werden, dass die Mobilität weniger gebildeter Männer im Alter von 60 Jahren jener von höher gebildeten 75 Jährigen gleicht.

Im zweiten Teil dieser Dissertation werden mögliche Einflussfaktoren auf kognitive Unterschiede zwischen Staaten und auch Unterschiede innerhalb eines Landes analysiert. Zunächst wird die Beziehung zwischen Kognition und Bildung (auf individueller sowie nationaler Ebene) in den einzelnen Ländern untersucht. Die Ergebnisse zeigen, dass eine Erhöhung des nationalen Bildungsniveaus mit besseren individuellen kognitiven Leistungen einhergeht, wobei der positive nationale Effekt zusätzlich zum bereits bekannten positiven individuellen Bildungseffekt zu sehen ist. Die Folgestudie betrachtet Geschlechtsunterschiede im kognitiven Verhalten innerhalb eines Landes aber auch zwischen europäischen Ländern. Ein höherer Lebensstandard und bessere Bildung im Laufe eines Lebens wirken positiv auf die individuelle kognitive Leistung. Darüber hinaus werden die Unterschiede zwischen den Geschlechtern in manchen Fähigkeiten kleiner, während bei Gedächtnisaufgaben Frauen ihren Vorteil ausbauen.

Contents

1 Introduction

Decreasing fertility, increasing life expectancy, and migration explain the aging trend that can be observed all over the world. More precisely, today about 600 million people are aged 65 years or older, which is about 8% of the total world population. By 2035, 1.1 billion people aged 65 or more will be alive, which is by then 13% of the total world population. Thus, the number of people over 65 is set to double within 25 years [7].

Taking up first life expectancy, which was quite constant between on average 25 to 40 years over centuries, it started increasing with the industrialization in the 18^{th} century. For instance, in 1990 the life expectancies of both sexes on average ranged already from 38 years in Sierra Leone to 79 years in Japan; worldwide a person born 1990 was expected to live 64 years, whereas Europeans were expected to live 72 years and Americans 75 years [2]. Nowadays, people live so long as at no other time in history with a global life expectancy of 70 years on average (2012: 46 in Sierra Leone, 84 in Japan, 76 in Europe, and 79 in the United States) [2].

Next to higher life expectancy, in recent years family size changed towards fewer children. For instance, the global total fertility rate decreased from 4.97 in the 1950s to 2.53 sixty years later [8]. However, the range in total fertility is wide; whereas more developed regions are below the replacement level (i.e. 2.1) in many African countries such as Niger women have still about 7 children on average [8].

In a nutshell, the world population is growing older on all continents [3]. These larger proportions in older ages are often represented with dependency ratios such as the old-age dependency ratio (OADR). For instance, in 2010 in Japan the ratio of the population above 64 to the economically active population (15-64 years) is 0.35, whereas it will double to 0.74 in 2050 [9]. In comparison to Japan, China - a country with similar fertility rates, but lower life expectancies - has an OADR of only 0.12 in 2010, which will more than triple to 0.39 till 2050. In other words, while the median age of China increases from 34.6 years in 2010 to 46.1 within forty years, every second Japanese was already above 44 years in 2010 and will be above 54 years in 2050 [9].

However, population aging does not necessarily have to be an economic and societal burden. In a recent study researchers show that labor force is graying due to the demographic changes, but increased longevity might also go along with higher productivity [1]. Therefore, unhealthy older populations can result in a societal burden, in contrast to healthy and productive older peers who are able to remain longer in the labor market and manage their life independently even at higher ages.

Motivated by this, over the past decades the compounds of healthy aging (e.g. affective, cognitive, and physical functioning) have been investigated more than ever. In particular cognitive aging attracts the attention of researchers from different disciplines, which might also be driven by the raising demand of cognitive ability within the labor market [5]. It is widely accepted that the process of cognitive decline starts from early adulthood, but aging does not equally affect all aspects of cognition [4, 13]. Moreover, there is a great variability in cognitive functioning among individuals as well as nations and the mechanism affecting cognitive decline is still not fully understood.

1.1 Contribution and research questions

The old-age dependency ratio (OADR) is a well established measure to compare populations. It indicates the ratio of the number of population aged at least 65 years and the working age population. Thus an OADR reflects the increase in life-expectancy and shrinking fertility rates, but it does not represent the actual economic activity or productivity of a population. Many countries have adapted their retirement systems due to increasing life-expectancies, therefore the age 65 as cutoff point for being economically inactive does not seem appropriate anymore. Hence, alternative indicators are established, such as the prospective old-age dependency ratio or the old-age healthy dependency ratio, which consider remaining life expectancy information, or health status. But how would the ranking of countries change if the capacity (physical or cognitive) of a population is considered in the OADR? Which countries do deal better with higher shares of older adults and low fertility rates? I will address this issue and suggest an OADR alternative which excludes people with good cognitive functioning from the burden side and rather includes them within the economically active population.

In addition to comparisons of aging on a macro level also the micro level is essential. How do individuals age? Which subpopulation (e.g. higher educated versus less educated) deals better with aging? Recent studies present biological age as an additional perspective to pure chronological age, whereas others remeasure age by investigating upper extremity strength. I contribute to the field with investigations on mobility. In particular, in the later years of life good mobility ensures a comfortable and independent lifestyle. Therefore, I explore walking speed as a proxy for mobility and review the hypothesis that individuals age differently in diverse subpopulations.

Finally, determinants of healthy aging are crucial as well. There are several dimensions such as affective, physical, and cognitive functioning, which all decline by age, but their trajectories vary. Here, I investigate variation in cognitive functioning and its determinants. Several studies show the positive relation between individual education and cognition, but does a higher educated neighborhood also positively influence cognition? Moreover, are there factors such as life-cycle or regional factors associated to higher cognition at older age? For the first time, I highlight differences across regions, cohorts, and gender within different dimensions of cognitive aging.

1.2 Structure of the thesis

Conceptually, this thesis is organized into two parts, with the first one focusing on measures of populations growing older. I investigate objective measures such as physical and cognitive functioning to compare aging on a macro and on a micro level from a national and international perspective. In the second part, I examine differences in cognitive functioning (i.e. across regions, cohorts, and gender). I address determinants of individual as well as national variability in cognitive aging.

The resulting four studies that synthesize my research are:

- Measures of individual and population aging
  - Variation in cognitive functioning as a refined approach to comparing aging across countries [6]
  - Differences in physical aging measured by walking speed [10]
- Determinants of aging
  - The effect of national and individual educational attainment on cognitive performance [11]
  - The changing face of cognitive gender differences in Europe [12]

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2

Measures of individual and population aging

Population dynamics are often identified by shares of the older adults or by ratios of the older to the younger population. In particular, the OADR is a very commonly used measure, representing the ratio of the population aged at least 65 years to the population aged 15 to 64 years; thus the ratio of the retired population to the economically active population. In Europe an age of 65 years used to be a reasonable cutoff point when the actual retirement age was located around 60 years. Nowadays this cutoff point has to be questioned. Several countries have adapted the retirement age for increased life expectancies of both men and women, therefore the threshold of age 65 should be adapted as well. Having this in mind and thinking additionally about recent changes in job requirements, we suggest to redefine the aging indicator OADR by considering cognitive abilities of older adults instead of being in or out of the labor market.

To construct our new indicator, the cognition adjusted dependency ratio (CADR), we use a common test for episodic memory to classify cognitive functioning, whereat ten words are read aloud and right after a survey participant has to recall as many words as possible without taking any notes. Good cognitive functioning is proxied by recalling at least one half of those ten words. Our new indicator, CADR, includes in the numerator everyone aged 50 and above with less than five recalled words, thus weak cognitive performance. The denominator includes everyone aged between 15 to 49 years and everyone above 50 years with good cognitive functioning. In a nutshell, we excluded people aged at least 50 with good cognitive functioning from the dependent group. Interestingly, according to the OADR India, Mexico, and China have the smallest shares of population aged above 65 years and therefore top the ranking. At the bottom end countries from northern Europe, continental Europe, and southern Europe can be found. Turning toward the CADR, this picture changes; the United States and northern Europe lead the ranking, whereas continental and southern Europe can still be found among the bottom end. This shows, that southern European countries have particularly high shares of older adults, who additionally perform at lower levels in cognitive functioning. On the contrary, in northern Europe there are relatively high shares of population aged at least 65, but they show notwithstanding a good cognitive performance.

Dependency ratio indicators facilitate comparisons of aging populations and rankings of countries. Nevertheless, proper aging measures also matter for individuals and their comparisons on the micro level. I approach this issue with investigating the changes of physical abilities (i.e. walking speed) by age and the differences across population subgroups, which are distinguished by either socio-economic factors or regional wealth. In a next step the differences between subpopulations in physical aging are converted into age years to demonstrate the magnitude of those gaps, which appear very high at early older ages particularly. The results show that higher education provides an advantage of up to 15 years for men and 10 years for women.

Article 1

Variation in cognitive functioning as a refined approach to comparing aging across countries.

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Variation in cognitive functioning as a refined approach to comparing aging across countries

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Comparing the burden of aging across countries hinges on the availability of valid and comparable indicators. The Old Age Dependency Ratio allows only a limited assessment of the challenges of aging, because it does not include information on any individual characteristics except age itself. Existing alternative indicators based on health or economic activity suffer from measurement and comparability problems. We propose an indicator based on age variation in cognitive functioning. We use newly released data from standardized tests of seniors' cognitive abilities for countries from different world regions. In the wake of long-term advances in countries' industrial composition, and technological advances, the ability to handle new job procedures is now of high and growing importance, which increases the importance of cognition for work performance over time. In several countries with older populations, we find better cognitive performance on the part of populations aged 50+ than in countries with chronologically younger populations. This variation in cognitive functioning levels may be explained by the fact that seniors in some regions of the world experienced better conditions during childhood and adult life, including nutrition, duration and quality of schooling, lower exposure to disease, and physical and social activity patterns. Because of the slow process of cohort replacement, those countries whose seniors already have higher cognitive levels today are likely to continue to be at an advantage for several decades to come.

The world population is growing older (1, 2). Comparisons of the burden of aging across countries hinge on the availability of valid and comparable indicators. Demographic indicators like the old-age dependency ratio and median age are widely used to characterize and rank how old countries are. Based on these measures, the populations of Germany, the United States, and Japan are much older than those of India, China, or Mexico. However, the fact that these indicators are exclusively based on chronological age distributions limits their usefulness in terms of drawing conclusions about the consequences of and possible responses to population aging. Alternative approaches to comparing the extent of aging across countries are based on subjective health, life expectancy, and economic activity (3–5). These studies show that different countries can be considered to be the oldest in the world depending on how aging indicators are defined. Such measures, however, can be influenced by culture- and nation-specific interpretations of health level and disability and by business cycle fluctuations.

In contrast to existing studies, we here compare the extent of aging across nations according to age variation in cognitive abilities. Recently released surveys allow us to compare country-level variation in seniors' cognitive functioning across populations with younger and older age distributions.

Studies have found that cognitive ability levels predict individual productivity better than any other observable individual characteristics and that they are increasingly relevant for labor market performance (6–10). This finding applies to a variety of countries and settings, including poorer countries and rural settings (11, 12). In the wake of long-term advances in countries' industrial composition and technological advances, the ability to handle new job procedures is now of high and growing importance, which increases the importance of cognition over time (7, 13).

The growing importance of seniors for the labor market and the fact that certain cognitive abilities decline considerably during late adult ages are the reasons why we focus our study on the population that is 50 y and older (14–18). The length of time for which individuals can retain high cognitive performance will influence the age until which they can potentially stay active in the labor market. We use standardized questions based on representative surveys from different world regions. These international comparable surveys of seniors include English Longitudinal Study of Aging (ELSA), Health and Retirement Study (HRS), World Health Organization (WHO) Study on global AGEing and adult health (SAGE), and Survey of Health, Aging and Retirement in Europe (SHARE), which together allow us to cover almost one-half (45.5%) of the world population (see *SI Materials and Methods* for more details). These surveys include a measure of cognitive ability that is operationalized comparably across all surveys, namely, immediate recall of a certain number of given words, which is a measure of short-term memory (19). Other variables that measure cognitive abilities, like delayed word recall or fluency, are either not included in every survey or not measured in a comparable way. Analysis for countries where these measures can be compared corroborates the results we get for immediate word recall (see Figs. S1 and S2, Tables S1 and S2, and *SI Results* for more details). This study compares seniors' age variation in cognitive abilities across countries from both developed and emerging economies by using results from standardized testing procedures. The inclusion of seniors from world regions with chronologically younger populations has become possible only recently with the release of SAGE.

Immediate recall has been shown to be important for a variety of outcomes, ranging from financial decisionmaking to the risk of developing dementia (20–23). Moreover, technological advances and changes in working procedures imply that the importance of the ability to learn and remember is increasing (24). Employers are particularly concerned that their employees are able to learn new work procedures and process new information (25), which also suggests that employers view the ability to immediately recall information as advantageous to labor market performance.

Results

Fig. 1 shows the age variation in immediate recall across countries and country regions. It depicts the proportion of words (out of 10 read out nouns) which the respondents are able to recall within 1 min (18 countries) and 2 min (UK and the US; 95% of

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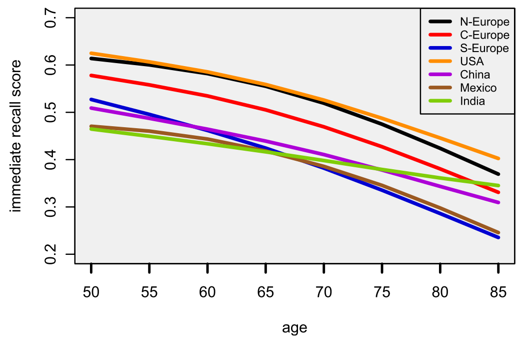

Fig. 1. Mean age-group–specific immediate recall scores (values between 0 and 1, where a score of 0.4 means being able to recall 40% of the given words). Curves are smoothed by using spline interpolations. Logistic regression to test for significant age-related decline, significance levels $P < 0.001$. Analysis of variance to test for differences between countries, significance levels $P < 0.01$.

the US participants completed the task within 1 min. See *SI Materials and Methods* for more details). In Table 1 summary statistics for all used variables of our dataset are provided.

The findings highlight a statistically significant age-related decline in all countries within the 50–85 age interval. Immediate recall age trajectories for northern and continental European countries and the United States run parallel to those of southern Europe, Mexico, and China, whereas the decline in India proceeds at a much slower pace. Our findings show statistically significant differences in the levels of cognitive performance between countries. Thus, seniors in the United States and northern and continental European countries have the highest immediate recall ability, whereas their peers in China, India, Mexico, and southern Europe perform worse.

To take the observed differences in cognitive functioning of seniors into account when comparing aging across countries, we propose an additional indicator that focuses on cognition and demographic change: cognition-adjusted dependency ratio (CADR). For this measure, the denominator is composed of everyone who is 15 to 49 y old and the 50+ population (no upper age bound) with good cognitive functioning (approximated by those who are able to recall at least one-half of the words in the test). The numerator consists of the number of persons aged 50+ who recall fewer than one-half the words in the test.

Our aging indicator is presented and compared with the usual old-age dependency ratio (OADR), which is defined as the ratio of the number of persons aged 65+ to the number of persons between the ages of 15 and 64, in Table 2. The rank ordering of the different countries and regions changes as we apply the alternative aging indicator: Mexico, India, and China do less well compared with the rank order based on the OADR, whereas the United States and continental and northern Europe do better.

This result implies that although continental European countries have a larger population share above the age of 65 than China, their lower CADR would suggest that these countries are effectively "younger." That is, they have a lower share of seniors with poor cognitive performance.

Discussion

One potential source of explanation for the international variation in seniors' cognitive functioning levels are life-course differences among the cohorts we consider. Present-day seniors in different countries have varying experiences with respect to a large number of influences, including their average length and quality of schooling, nutrition (prenatal, early life, and adult), exposure to famines, disease, and pollutants, physical and social activity patterns, and whether working conditions have been stimulating or detrimental to cognitive performance (26–37).

An increase in cognitive performance among successive cohorts describes a phenomenon that has been observed in many countries for an extended period (38–40). In the United States, such evidence began with comparisons of test performances of conscripts from World War I and World War II, with continued cognitive improvements having been documented for most of the 20th century. Successive cohorts in western countries have been shown to generally perform better at cognitive tests for long periods, whereas in other countries, cohort improvements have only been documented for recent cohorts. The likely later onset of cognitive improvement would follow the observed delayed onset of drivers of cognitive improvements, including mortality decline, universal education, improved nutrition, and better economic conditions (40–44).

In some countries, particularly in India, the cohorts presently 50 y and older have grown up during periods of widespread poverty and deprivation and where mortality levels were high, which could lower the overall levels of cognition among the cohorts presently old (41, 45). At the same time, large socioeconomic mortality differentials within a population could imply that the population is positively selected at a more advanced age. Given that those with higher cognitive performance live longer,

Table 1. Summary statistics of the survey subsets

	HRS	SAGE			SHARE (Northern Europe)	SHARE (Continental Europe)	SHARE (Southern Europe)
Measurements	United States	China	India	Mexico	Denmark, England, Ireland, Sweden	Austria, Belgium, Czech Republic, France, Germany, Netherlands, Poland, Switzerland	Greece, Italy, Spain
Year	2006/07	2007–2009	2007–2009	2007–2009	2006/07	2006/07	2006/07
Sample size	17,995	13,367	7,150	2,306	4,736	14,948	6,153
Females, %	58.3	53.1	49.4	60.5	53.4	55.2	54.6
Birth cohorts	1901–1956	1910–1959	1909–1957	1904–1959	1907–1957	1903–1957	1905–1957
None of the words recalled, %	0.7	1.3	1.0	2.8	0.4	1.9	2.9
All words immediately recalled, %	0.7	0.4	0	0	0.9	0.4	0.5

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Table 2. Different measures for the burden of aging

Country/group	Rank (ratio) CADR	Rank (ratio) OADR
United States of America	1 (0.10)	4 (0.19)
Northern Europe (Denmark, England, Ireland, Sweden)	2 (0.12)	5 (0.24)
India	3 (0.14)	1 (0.07)
Mexico	3 (0.14)	2 (0.09)
China	5 (0.15)	3 (0.12)
Continental Europe (Austria, Belgium, Czech Republic, France, Germany, Netherlands, Poland, Switzerland)	6 (0.18)	6 (0.25)
Southern Europe (Greece, Italy, Spain)	7 (0.32)	7 (0.27)

Source: Population data for the year 2005 from UN (2009) and for England for the year 2005 from the Office for National Statistics (2010); survey data from HRS, SAGE, and SHARE.

this could entail a "flatter" age-cognition curve (46, 47), such as for India (48–50).

A few studies suggest that there has been a leveling off and reversal in cognitive increases among recent generations of younger men in some countries; however, it will take several decades until these cohorts attain senior age (51, 52).

Education has been identified as significantly raising levels of cognitive functioning, including memory (16, 53, 54). The countries in our study with better cognitive functioning levels are also the countries with higher educational attainment. Northern Europeans and Americans have globally the highest educational attainment among their 50+ population, whereas education levels are much lower in the Chinese and Mexican senior populations. Epidemiological research has identified low educational attainment as an important risk factor for low cognitive functioning and Alzheimer's disease (55, 56). Education is related to better cognitive performance in late life, and researchers relate the effect to occupational complexity and the acquisition of a lifelong ability to sustain attention and conceptualize problems. Although it is uncertain whether education affects the rate of decline (57), it can affect the cognitive level for all age groups (53, 54). Being mentally active, through courses and cognitive training, has been shown to improve cognitive functioning among older people (33, 58–60). Education may increase the synaptic density in the neocortical association cortex and, therefore, delay cognitive decline and dementia by several years (61). At the same time, lower childhood intelligence in early life appears to be a reliable proxy for lower cognitive ability later in life (62–64).

Later born cohorts with higher cognitive functioning will eventually replace older cohorts with poorer cognitive performance. If this trend continues, cognitive performance is likely to improve along cohort lines at senior adult ages (65). In Mexico, where time series data allow comparison of successive cohorts, we find that individuals of the 1941–45 cohorts at age 60 were able to remember on average 4.2 words, whereas those born 1946–50 were able to recall 5.1 words at the same age. The same holds for England's 60-y-olds: Here, we find an increase from 6.0 to 6.3 recalled words for the 1941–45 relative to the 1946–50 cohorts. Overall, these developments suggest that there will be a universal increase in cognitive functioning among seniors in the coming decades. However, as cohort replacement is a slow process, the countries whose seniors have higher cognitive levels today are likely to continue to have an advantage for several decades ahead.

Age-related norms (such as at which age a person is regarded as being "old") can vary by countries and cultures (66, 67). They may be influenced by age-related laws and regulations, including official retirement ages, which vary significantly between countries (68). Retiring at older ages can imply that one stays mentally active until higher ages, which could improve the level of cognitive functioning until higher ages (69).

Conclusion

The current study's shift in focus from chronological age distributions to actual cognitive functioning at older ages leads to a relevant additional possibility to compare aging across countries. This shift in perspective is crucial because it changes focus from predictable changes in the demographic age structure toward the importance of improving and maintaining cognitive abilities. Because the adjustment for aging requires long-term investments and changes in training policies and lifestyles, it is essential to implement policies and efforts that prepare societies for an older population by maintaining cognitive abilities throughout the life cycle (70, 71).

The degree to which demographic aging translates into societal challenges depends to a considerable extent on the age at which mental functioning becomes significantly impaired. Technological improvements increasingly allow seniors to participate longer in the working life (72, 73). Normal aging, however, also tends to involve a decline in certain cognitive abilities, where technological innovations are less likely to be able to compensate to a significant extent for cognitive decline. At the same time, the need for cognitive fitness seems to continue to increase. Nations that are truly challenged by aging may be those where the cognitive performance among their seniors is poor; not those who have chronologically older age structures.

Materials and Methods

A growing number of surveys are focusing on the elderly (for an overview of selected cross-national and single-country databases, see ref. 1). However,

Table 3. Overview of all used datasets

Dataset	Country/region	Year	Sample size
ELSA (English Longitudinal Study of Aging)	England	2006/07	9,771
HRS (Health and Retirement Study)	United States	2006/07	18,469
MHAS (Mexican Health and Aging Study)	Mexico	2003	13,704
SAGE (WHO Study on global Aging and adult health)	China, India, Mexico	2007/09	32,696
SHARE (Survey of Health, Aging and Retirement in Europe)	Europe	2006/07	26,515

the number of surveys that contain the information we need for our analysis is limited (Table 3). The main reasons for excluding data sources are (*i*) The survey only includes people above 60 or 65, which is higher than our lower age bound of 50 y and (*ii*) the measure for cognitive ability is not included in the survey or not comparable to our measure of word recall.

Data Sources and Variables. ELSA, representative for the population aged 50+ of England, consists of four waves (2002–2009) (74). HRS is representative for the 50+ population of the United States. It started 1992 and was conducted every year until 1996. Thereafter it was done only every other year. So far, 11 waves are available. For our purpose we took the RAND HRS dataset, a user-friendly subset of HRS (75). SHARE is a European survey that is representative of the participating countries' population aged 50+. The first survey was conducted in 11 countries in 2004/2005. Three more countries were added for the second wave in 2006/07. We divided the individual country files of SHARE into three regional datasets: continental (Austria, Belgium, the Czech Republic, France, Germany, the Netherlands, Poland, and Switzerland), southern (Greece, Italy, and Spain) and northern Europe (Denmark, Sweden, and Ireland) (76). Mexican Health and Aging Study (MHAS) consists of two waves. The baseline survey was conducted in 2001, the follow-up in 2003. The survey population is representative of Mexicans aged 50+ (77). SAGE was initiated by WHO to collect longitudinal information on health and well-being of adults (18+ with an emphasis on 50+). We use this data for China, India, and Mexico (78).

ELSA is part of the Northern European country group. All "don't know" and "refused" answers are coded as missing in all surveys. For cross-country comparison we use the 2006/07 waves to compare cognitive performance by age and country/region for a similar period. MHAS was only used for obtaining cohort differences in cognitive functioning. All provided results are gained by including the provided cross-sectional individual sample weights or individual sample weights for longitudinal investigations.

CADR. As described above, we introduce CADR, which is formally defined by the following equation.

$$CADR = \frac{|\{x \in P | (m_x < 0.5) \wedge (age_x \geq 50)\}|}{|\{x \in P | (15 \leq age_x < 50\} \cup \{m_x \geq 0.5) \wedge (age_x \geq 50)\}|},$$

where m_x represents the memory score of person x, age_x represents the age of person x, and P is the population.

Trends in Cognitive Abilities. We use all four waves of ELSA and calculate the mean immediate recall score at age 60 for the cohorts born between 1941 and 1945 and the cohorts born between 1946 and 1950. MHAS data for 2001 and 2003 are combined with SAGE data for 2007/09, because both surveys are representative for the 50+ population in Mexico. The cohorts born between 1941 and 1945 and the cohorts born between 1946 and 1950 are analyzed in an analogous manner to ELSA.

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Supporting Information

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SI Materials and Methods

All surveys are based on the HRS framework and are specifically designed to allow for a high degree of comparability across countries. Although they all use common instruments and methods, further work should be carried out in terms of formal calibration of measurement instruments across countries (1–3).

Item Wording of Analyzed Variables.

ELSA.

Immediate recall: "The computer will now read a set of 10 words. I would like you to recall as many as you can. We have purposely made the list long so it will be difficult for anyone to recall all the words. Most people recall just a few. Please listen carefully to the set of words as they cannot be repeated. When it has finished, I will ask you to recall aloud as many of the words as you can, in any order. Is this clear?"

[10 words out of four possible lists (read by computer or person), up to 2 min for recalling]

Delayed recall: "A little while ago, you were read a list of words and you repeated the ones you could remember. Please tell me any of the words that you can remember now."

(Asked after some delay, up to 2 min for recalling)

Fluency: "Now I would like you to name as many different animals as you can think of. You have one minute to do this. The computer voice will tell you when to stop."

(Valid answers are different breeds, sex- or generation-specific names; not valid are named animals and redundancies)

HRS.

Immediate recall: "I'll read a set of 10 words and ask you to recall as many as you can. We have purposely made the list long so that it will be difficult for anyone to recall all the words–most people recall just a few. Please listen carefully as I read the set of words because I cannot repeat them. When I finish, I will ask you to recall aloud as many of the words as you can, in any order. Is this clear?"

(1 list of 10 words out of four possible lists, up to 2 min for recalling)

Delayed recall: "A little while ago, I read you a list of words and you repeated the ones you could remember. Please tell me any of the words that you remember now."

(Asked ≈5 min after immediate recall item, up to 2 min for recalling)

MHAS.

Immediate recall: "I'm going to read you a list of words. Listen carefully. When I finish reading them, you should repeat all the words that you can. It does not matter in which order you repeat them."

(A list of eight words out of two possible lists, afterward this procedure was repeated twice (reading and recalling). We used only the results of the first trial)

SAGE.

Immediate recall: "We are now going to test your memory. I know these questions may be difficult to answer, but please try to provide an answer. I am going to read you a list of words. Listen to them carefully and try to remember as many of them as you can, not necessarily in order. I will ask you to repeat them again after some time."

(10 words, 1 min for recalling, afterward this procedure was repeated twice (reading and recalling). We used only the results of the first trial)

Delayed recall: "I read you a list of words about 10 minutes ago. I will NOT repeat this list to you now, but could you please repeat to me as many of them as you can remember?"

(Asked ≈10 min delay, 1 min for recalling)

Fluency: "Now we are going to ask you to think of animals and name as many as you can. I am going to give you one minute and I want to see how many animals you can name."

(Valid answers are birds, insects, and fish, as well as different breeds and sex- and generation-specific names; not valid are numbers, proper names, or places)

SHARE.

Immediate recall: "Now, I am going to read a list of words from my computer screen. We have purposely made the list long so it will be difficult for anyone to recall all the words. Most people recall just a few. Please listen carefully, as the set of words cannot be repeated. When I have finished, I will ask you to recall aloud as many of the words as you can, in any order. Is this clear?"

(10 words, 1 min for recalling)

Delayed recall: "A little while ago, I read you a list of words and you repeated the ones you could remember. Please tell me any of the words that you can remember now?"

(Asked ≈5 min after immediate recall item, 1 min for recalling)

Fluency: "Now I would like you to name as many different animals as you can think of. You have one minute to do this. Ready, go."

(Valid answers are any members of the animal kingdom, real or mythical, specifically species name any accompanying breeds within the species as well as male, female, and infant names within the species; not valid are repetitions and proper nouns)

The words are always given in the national language (except for SAGE where the questionnaire is given in the local language) and all of them belong to different areas of everyday speech. For instance, SHARE used the following words: butter, arm, letter, queen, ticket, grass, corner, stone, book, stick.

The recall time for immediate recall and delayed recall tasks was fixed at 1 min for all surveys with the exception of ELSA and HRS where everyone had an additional minute. However, the great majority of HRS respondents did not make use of the second minute: 90% of respondents used <50.4 s for the delayed recall task and 95% needed <1 min. In case of the immediate recall task, 90% of respondents needed <49.2 s and 95% completed within <1 min. Considering only those completing within 1 min does not change the rank ordering based on the CADR. Because of the absence of a response time variable in ELSA, it is not possible to present the respective statistics for the United Kingdom.

Data Preparation. The data we analyze come from four surveys representing the elderly population in the respective countries.

Because there are similarities between European countries, we group these according to the UN grouping of geographical regions. Northern Europe includes Denmark, England, Ireland, and Sweden. Southern Europe consists of Greece, Italy and Spain. The UN distinguishes between eastern and western Europe, whereas we decided to merge these two groups as continental Europe.

Table 1 provides summary statistics of our dataset. Table S1 gives a more detailed overview of the cognitive ability measures used and comprises mean and variance for immediate recall, delayed recall, and fluency. Variances for the two recall tasks are fairly equal, whereas there are bigger differences for fluency.

Immediate recall and delayed recall are not only equal in terms of variation. The correlation coefficients between the recall tasks (Table S2) are strongly positively correlated (correlation coefficient >0.7) except for the SAGE countries (China, India, and Mexico). The crystallized ability fluency also correlates positively with the recall tasks, but not as strongly (Table S2).

SI Results

Statistics on a Broader Range of Cognitive Measures to Assess Productivity Variation. Fig. 1 showed a pattern of general decline of immediate recall ability after age 50, and country differences were mainly due to differences in the starting level at age 50. Similar patterns can be recognized for the delayed word recall in Fig. S1. We focus on Europe and the US because the word list was read just once to the participants there. The decrease in delayed recall with increasing age has a similar decline as the trajectories of immediate recall; the differences in starting levels at age 50 are a bit wider.

Cognitive skills are often categorized according to how they develop over the life cycle, where fluid abilities are those that decrease considerably by age, whereas crystallized abilities decline less (4, 5). Fluid abilities include abilities such as processing speed, task solving, and short-term memory. Crystallized abilities cover the knowledge spectrum and include vocabulary size and word fluency. In our study, our two memory items cover the fluid spectrum, whereas fluency can be seen as part of the crystallized spectrum.

Having a look at fluency, where respondents were asked to name as many animals as possible, we identify a country ranking that is similar to what we found by using the other two measures. Northern Europe performs best, followed by Continental European countries, whereas India performs worst. Although the gap between the mean fluency ability for 50- to 55-y-olds is the biggest, the difference between the countries is lower at higher ages. India has the smallest decline (Fig. S2).

When comparing age declines in the recall items with the fluency item, we find a stronger decline in recall functioning, which is in line with earlier findings on this topic (5). Although fluency on average decreases by 27% from age 50–80, immediate recall decreases by 34% and delayed recall by 47%.

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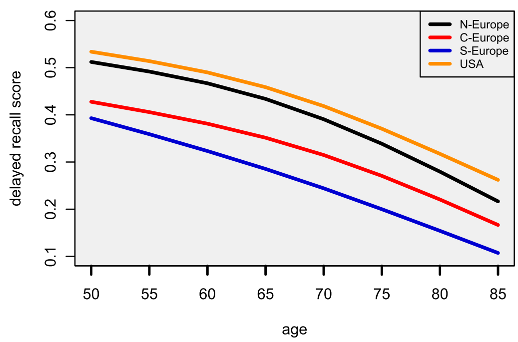

Fig. S1. Mean 5-y age group-specific delayed recall of older adults; Europe and US 2006/07; Curves are smoothed with spline interpolation.

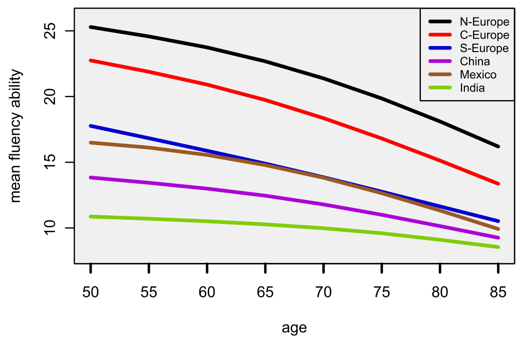

Fig. S2. Mean 5-y age group-specific fluency ability of older adults; Europe 2006/07, Mexico and India 2007/09; Curves are smoothed with spline interpolation.

Table S1. Mean and variance for cognitive abilities, immediate, and delayed recall and fluency

	HRS	SAGE			SHARE (Northern Europe)	SHARE (Continental Europe)	SHARE (Southern Europe)
Measurement	United States	China	India	Mexico	Denmark, England, Ireland, Sweden	Austria, Belgium, Czech Republic, France, Germany, Netherlands, Poland, Switzerland	Greece, Italy, Spain
Mean immediate recall (variance)	0.56 (0.03)	0.55 (0.03)	0.49 (0.03)	0.49 (0.02)	0.55 (0.03)	0.50 (0.03)	0.42 (0.04)
Mean delayed recall (variance)	0.46 (0.04)	0.62 (0.05)	0.54 (0.04)	0.58 (0.04)	0.43 (0.04)	0.35 (0.04)	0.28 (0.04)
Mean fluency (variance)	—	14.4 (26.8)	11.0 (13.5)	17.1 (33.0)	22.5 (53.5)	19.7 (59.3)	14.9 (56.3)

Table S2. Correlation coefficients of immediate and delayed recall, immediate recall and fluency, and delayed recall and fluency

	HRS	SAGE			SHARE (Northern Europe)	SHARE (Continental Europe)	SHARE (Southern Europe)
Measurement	United States	China	India	Mexico	Denmark, England, Ireland, Sweden	Austria, Belgium, Czech Republic, France, Germany, Netherlands, Poland, Switzerland	Greece, Italy, Spain
Immediate recall–delayed recall	0.78	0.57	0.55	0.52	0.72	0.72	0.75
Fluency—immediate recall	—	0.29	0.26	0.43	0.45	0.48	0.40
Fluency—delayed recall	—	0.41	0.34	0.45	0.44	0.44	0.38

Article 2

Differences in physical aging measured by walking speed.

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An earlier version of this article has been published as working paper

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Differences in physical aging measured by walking speed

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Abstract

Physical functioning and mobility of older populations are of increasing interest when populations are aging. Lower body functioning such as walking is a fundamental part of many actions in daily life. Limitations in mobility threaten independent living as well as quality of life in old age. In this study we examine differences in physical aging and convert those differences into the everyday measure of single years of age.

We use the English Longitudinal Study of Ageing, which was collected biennially between 2002 and 2012. Data on physical performance, health as well as information on economics and demographics of participants aged 50 years and above were collected over a ten year period. Lower body performance was assessed with two timed walks at normal pace each of 8 ft (2.4 m) of survey participants aged at least 60. We employed latent growth models to study differences in physical aging and followed the characteristic based age approach to illustrate those differences in single years of age.

First, we examined walking speed of about 11,700 Englishmen, whereat we identified differences in age trajectories by sex and characteristics (e.g. education, occupation, regional wealth). Interestingly, higher educated and non-manual workers

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outperformed their counterparts for both men and women. Moreover, we transformed the differences between subpopulations into single years of age to demonstrate the magnitude of those gaps, which appear very high at early older ages particularly.

This paper expands research on aging and physical performance. In conclusion, higher education provides an advantage of up to 15 years for men and 10 years for women. Thus, encouragements in higher education have the potential to ensure better mobility and independent living in old age for a longer period.

1 Introduction

Looking at functional capacities such as physical and cognitive function, the aging process varies across populations and beyond that even across populational subgroups (Leopold and Engelhardt, 2013; Sanderson and Scherbov, 2014; Soer et al., 2012; Weber et al., 2014). Walking is one of those physical capacities, which represents musculoskeletal strength and power. It is required for any dynamic activity and hence ensures independent life at higher ages. There are several dimensions of walking such as gait rate, stride length, and walking speed (also termed gait speed). The measure walking speed is very popular in aging surveys as it can easily be assessed by nonprofessional staff.

Some previous research showed that walking speed declines with age, whereas men outperform women at all ages. In a meta analysis researchers identified walking speed to be relatively consistent between the age decades up to late 60s in both sexes, thereafter the mean pace was significantly less than in the previous decade (Bohannon and Andrews, 2011).

Moreover, walking speed is associated with survival at all ages in both sexes, and particularly informative for people aged 75 years and higher (Cooper et al., 2014; Studenski et al., 2011). Over and above survival, objective physical capability measures such as walking speed are also predictors of general health in elderly (Cooper et al., 2014). Factors explaining this association are manifold such as health behavior, cardiovascular risk factors, and even more important inflammatory markers (Elbaz et al., 2013).

The aims of this study are to investigate the differences in physical aging, proxied with mean walking speed, between subpopulations of England's older adults and to convert those differences into a more common measure.

2 Methods

2.1 Data Source

We used the English Longitudinal Study of Ageing (ELSA), which is a longitudinal study of a representative sample of the English non-institutionalized population aged 50 years and older (mar, 2014). The first wave was collected in 2002 and thereafter participants were reinterviewed every second year until 2012. Sample refreshment were added in waves three, four and six (Banks et al., 2014; Steptoe et al., 2013). Data were collected within a face-to-face interview using CAPI (computer-assisted personal interview) and a self-completion questionnaire. In addition, there was a nurse visit in waves two, four, and six to measure physical functioning and to take blood samples as well as anthropometric measurements. Ethical approval for all the ELSA waves was granted by the National Research and Ethics Committee. All participants signed full informed consent to participate in the study. More information on ELSA can be found at http://www.ifs.org.uk/elsa/documentation.php. Data were accessed through the Economic and Social Data Service.

For the present study we use all six available waves; thus panel data over a period of ten years.

2.2 Subjects

ELSA used a multistage, clustered, stratified sampling strategy to draw the sample. In total, about 17,980 participants were interviewed within all six waves. We restricted the data to participants aged between 60 and 89 years for this study. Further, we excluded people if their self-assessed age and the calculated age based on year of birth and survey year differed by more than two years. Only non-institutionalized older adults with complete data on walking speed were selected, whereas a speed of less than 0.09m/s was considered as missing. These restrictions resulted in a final sample of 5,490 men, 6,221 women (N=11,711) and in total 35,596 observations. Table 1 provides an descriptive overview for each wave.

2.3 Measures

2.3.1 Walking speed

Each participant aged 60 and above was eligible for the *timed walk* test. In addition, prior to the actual test respondents were asked if they had any problems from recent surgery, injury, or other health conditions that might prevent them from walking. Only persons aged at least 60 years, willing to do the test and being able to walk (walking aids were permitted) were asked to walk twice 8 feet (2.4m) at their usual walking pace. The time for both walks was recorded separately. In our analysis we use the mean speed (measured in m/s) of the two trials.

2.3.2 Anthropometrics

The anthropometric measures body weight and height were taken by nurses in waves 2, 4, and 6. A body weight of less than 29kg and a body height of less than 1.29m were coded as missing information. In our analysis we included the mean height and weight of each participant to overcome the information lack in the odd waves.

2.3.3 Education

Information about the highest educational qualification was collected within the first interview. Thereafter (e.g. in the follow-up interviews) all participants were asked whether further education was attended and if so which one. Participants could select one out of seven categories ranging between no qualification and higher education with degree. We coded the seven categories into higher educated (nvq2/gce or higher) and lower educated (no qualification or nvq1/cse).

2.3.4 Occupation

Current or most recent job information was provided for each respondent using the National Statistics socio-economic classification (NS-SEC). We dichotomized that variable by clustering managerial, professional, and intermediate occupations into non-manual occupation and routine and manual occupations into manual occupation.

2.3.5 Regional wealth

The Government Office Region (GOR) variable was available for each participant. We categorized North East, North West, Yorkshire and The Humber, East Midlands, and West Midlands as less wealthier region and East of England, London, South East, and South West as wealthier region, whereas a Regional Gross Value Added (GVA) per head of less than £21,000 per capita in 2013 was used as cutoff point (Office for National Statistics, 2014).

2.4 Analysis

Following a sample description, we identified differences in walking speed. We explored these differences in physical function by age and subpopulations with growth curve models (Raudenbush and Bryk, 2002; Steele, 2008). The subpopulations were distinguished by three different characteristics (i.e. regional wealth and the two socioeconomic classification characteristics education and occupation). The models were applied separately by sex and characteristics.

First, we identified a non-linear growth model considering mean weight, mean height and survey wave as covariates (verified by likelihood-ratio tests). We added the dummy coded group variable for the subpopulation with less education, manual occupation, and living in a less wealthier region as reference categories for examining between-person variability in walking speed. In addition, we included an acceleration subpopulation effect for women and a slope subpopulation effect for men (identified by likelihood-ratio tests). Further, the time variable age was centered at 70 years, the mean age within our data sample.

The model for women was specified as follows:

$$Y_{ti} = \pi_{0i} + \pi_{1i}(age_{ti} - 70) + \pi_{2i}(age_{ti} - 70)^2 + \pi_{3i}wave_{ti} + e_{ti}$$

$$\pi_{0i} = \beta_{00} + \beta_{01}group_i + \beta_{02}height_i + \beta_{03}weight_i + r_{0i}$$

$$\pi_{1i} = \beta_{10} + r_{1i}$$

$$\pi_{2i} = \beta_{20} + \beta_{21}group_i$$

$$\pi_{3i} = \beta_{30}$$

and for men

$$Y_{ti} = \pi_{0i} + \pi_{1i}(age_{ti} - 70) + \pi_{2i}(age_{ti} - 70)^2 + \pi_{3i}wave_{ti} + e_{ti}$$

$$\pi_{0i} = \beta_{00} + \beta_{01}group_i + \beta_{02}height_i + \beta_{03}weight_i + r_{0i}$$

$$\pi_{1i} = \beta_{10} + \beta_{11}group_i + r_{1i}$$

$$\pi_{2i} = \beta_{20}$$

$$\pi_{3i} = \beta_{30}$$

with i indicating the individual and t indicating the time. We assumed that the errors e_{ti} were independent and normally distributed with common variance σ^2.

Finally, the magnitudes of the variability due to education, occupation or regional wealth were converted into single years of age following a characteristic-based age approach (Ryder, 1975; Sanderson and Scherbov, 2013). In more detail, walking speed was written as a function of chronological age and a set of covariates for each sex. These functions were used to calculate the so called α-ages $\alpha_{k,t}$, whereat $\alpha_{k,t}$ represents the chronological age of the "higher" subpopulation equivalent to a particular walking speed k at age t of the reference subpopulation (Sanderson and Scherbov, 2013). Thus to highlight the differences in physical aging, we can report the α-ages for higher educated, non-manual workers, and people living in wealthier regions associated with the walking speed of their counterparts at a certain age.

We carried out all analyses and produced all figures with R 3.0.2 (R Core Team, 2013). Sampling weights were used for all descriptive statistics to adjust for non-response and to ensure population representativeness.

3 Results

In total our selected sample included 11,711 people who participated at least in one of the six waves of ELSA. About 12.7 % of the participants aged at least 60 had to be excluded, as they did not participate in the timed walking test. An overview of our sample including descriptive statistics by survey wave is presented in Table 1.

As previously reported, men showed faster walking speed over all ages than women. Moreover, differences were not only observed across sex, but also observed across subpopulations demonstrating a socio-economic gradient indicating an advantage of higher socio-economic class subpopulations for both sexes. Additionally, the analysis of the pooled six waves enabled us to confirm a non-linear age effect on walking speed.

Focusing first on differences in lower body performance due to education, higher

Table 1: Descriptive sample overview by wave, including summary statistics such as mean (SD) on walking speed, age, height, and weight and shares of women, higher educated, non-manual worker, living in wealthier region.

variables	wave 1	wave 2	wave 3	wave 4	wave 5	wave 6
walking speed	0.85 (0.28)	0.85 (0.27)	0.84 (0.28)	0.86 (0.28)	0.88 (0.27)	0.88 (0.28)
age	70.6 (7.4)	70.6 (7.4)	70.5 (7.6)	70.0 (7.6)	70.1 (7.5)	70.1 (7.4)
height	1.64 (0.09)	1.64 (0.10)	1.65 (0.09)	1.65 (0.09)	1.66 (0.09)	1.65 (0.10)
weight	74.5 (14.1)	75.1 (14.7)	75.9 (14.8)	76.8 (15.4)	77.8 (15.5)	77.6 (15.9)
females	54.47	54.85	53.94	53.57	52.72	52.97
higher educated	38.57	42.43	51.33	52.63	57.43	60.9
non-manual occupation	50.33	51.89	52.09	53.09	55.29	57.47
wealthier region	50.06	49.86	50.58	52.24	51.98	51.63
unweighted N	6107	5458	5181	6213	6330	6347

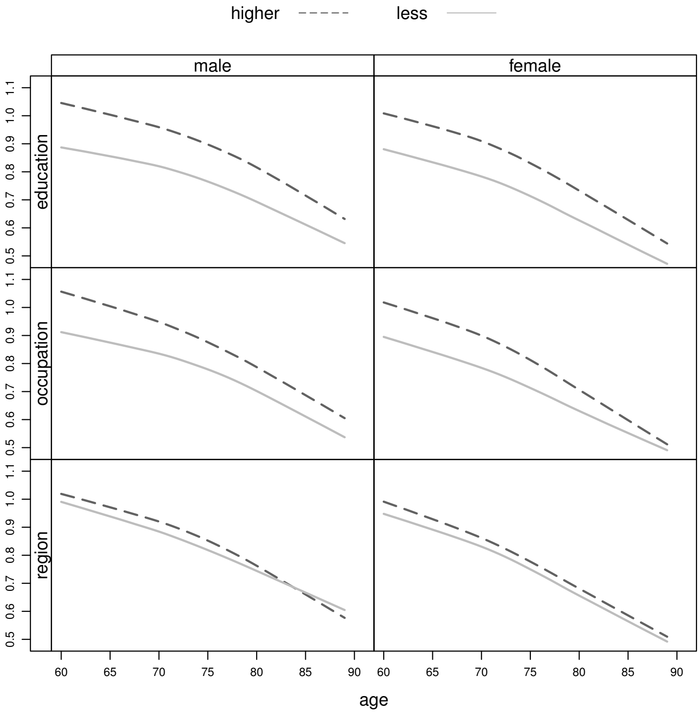
educated men and women walked on average faster than their lower educated counterparts. This was particularly true for the population aged about 60 years of both sexes (see Figure 1). However, age and education interactions varied by gender. The interaction between age^2 and education was significant for women, but there was no significant interaction between age and education for men (Tables 4 and 5). The advantage of higher educated women diminished slightly at higher ages.

In occupational subgroups, non-manual workers walked on average faster than manual workers (see Figure 1). Interestingly, the gap in walking speed between the occupational subpopulations almost vanished at higher ages, particularly for women. In contrast to education, occupational subpopulations experienced significantly different aging in walking speed for both gender indicating a flatten advantage of non-manual workers (Tables 6 and 7).

Turning to the region of living, there was a tendency of a slightly higher walking speed for people living in wealthier regions. However, this gap almost vanished particularly for women. There was also no significant interaction between age and regional wealth for neither women nor men (Tables 8 and 9).

To emphasize the extent to which our investigated characteristics education, occupation, and regional wealth contributed to differences in physical aging, α-ages were calculated for subpopulations separately by gender. For instance, lower edu-

Figure 1: Trajectories of walking speed across subpopulations: average walking speed by age and subpopulation separately by sex and characteristics (education, occupation, and regional wealth.



cated women aged 60 years performed at the same walking speed as their almost 10 years older higher educated counterparts. A higher occupational status was associated with an advantage of 9 years for 60 years old women, whereas higher regional wealth provided an advantage of only four years. These advantages diminished to only two and one years at older age.

Turning to men, we found even bigger gaps between subpopulations. For instance, a 60 year old lower educated man walked on average at the same pace as his 15 years older higher educated counterpart, whereas at higher ages the gap shrank to a five years advantage. In occupational subpopulations, the difference ranged from 13 years at younger ages to 2.7 years at higher ages. For regional wealth, the results were similar to women's showing a four years advantage at younger ages and a difference of one year at higher ages.

Table 2: Alpha-ages of higher educated women, women with higher occupation status, and women living in wealthier regions.

age	α-age education	α-age occupation	α-age region
60	70.82	69.18	64.05
65	73.37	72.39	67.83
70	76.52	75.89	72.14
75	80.03	79.58	76.72
80	83.75	83.37	81.43
85	87.61	87.23	86.22

Table 3: Alpha-ages of higher educated men, men with higher occupation status, and men living in wealthier regions.

age	α-age education	α-age occupation	α-age region
60	75.38	73.05	64.44
65	76.73	74.36	67.75
70	79.17	76.77	71.94
75	82.4	79.96	76.48
80	86.13	83.67	81.2
85	90.21	87.72	86

4 Discussion

In this study we explored the non-linear age trajectory of walking speed as a proxy of lower body functioning of England's older adults using six waves of the English longitudinal study of Ageing (ELSA). The mean walking speed declined by age for both sexes with men performing at higher levels than their female counterparts. Next to the variation across age and sex we moreover detected disparities between subpopulations distinguished by either socio-economic factors or regional wealth.

Earlier reports highlighted the importance of the lower extremity function walking, which was predictive of institutionalization, hospitalization, and mortality in particular at older age (Blain et al., 2010; Elbaz et al., 2013; Guralnik et al., 1994; Studenski et al., 2011). Moreover, a loss of mobility represents a turning point in older person's life as it was linked with the slowing down process (Ferrucci and Guralnik, 2013; Himann et al., 1988). Previous research showed, that the age decline for normal walking speed started at the 60s only and that a speed of less than 0.6m/s is analog to substantial impairments (Bohannon, 1997; Bohannon and Andrews, 2011; Ferrucci and Guralnik, 2013). Therefore, older adults in particular should aim for sustaining walking speed at a high level.

We found that higher education was associated with higher walking speed for both sexes and across all ages. A 70 years old higher educated person walked with an about 0.1m/s faster normal pace than the lower educated counterpart considering covariates. This was in accordance with previous studies (Welmer et al., 2013; Zaninotto et al., 2013). For instance, in a cross-sectional study on advanced aged Swedish higher education was associated with better lower extremity performance, such as walking speed, balance, chair stands, and in addition with upper extremity performance hand grip strength (Welmer et al., 2013).

Interestingly, Studenski et al. reported an increase of 0.1m/s in gait speed to be associated with 0.88 survival hazard (Studenski et al., 2011). An added value of our study is the conversion into α-ages, which highlights the advantage in single years. Roughly speaking, high educated 70 years old can be associated with a 0.88 survival hazard. In other words, lower educated 70 years old walked on average at the same pace as 6.5 to 9 years older but higher educated counterparts. However, our findings suggested a faster acceleration of the age decline among higher educated women, but no significant interaction between education and age among men.

When looking at disparities in walking speed due to occupation, another dimension of socio-economic status, we received similar results. Older adults with higher occupational status performed at higher levels within the walking speed test than manual workers for both sexes across all ages. The advantage in walking speed due to higher occupational status was slightly less than the one due to higher education, which could be best emphasized with α-ages. It strikes that there is a significant age occupational status interaction for both sexes, although we did not find a significant education age interaction for men.

Numerous studies documented, that in particular at older ages higher socioeconomic status was positively associated with better physical functioning such as upper extremity functions (e.g. hand grip strength) as well as lower extremity functions (e.g. walking speed, chair stand, and balance), but also with less impairments such as IADLs (Ostir et al., 2007; Sanderson and Scherbov, 2014; Welmer et al., 2013; Zaninotto et al., 2013). However, these studies were inconsistent when it came to the significance of the interaction between socioeconomic status and age, which we could confirm by investigating separately the effect of education and occupation.

Next to individual factors, we also found that living in a wealthier region was positively assigned with higher walking speed. This was in accordance with previous studies showing a positive association between regional factors (e.g. GDP, unemployment rate, regional development) and well-being, as well as higher cognitive performance (Gerstorf et al., 2010; Weber et al., 2014). However, the magnitude of the gap due to regional living was only minor in comparison to socioeconomic status (i.e 0.03m/s for men and 0.025m/s for women). Interestingly, the daily routine of walking for transportation instead of using the car might support the regional effect. A recent study by van Cauwenberg et al. showed that older adults living in urban areas were more likely to walk daily for transportation than their counterparts living in semi-urban or rural areas (Van Cauwenberg et al., 2012). Moreover, feelings of unsafety were assigned to lower rates of walking for transportation.

Our analysis contributes to the literature on physical aging because next to confirming the socioeconomic and regional wealth differences in physical functioning it, moreover, highlights the differences with converting them into single years of age. Therefore, identifying socioeconomic differences in walking speed of up to 10 age years stresses the need of policy changes to address socioeconomic inequality. Our research and previous studies showed, that increasing socioeconomic equality could contribute to better physical functioning, which is critical to the quality of older adults' daily lives.

5 Conclusion

In summary, this study identified disparities in lower body functioning between socioeconomic groups, whereas the magnitude of the difference in physical aging between sub-populations at older ages declined by age. Nevertheless, higher socioeconomic status such as higher education provided older adults an advantage in mobility of up to 15 years. Therefore, improving the living conditions and education of the disadvantaged groups may have a positive impact on lower body functioning in old age, which is positively assigned with independent living.

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Appendix

Table 4: Linear Model of Growth in women's walking speed: effects of education.

Fixed Effect		Estimate	Std. Error	t value
Initial status				
	Intercept	-9.96E-02	8.10E-02	-1.229
	higher education	1.06E-01	7.36E-03	14.343
	pheight	7.77E-01	5.36E-02	14.485
	pweight	-4.62E-03	2.31E-04	-20.034
Aging growth rate				
	Intercept	-1.30E-02	4.29E-04	-30.314
Aging acceleration rate				
	Intercept	-3.55E-04	4.65E-05	-7.619
	higher education	-1.34E-04	6.69E-05	-1.998
Wave growth rate				
	wave 2	8.69E-04	4.75E-03	0.183
	wave 3	-1.33E-02	5.04E-03	-2.639
	wave 4	-1.64E-02	5.20E-03	-3.155
	wave 5	-4.29E-03	5.55E-03	-0.773
	wave 6	-7.73E-03	5.89E-03	-1.312
Random Effect		Variance	Std. Dev.	
Level 1				
	Temporal variation	2.34E-02	0.15288	
Level 2				
	Ind. initial status	3.08E-02	0.175435	
	Ind. aging	6.75E-05	0.008214	
Observations:		15159		

Table 5: Linear Model of Growth in men's walking speed: effects of education.

Fixed Effect		Estimate	Std. Error	t value
Initial status				
	Intercept	1.43E-01	9.08E-02	1.573
	higher education	1.31E-01	7.30E-03	17.882
	pheight	5.39E-01	5.75E-02	9.379
	pweight	-2.72E-03	2.75E-04	-9.878
Aging growth rate				
	Intercept	-1.04E-02	4.79E-04	-21.737
	higher education			
Aging acceleration rate		-4.16E-04	3.95E-05	-10.534
	Intercept			
Wave growth rate				
	wave 2	-6.31E-04	5.22E-03	-0.121
	wave 3	-1.84E-02	5.54E-03	-3.319
	wave 4	-2.24E-02	5.73E-03	-3.909
	wave 5	-1.04E-02	6.14E-03	-1.692
	wave 6	-1.27E-02	6.55E-03	-1.944
Random Effect		Variance	Std. Dev.	
Level 1				
	Temporal variation	2.47E-02	0.157138	
Level 2				
	Ind. initial status	3.24E-02	0.179967	
	Ind. aging	9.50E-05	0.009749	
Observations:		13643		

Table 6: Linear Model of Growth in women's walking speed: effects of occupation.

Fixed Effect		Estimate	Std. Error	t value
Initial status				
	Intercept	-7.45E-02	7.69E-02	-0.97
	higher occupation	9.92E-02	6.86E-03	14.4
	pheight	7.47E-01	5.09E-02	14.67
	pweight	-4.43E-03	2.23E-04	-19.89
Aging growth rate				
	Intercept	-1.41E-02	4.02E-04	-35.09
Aging acceleration rate				
	Intercept	-3.07E-04	4.93E-05	-6.22
	higher occupation	-1.54E-04	6.41E-05	-2.4
Wave growth rate				
	wave 2	4.48E-03	4.53E-03	0.99
	wave 3	-7.96E-03	4.80E-03	-1.66
	wave 4	-7.72E-03	4.95E-03	-1.56
	wave 5	6.54E-03	5.26E-03	1.24
	wave 6	6.96E-03	5.58E-03	1.25
Random Effect		Variance	Std. Dev.	
Level 1				
	Temporal variation	2.32E-02	0.152446	
Level 2				
	Ind. initial status	3.05E-02	0.174682	
	Ind. aging	7.17E-05	0.008467	
Observations:		16609		

Table 7: Linear Model of Growth in men's walking speed: effects of occupation.

Fixed Effect		Estimate	Std. Error	t value
Initial status				
	Intercept	5.25E-02	8.89E-02	0.59
	higher occupation	1.05E-01	6.96E-03	15.141
	pheight	5.96E-01	5.62E-02	10.618
	pweight	-2.73E-03	2.69E-04	-10.129
Aging growth rate				
	Intercept	-1.05E-02	6.80E-04	-15.436
	higher occupation	-2.22E-03	7.91E-04	-2.807
Aging acceleration rate				
	Intercept	-4.22E-04	3.90E-05	-10.817
Wave growth rate				
	wave 2	1.16E-03	5.13E-03	0.227
	wave 3	-1.01E-02	5.43E-03	-1.868
	wave 4	-1.46E-02	5.61E-03	-2.612
	wave 5	1.22E-03	5.97E-03	0.204
	wave 6	1.74E-03	6.35E-03	0.273
Random Effect		Variance	Std. Dev.	
Level 1				
	Temporal variation	2.47E-02	0.157148	
Level 2				
	Ind. initial status	3.28E-02	0.180996	
	Ind. aging	9.67E-05	0.009833	
Observations:		14159		

Table 8: Linear Model of Growth in women's walking speed: effects of regional wealth.

Fixed Effect		Estimate	Std. Error	t value
Initial status				
	Intercept	-1.82E-01	7.76E-02	-2.35
	wealthier region	3.23E-02	6.07E-03	5.32
	pheight	8.55E-01	5.11E-02	16.73
	pweight	-4.80E-03	2.23E-04	-21.5
Aging growth rate				
	Intercept	-1.42E-02	4.03E-04	-35.39
Aging acceleration rate				
	Intercept	-3.92E-04	3.27E-05	-12.01
	wealthier region			
Wave growth rate				
	wave 2	3.05E-03	4.48E-03	0.68
	wave 3	-8.02E-03	4.75E-03	-1.69
	wave 4	-8.28E-03	4.91E-03	-1.69
	wave 5	6.80E-03	5.23E-03	1.3
	wave 6	8.20E-03	5.55E-03	1.48
Random Effect		Variance	Std. Dev.	
Level 1				
	Temporal variation	2.33E-02	0.15251	
Level 2				
	Ind. initial status	3.25E-02	0.18024	
	Ind. aging	7.28E-05	0.00853	
Observations:		16948		

Table 9: Linear Model of Growth in men's walking speed: effects of regional wealth.

Fixed Effect		Estimate	Std. Error	t value
Initial status				
	Intercept	-7.43E-02	9.07E-02	-0.818
	wealthier region	2.50E-02	6.87E-03	3.642
	pheight	7.11E-01	5.71E-02	12.448
	pweight	-2.99E-03	2.75E-04	-10.881
Aging growth rate				
	Intercept	-1.21E-02	4.70E-04	-25.741
	wealthier region			
Aging acceleration rate				
	Intercept	-4.15E-04	3.92E-05	-10.588
Wave growth rate				
	wave 2	2.32E-03	5.13E-03	0.453
	wave 3	-9.40E-03	5.43E-03	-1.729
	wave 4	-1.21E-02	5.63E-03	-2.15
	wave 5	4.06E-03	6.02E-03	0.674
	wave 6	5.85E-03	6.41E-03	0.913
Random Effect		Variance	Std. Dev.	
Level 1				
	Temporal variation	2.47E-02	0.15721	
Level 2				
	Ind. initial status	3.51E-02	0.18724	
	Ind. aging	1.04E-04	0.01019	
Observations:		14290		

3

Determinants of aging

In this second part of my thesis, I investigate differences in cognitive functioning and its determinants. Descriptive statistics show variations in older adults' cognitive performance across countries. Moreover, these variations remain when comparing episodic memory and category fluency scores by individual education. Thus cognitive functioning differs within and between countries even after controlling for individual education.

Several studies show increases in compulsory schooling having a positive effect on cognition. Furthermore, one's surroundings has been shown to be important for school performance. Thus, we examine the effect of the national educational level next to individual educational attainment on cognitive performance of older adults. We hypothesize that individual's cognition (e.g. episodic memory and category fluency) benefit from a higher educated surrounding, which is approached with multilevel models. Our results indicate that higher cognitive performance is associated with better educated societies over and above higher individual education. Interestingly, women's episodic memory, in particular, benefits more from higher educated societies than their male counterparts.

Analyzing the education effect, it is essential to be aware of endogeneity issues. For instance, the reverse causality between education and cognition has been debated a lot in the literature. However, in our study the two variables were measured at different times as we analyze the cognitive performance at older age and the individual education process was mainly finished at younger age. Additionally there might be omitted variables which bias the education estimates. The use of aging surveys do not offer many possibilities to solve this issue. It is common to use for instance distance to school or changes in compulsory schooling as an instrument to solve this endogeneity issue. This information is unfortunately not provided in all aging surveys we compare here.

Next to the influence of education we investigate a regional development index as a determinant of variations in cognitive performance, more precisely cognitive gender differences. Here, the regional development index captures country- and birth cohort-specific information on cognitive stimulation as well as health and living conditions. We find, that improved living conditions and educational opportunities are associated with increased gender differences favoring women in some cognitive functions and decreases or eliminations in others. To sum up, the results suggest that women gain more than their male counterparts from societal improvements.

Article 3

The effect of national and individual educational attainment on cognitive performance.

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The effect of national and individual educational attainment on cognitive performance

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Abstract

A strong positive association between individual level education and cognitive performance is typically found, but to what extent the national education level influence this relationship is unclear. This study aims to determine the association between education (individual and national) and cognitive performance across countries that vary substantially in terms of their demography, average national education, and level of economic and social development. We investigate performance on episodic memory and verbal fluency tasks from representative surveys, conducted in 2010-2012 covering more than 19 countries in Northern America, Asia, and Europe, and involving about 90,000 men and women aged between 50 and 85 years. We find a positive association between education and cognitive performance across all our countries. Moreover, our results show that higher average national educational level is related to better individual cognitive performance, so that individuals with

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primary education living in more educated societies reach similar cognitive performance as individuals with secondary education in societies with lower average levels of education.

1 Introduction

Educational attainment is positively associated with cognitive performance, and this relationship has been shown to hold both at younger and older ages (Botwinick, 1977; Christensen and Henderson, 1991; Clouston et al., 2012; Nisbett, 2009). Although the causal effect of education is difficult to determine because of the positive selection of individuals with better cognitive ability into higher schooling, longitudinal studies suggest that education may positively influence subsequent cognition (Glymour, 2008; Richards and Sacker, 2003, 2011). Evidence from increases in compulsory schooling suggests that schooling positively affects cognition both at younger and older ages (Banks and Mazzonna, 2012; Brinch and Galloway, 2012; Glymour, 2008). More specifically, several studies found a positive effect of education on executive functioning (e.g. category fluency) and episodic memory (e.g. immediate and delayed word recall) (Kempler et al., 1998; Mathuranath et al., 2003). However, specific cognitive abilities are differently sensitive to education; for instance education accounted for more variance than age for phonemic verbal fluency, while for category fluency age accounted for more variance than education (Tombaugh et al., 1999).

The importance of one's surrounding has been shown for school performance, where being socialized with studious, disciplined peers can be beneficial (Aizer, 2008; Bishop, 2006; Morgan, 2004). Next to increased exposure to cognitive stimulations, improvements in living conditions positively affect cognitive performance (Flynn, 1987; Lynn, 1998; Rönnlund and Nilsson, 2009; Sundet et al., 2008; Weber et al., 2014). However, so far most studies have focused on the impact of individual characteristics within a country or a region (Baltes and Mayer, 1999; Deary et al., 2010;

Zahodne et al., 2011), whereas the present study investigate to what extent the national educational levels adds to the effect of the individual level of education to the cognitive performance (i.e., episodic memory and verbal fluency) of adults aged between 50 and 85 years, across nineteen countries.

2 Methods

2.1 Sample Data

We use four harmonized aging surveys (ELSA, HRS, JSTAR, and SHARE), whose instruments were adapted from the HRS questionnaire. All our aging surveys provide information on physical and cognitive functioning, self-reported health status as well as economic and demographic information of the non-institutionalized population aged 50 and above. These data were collected from personal interviews in ELSA, JSTAR, and SHARE while personal and phone interviews are used in HRS.

The ELSA (English Longitudinal Study of Ageing) data is a panel survey of the 50+ English population that began in 2002 (Marmot et al., 2003). We use the fifth wave which was collected in 2010/11, including 9,600 respondents aged between 50 and 85 years (Banks and Mazzonna, 2012). The HRS (Health and Retirement Study) is a large-scale longitudinal project launched by the University of Michigan in 1992 in the United States (National Institute on Aging, 2007). For our analysis we use wave 10 collected in 2010/11, where additional cognitive tests such as verbal fluency were included. The sample size for the population aged 50 to 85 is larger than for any other country we consider (n=19,700). In 2007 the Japanese Study of Aging and Retirement (JSTAR) was conducted by the Research Institute of Economy, Trade and Industry (RIETI), Hitotsubashi University, and the University of Tokyo. This survey was designed to ensure, to the maximum extent possible, comparability with HRS, ELSA, and SHARE. In the third wave, which we use, about 4,500 Japanese aged at least 48 were interviewed face-to-face in 2011 (Ichimura et al., 2009). The Survey of Health, Ageing and Retirement in Europe (SHARE) was launched with its first wave 2004/05 in 11 Continental European countries (Börsch-Supan et al., 2005; Börsch-Supan and Jürges, 2005). The fourth wave of this multidisciplinary and cross-national panel database, which we use for our study, was collected in 15 countries (Austria, Belgium, Czech Republic, Denmark, Estonia, France, Germany, Italy, Netherlands, Poland, Portugal, Slovenia, Spain, Sweden, and Switzerland) in 2010-2012. The sample size for the 50 up to 85 years old Europeans is almost 56,000 in total.

2.2 Measures

Cognitive functioning. We investigate: 1) episodic memory in which ten words (randomly assigned list with the 10 words out of 3 lists for JSTAR and out of 4 lists for all other surveys) are read out aloud and the respondents have one minute to recall immediately as many words as possible (in ELSA and HRS up to two minutes, whereas for instance in the HRS sample 98% finished this task within one minute), and 2) verbal fluency (category fluency), where the task is to name as many different animals as the interviewee can think of within one minute.

Education. Respondents were asked for their highest completed school degree within all surveys. Educational attainment based on the International Standard Classification of Education (ISCED) is used to compare individual education across countries, with a distinction between the following categories: (i) no formal education, uncompleted primary up to uncompleted lower secondary (ISCED 0-1), (ii) secondary which includes completed lower secondary, (un)completed higher secondary, and uncompleted tertiary education (ISCED 2-4), and (iii) tertiary including completed tertiary (ISCED 5-6). To represent the national educational level, we use a country's mean years of schooling of the 50 and above year olds in 2010 (Wittgenstein

Centre Data Explorer Version 1.2.)(KC et al., 2014).

Economic development. The gross domestic product (GDP) per capita in current USD in 2010 is considered in our analysis to control for a country's economic development (The World Bank, 2015).

Age. In our analysis we include age measured in single years.

2.3 Procedure

In order to examine the effect of educational attainment and national educational level on cognitive performance (e.g., episodic memory and verbal fluency) multilevel analyses with two levels (individual as level 1 unit and country as level 2 unit) are carried out for each measure of cognitive performance (Raudenbush and Bryk, 2002).

In addition to individual education and national education, we control for the covariates age, sex, and economic development (i.e. GDP in thousands), and subsequently include the cross-level interaction sex x national educational level. We have seen descriptively, that the effect of individual education varies across countries, which we address with the cross-level interaction individual education x national educational level and a random slope (verified with likelihood ratio tests). Consequently, we include a random intercept and random coefficients for individual education.

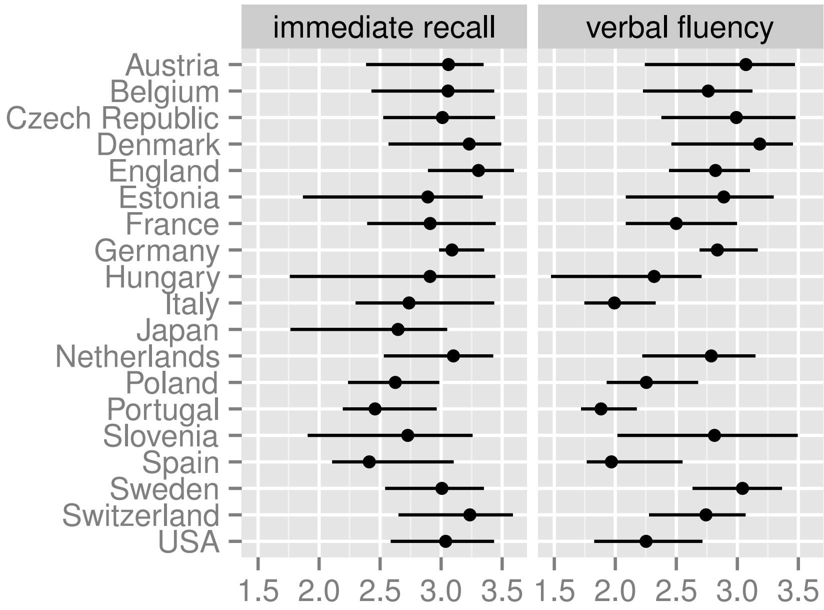
3 Results

3.1 Descriptive results

Our sample countries vary a lot in their mean years of individual education and also in their national educational level. In some countries, the population above 50 has on average more than 12 years of schooling, while their counterparts in other countries have on average less than 8 years of schooling (Figure 1).

Ranking the countries by their average cognitive performance, we find that the

Figure 1: Mean years of schooling by country in 2010



northern European countries have the highest performance levels (Table 1). Comparing the average cognitive performance scores of each country by individual education, we identified a large variation particularly between those with primary education (Figure 2). Older adults' cognitive performance in episodic memory varies considerably between countries (range for primary educated: 1.8 to 2.9; range for tertiary educated: 3.0 to 3.6). The gap in average verbal fluency between the countries is almost constant across individual education levels (range for primary educated: 1.5 to 2.7; range for tertiary educated: 2.2 to 3.5).

Next to between country variations, the magnitude of the difference in cognition also varies within countries. While only little variation can be found between lower and higher educated older adults in Germany, the difference is much larger between lower and higher educated Hungarians or in verbal fluency between lower and higher educated Slovenians, respectively.

Descriptively, we identify variation within and between countries in older adults

Table 1: Sample characteristics by country with sample size (N), share of females, and mean (SD) of age, episodic memory, verbal fluency, mean years of individual education, and GDP.

country	size	females	age	memorys	fluency	years of schooling	GDP
Austria	5009.00	57.00	65.2 (9.0)	5.5 (1.9)	22.9 (8.6)	11.25	46593.39
Belgium	4982.00	54.30	64.3 (9.6)	5.5 (1.8)	20.6 (6.7)	10.20	44360.90
Czech Republic	5845.00	56.90	65 (8.7)	5.4 (1.7)	22.3 (7.6)	11.76	19763.96
Denmark	2198.00	53.10	64.3 (9.5)	5.8 (1.7)	23.7 (6.9)	11.74	57647.67
England	9636.00	54.70	66 (8.5)	5.9 (1.8)	21 (6.8)	9.49	38362.22
Estonia	6508.00	59.00	66.1 (9.3)	5.2 (1.9)	21.5 (7.3)	12.10	14632.08
France	5421.00	55.20	65.2 (9.6)	5.2 (1.8)	18.6 (6.5)	9.23	40708.50
Germany	1533.00	51.90	67.6 (7.8)	5.5 (1.7)	21.2 (6.8)	13.30	41725.85
Hungary	2926.00	55.80	64.5 (8.7)	5.2 (1.8)	17.3 (5.8)	8.62	12958.27
Italy	3469.00	53.90	66.4 (8.8)	4.9 (1.8)	14.9 (5.6)	11.42	35877.87
Japan	3025.00	51.60	68.2 (7.2)	4.7 (1.9)		9.98	42909.20
Netherlands	2663.00	55.10	65.4 (8.6)	5.5 (1.6)	20.8 (6.6)	10.84	50341.25
Poland	1768.00	55.20	67.2 (8.4)	4.7 (1.8)	16.8 (6.3)	11.20	12530.31
Portugal	1969.00	55.50	64.7 (8.9)	4.4 (1.8)	14 (6)	4.91	22539.99
Slovenia	2644.00	55.80	64.9 (9.4)	4.9 (1.8)	21 (7.7)	11.12	23417.64
Spain	3358.00	53.70	67 (9.7)	4.3 (1.8)	14.7 (5.9)	7.21	30737.83
Sweden	1906.00	53.50	68.9 (7.9)	5.4 (1.6)	22.7 (7.1)	11.76	52076.43
Switzerland	3551.00	53.50	64.8 (9.3)	5.8 (1.7)	20.5 (6.6)	12.20	74277.12
USA	20064.00	56.30	64.9 (9.8)	5.4 (1.6)	16.8 (7.1)	12.62	48374.06

cognitive performance, which might be associated with the differences in the national educational levels. We examine the effect of individual education, national education, and their interaction with linear multilevel regression models, controlling for sex, age, and GDP, separately for episodic memory and verbal fluency.

3.2 Episodic memory

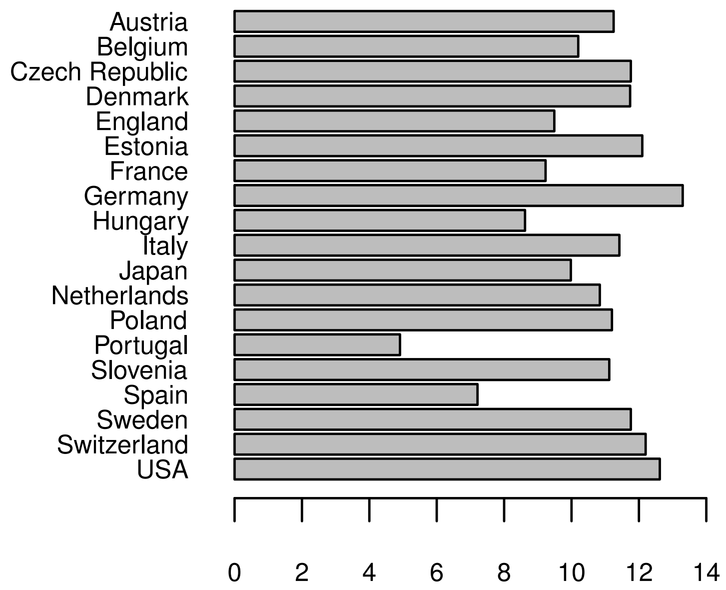
Our results show significant age differences, more precisely younger participants gained on average higher levels than their older counterparts. Women outperformed men when living in countries with at least 6 years of mean years of schooling. Moreover, the female advantage increases with higher national educational level (Table 2).

Table 2: Results of the linear multilevel models for episodic memory and category fluency. Individual education varies significantly across countries. Age in years is centered at age 50; country mean years of schooling are centered at 5 years; males and secondary educated serve as reference group.

	episodic memory	verbal fluency
Age-50	-0.053^{***}	-0.195^{***}
	(0.001)	(0.003)
Gender (f)	-0.023	-0.667^{***}
	(0.040)	(0.163)
primary education	-1.049^{***}	-2.246^{***}
	(0.128)	(0.633)
tertiary education	0.242	1.000
	(0.165)	(0.704)
years of schooling	0.013	0.505^{*}
	(0.036)	(0.268)
GDP per tsd	0.063	0.489^{*}
	(0.039)	(0.279)
Gender (f)x years of schooling	0.066^{***}	0.116^{***}
	(0.006)	(0.026)
primary education x years of schooling	0.027	-0.133
	(0.022)	(0.107)
tertiary education x years of schooling	0.065^{**}	0.288^{**}
	(0.028)	(0.118)
Intercept	5.607^{***}	17.931^{***}
	(0.219)	(1.628)
Country Random Effect	Variance	Variance
Intercept	0.08	4.67
primary education	0.02	0.65
tertiary education	0.05	0.86
Level-1 effect	2.48	40.65
N	81419	79141
Log Likelihood	-152544.000	-258997.100
AIC	305122.000	518028.200
BIC	305280.200	518186.000

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$

Figure 2: Mean standardized episodic memory and verbal fluency performance scores within each country as a function of individual education



Note: The range between the average standardized scores of the lowest educated and the highest educated population within a country are represented with a solid line, while the dots represent the average standardized scores per country for both measures.
Source: ELSA, HRS, JSTAR, and SHARE; own calculations

Consistent with literature for single countries and our expectations, the fixed effect estimates for individual education indicate that higher individual education is associated with higher episodic memory scores. Further, we find that the average episodic memory score of a person is also higher within countries with a higher national educational level (i.e., more mean years of schooling), whereas tertiary educated benefit more than secondary educated from more mean years of schooling. Interestingly, primary educated catch up with higher national education, thus the advantage of secondary educated over primary educated decreases living in a cognitively more stimulating country. This implies that the country of residence is particularly important for the primary educated population, which is also indicated by the highest between country variance among the educational levels (primary: 0.14, secondary:

0.08, tertiary: 0.07).

3.3 Fluency

Focusing on verbal fluency, the results show a male advantage, which reduces with higher national educational level (i.e higher mean years of schooling). However this advantage still exists in countries with on average 10 years of schooling.

In respect to individual education, we recognize a similar pattern to episodic memory results. Higher education is associated with higher verbal fluency scores and tertiary educated have the highest gain (Table 2). Interestingly, the gap between primary and secondary educated does not reduce with more mean years of schooling on the country level as it does for episodic memory. Everyone benefits from higher national educational levels regarding the verbal fluency performance, whereas tertiary educated gain most from increasing a country's national educational level for an additional year.

Compared to episodic memory, here the between country variance is the highest among tertiary educated while the lowest variance is among primary educated (primary: 3.4, secondary: 4.7; tertiary: 6.2). Thus, in terms of verbal fluency scores, the country matters most for tertiary educated individuals.

4 Conclusion

It has previously been shown that higher individual education is associated with higher cognitive performance at younger and older ages, and that increases in compulsory schooling have a positive effect on cognition. In this study we contribute to literature by showing that older adults cognitive performance (i.e., episodic memory and category fluency) varies not only within countries, but also between countries. More precisely, tertiary educated living in a country with low education level perform at lower levels than their counterparts living in a country with higher education. Thus, not only does the individual educational attainment matter for episodic memory and verbal fluency, but also the educational level of a country. Here, we show, that episodic memory scores of primary educated benefit relatively more from living in a cognitively more stimulation country than their secondary educated counterparts. This is consistent with a model of community level spill-over effects, net of individual level influences.

At the global level, Northern Europeans and Americans have the highest educational attainment among their 50+ population, which can be an important reason for their relatively high cognitive performance at older ages (KC et al., 2010; Skirbekk et al., 2012). Our results show a significant effect of the national educational level on both, episodic memory and verbal fluency, but we actually cannot control for education quality. Economically more developed countries are supposed to have higher qualities; therefore we include GDP in all our models. Actually, GDP never turned out to have a significant influence, neither on episodic memory nor on verbal fluency. There might also be other factors next to quality of education such as better nutrition in childhood, which we could not control separately. In addition, when investigating the effect of educational attainment on cognitive performance it is challenging to consider reverse causality issues. Nevertheless, studies examining the effect of increasing compulsory schooling show a positive effect of educational attainment on cognition.

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Article 4

The changing face of cognitive gender differences in Europe.

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The changing face of cognitive gender differences in Europe

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Cognitive gender differences and the reasons for their origins have fascinated researchers for decades. Using nationally representative data to investigate gender differences in cognitive performance in middle-aged and older populations across Europe, we show that the magnitude of these differences varies systematically across cognitive tasks, birth cohorts, and regions, but also that the living conditions and educational opportunities individuals are exposed to during their formative years are related to their later cognitive performance. Specifically, we demonstrate that improved living conditions and less gender-restricted educational opportunities are associated with increased gender differences favoring women in some cognitive functions (i.e., episodic memory) and decreases (i.e., numeracy) or elimination of differences in other cognitive abilities (i.e., category fluency). Our results suggest that these changes take place due to a general increase in women's cognitive performance over time, associated with societal improvements in living conditions and educational opportunities.

cognitive aging | gender inequality | sex differences | cross-cultural research

The magnitude, pattern, and explanation of cognitive gender differences is a topic that continues to engender considerable scientific and political debate. Here we investigate the extent to which improvements in living conditions and education, taking place over time, are associated with gender differences in cognitive functions among middle-aged and older adults in Europe.

During the 20th century, there have been substantial increases in cognitive performance in many nations (1). These increases have been attributed to changes in living conditions [e.g., gross domestic product (GDP), family size, health] (2, 3) and increased exposure to cognitive stimulation (e.g., education) (4, 5). Despite these societal improvements, cognitive gender differences are still reported, typically with a life-long advantage for men in tasks assessing visuospatial (6) and mathematical (7, 8) abilities, whereas women are often found to outperform men in tasks assessing episodic memory (9, 10) and reading literacy (11). In other cognitive tasks, such as category fluency and vocabulary, gender differences are typically not observed (12, 13). Although biologically based explanations for these differences have been proposed (14, 15), there are also studies indicating that societal factors influence cognitive gender differences.

Some studies investigating math performance in adolescents have found that gender differences favoring boys are smaller in more gender-equal societies (16, 17), suggesting that gender equity positively affects girls' math performance. Others, however, have failed to find an effect of gender equity on mathematics in adolescents (11, 18) or on visuospatial performance in adults (19). These inconsistencies may reflect differences in the gender equity indicators used (20), or in sample representativeness (19), but they also point to the necessity of using indicators pertinent to the population under study. Specifically, most studies (11, 16–19) have examined gender differences in adolescents with gender equity indicators (e.g., Gender Empowerment Measure, Standardized Index of Gender Equality, and Gender Gap Index) (20) based on earlier cohorts' experiences (e.g., the adult female population's share of parliamentary seats and earned income) or used recent gender equity indicators to assess earlier cohorts (19). As previous research has shown that improvements in living conditions and educational opportunities positively affect cognitive performance (1, 2, 4, 21), we hypothesize that women who may be more disadvantaged than men (20) will benefit disproportionately from such societal improvements. To investigate this hypothesis and illuminate how improvements in living conditions and educational opportunities influence the magnitude and pattern of cognitive gender differences, we investigate the cognitive performance of middle-aged and older adults from three European regions, raised during different time periods, and therefore exposed to varying levels of educational opportunities and living conditions.

We use data from the Survey of Health, Aging and Retirement in Europe (SHARE) (22), in which noninstitutionalized men and women >50 y of age living in Europe were interviewed and tested individually. In addition to answering demographic questions, participants were tested on cognitive tasks assessing episodic memory (a 10-word list was read out aloud and respondents were asked to recall the words after a brief interval); numeracy [five questions, e.g., "A second hand car dealer is selling a car for 6,000 (local currency). This is two-thirds of what it costs new. How much did the car cost new?"]; and category fluency (name as many different animals as possible within 1 min). Data from the second wave (2006/07), with ∼31,000 participants from 13 countries, are used in our analyses. For descriptive analyses, we merged the 13 countries into three geographical regions (23, 24): Northern Europe (Denmark, Sweden); Central Europe (Austria, Belgium, Czech Republic, France, Germany, The

Significance

Results showing that gender differences in mathematics and science are smaller in countries with higher gender equality have led researchers to conclude that cognitive gender differences are decreasing as a function of increased gender equality. Instead, we find that improved living conditions and less gender-restricted educational opportunities are associated with increased gender differences favoring women in some cognitive functions and decreases or elimination of gender differences in other cognitive abilities. Our results suggest that these changes take place as a result of women gaining more than men from societal improvements over time, thereby increasing their general cognitive ability more than men.

Author contributions: D.W., V.S., I.F., and A.H. designed research; D.W. analyzed data; D.W. and A.H. wrote the paper; D.W. led the research; and D.W. and A.H. provided the methodological and theoretical framework.

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Netherlands, Poland, Switzerland); and Southern Europe (Greece, Italy, Spain).

Results

As previously reported (25, 26), differences were observed across regions and cognitive tasks, demonstrating both a birth cohort gradient, with later cohorts (younger age) performing at higher levels than earlier cohorts (older age), and a geographic skill gradient, indicating a northern advantage over central and southern regions (Fig. 1 *A–I*). A novel finding was that the magnitude of gender differences varied systematically across birth cohorts and regions, as specified below.

Focusing first on episodic memory performance (Fig. 1 *A–C* and Tables S1 and S2), it is clear that, although women in Northern Europe perform at a higher level than men across all birth cohorts, the pattern is different in Central and Southern Europe. In Central Europe, the female advantage is only found for birth cohorts born in 1932 or later, but not in earlier cohorts. In Southern Europe, there is even less of a female advantage, which switches to a male advantage in the earliest cohort.

The performance pattern is different for numeracy (Fig. 1 *D–F* and Tables S1 and S2). In all regions and across all birth cohorts, there was an advantage for men. However, as evidenced by significant random slopes, the male advantage is larger in earlier cohorts in Central and Southern Europe, although the performance trajectories of men and women do not intersect in any region.

In category fluency (Fig. 1 *G–I* and Tables S1 and S2), there were no significant differences between men and women across birth cohorts in Northern Europe. In Central Europe, there was a tendency for men to outperform women for most birth cohorts ($P < 0.10$). Finally, in Southern Europe, men excelled in all but two birth cohorts.

These data demonstrate that gender differences in cognitive functions vary systematically across birth cohorts and regions (Table S2). Our further analyses demonstrate that differences in cognitive stimulation can help to explain these findings, as gender differences in years of education are associated with the magnitude of the cognitive gender differences. Specifically, as can be seen in Fig. 2, gender differences in education are strongly related to the magnitude of the gender difference in episodic memory ($r = 0.74$), so that differences favoring women in episodic memory performance are larger in birth cohorts with smaller educational differences. In numeracy ($r = 0.54$), lower educational gender differences are associated with a reduction in the male advantage, and in category fluency ($r = 0.62$), reduction of educational differences are associated with reductions in gender differences, with similar levels of education being associated with no gender differences. These findings suggest that if women and men had equal levels of education, we should expect a female advantage in episodic memory, a male advantage in numeracy, and no gender differences in category fluency (Fig. 2).

To determine the extent to which cognitive stimulation and differences in living conditions contribute to these patterns,

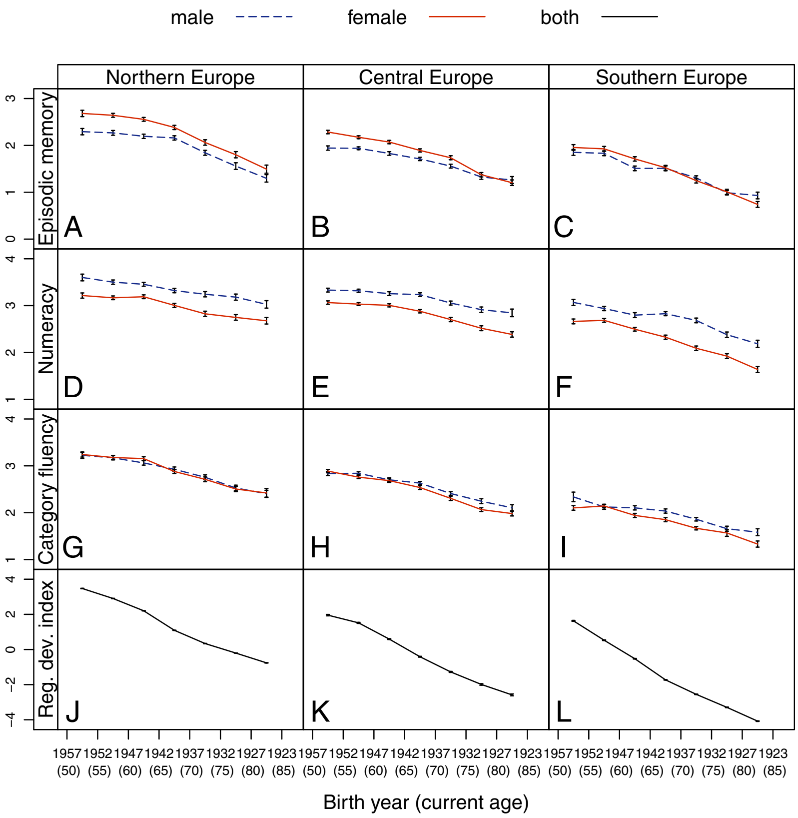

Fig. 1. Mean standardized performances (±SEM) in episodic memory (*A–C*), numeracy (*D–F*), and category fluency (*G–I*) per 5-y birth cohort by gender for Northern, Central, and Southern Europe. (*J–L*) Mean RDI (±SEM) per 5-y birth cohort for Northern, Central, and Southern Europe. As can be seen in *A–I*, gender differences in the cognitive tasks vary systematically across birth cohorts and regions (see Table S2 for raw mean differences, indicator of significance, pooled SD, and Cohen's *d*). (*J–L*) RDI is lower in earlier birth cohorts, and Northern Europe has the highest RDI followed by Central and Southern Europe.

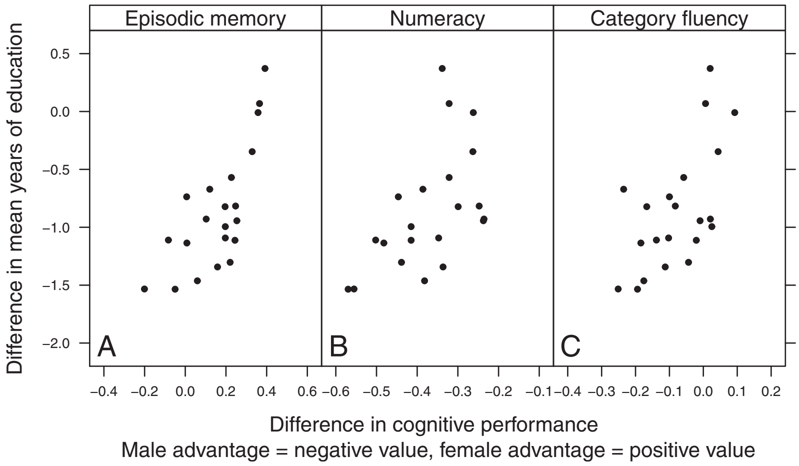

Fig. 2. Association between difference score for education (women's average level of education minus men's average level of education) and difference score in cognitive performance (women's average standardized episodic memory/numeracy/category fluency performance minus men's average standardized memory/numeracy/ category fluency performance), displayed separately for (*A*) episodic memory ($r = 0.74$, $P < 0.001$), (*B*) numeracy ($r = 0.54$, $P = 0.01$), and (*C*) category fluency ($r = 0.62$, $P = 0.003$), indicating that there are larger differences favoring women in episodic memory performance in birth cohorts with smaller educational differences. In numeracy, smaller educational differences are associated with a smaller male advantage, and in category fluency, smaller or no educational differences are associated with gender differences clustering around zero.

a regional development index (RDI) for each birth cohort and country was created (Fig. 1 *J–L*). We collected information on the country's GDP per capita and total fertility rate (TFR; representing family size) from the years each of the participants were 25 y old (early in their reproductive period), infant mortality and life expectancy (representing health and nutrition) from the years the birth cohorts were aged 37, and national education levels (representing cognitive stimulation) from the years the birth cohorts were 45–49 y old (an age when most have completed their education). These measures were selected as they have been found to be associated with increases in cognitive performance over time in many countries (1–4).

We find, first, that in countries with a higher RDI, episodic memory and category fluency performance is also higher (Table S3). Second, and perhaps more importantly, the significant interactions between RDI and gender for episodic memory and numeracy demonstrate that women's performance, in particular, is higher in regions with a higher RDI. For category fluency, higher education is associated with higher performance, especially for women (Table S3). These results suggest that factors associated with RDI and individual education influence women more than men (see Fig. S1 for a descriptive illustration).

Further, in regions and birth cohorts in which the female advantage in episodic memory is large, there is a smaller performance advantage for men on the numeracy task, as evidenced by the significant correlation coefficient between gender differences in episodic memory and gender difference in numeracy ($r = -0.76$; $P < 0.001$; Fig. S2).

Taken together, our results show that, as living conditions and educational levels have risen over four decades, women have increased their cognitive performance more than men (Fig. S1). The results further suggest that women's cognitive performance gains lead to increased gender differences favoring women in episodic memory, to decreased gender differences in numeracy, and to no gender differences in category fluency (Fig. 2).

Conclusions and Implications

Although it has previously been shown that gender differences in mathematics among young adults are smaller in more gender-equal nations (11, 16, 17), this is the first time, to our knowledge, that it has been demonstrated that the magnitude of gender differences in three separate cognitive domains (episodic memory, numeracy, and category fluency) (*i*) vary systematically across birth cohorts and regions and (*ii*) are associated with changes in living conditions and cognitive stimulation taking place over time. Importantly, (*iii*) our data suggest that women, more than men, benefit cognitively from these societal improvements, giving rise to increased gender differences in episodic memory, decreased gender differences in numeracy, and elimination of gender differences in category fluency.

Our findings are in line with others showing that increased exposure to cognitive stimulation, economic prosperity, health improvements, and changes in average family size are associated with increases in cognitive performance over time (1–4). Although it is still an open question why women appear to be more positively affected by these societal improvements than men, we hypothesize that women benefit disproportionately from societal improvements because they may start from a more disadvantaged level (20). Following this reasoning, we would expect women to improve their cognitive abilities the most in countries which progress from relatively low levels of living conditions, educational opportunities, and gender equity, to higher levels.

Some limitations of the study should be noted. First, we did not control for, or evaluate, the effect of other factors that may influence cognitive performance, such as self-rated health, use of medication, or marital status, mainly because there may be regional, cohort, and gender variations in how these factors are reported, prescribed, and valued, and because the effects of these variations may have different meanings in different contexts. As we wanted to avoid uncertainty in the analyses, these factors were not included. Second, results showing that the pattern of gender differences vary as a function of birth cohort and region could be interpreted as men and women showing regional differences in the rate of age-related cognitive decline. As studies find similar cognitive age trajectories in men and women (27–29), this is an unlikely scenario. Nonetheless, a longitudinal design, following several birth cohorts over time, is needed to unequivocally rule out this alternative. Further, for expositional purposes, we grouped the 13 European countries into three groups based on geographical proximity. Thus, our results do not necessarily pertain to the other Northern, Central, or Southern European countries not participating in SHARE. It should also be noted that, although we find systematic and stable associations between our societal indicators (i.e., RDI) and cognitive performance indicating that women's cognitive performance, in particular, is positively influenced by improvements in living conditions and educational opportunities, associations do not necessarily imply causation. Finally, although factors included in the RDI (e.g., GDP, total fertility rate, and national education level) are indirectly related to gender equity, it is likely that factors directly assessing gender equity (20) would also have been found to be associated with women's cognitive performance. Unfortunately, however, historical indicators of gender equity are not available and could therefore not be evaluated in this context.

Both scientific and policy-related implications follow from these results. Scientifically, our results demonstrate that improved living conditions and less gender-restricted educational opportunities are associated with increased gender differences in some cognitive functions (i.e., episodic memory), and also decreases (i.e., numeracy), or erasure (i.e., category fluency) of others. The increases and decreases or eliminations of the cognitive gender differences take place as a result of a general improvement over time in women's cognitive performance, which we associate with societal enhancements in living conditions and educational opportunities. As a result, in regions with relatively large gender differences favoring women in episodic memory, we should expect relatively small differences favoring men in numeracy (Fig. S2). This finding is in line with research on adolescents showing that a larger female advantage in reading literacy is associated with a smaller male advantage in mathematics (16, 18). Consequently, there are no reasons to expect that all cognitive gender differences will diminish with improved living conditions and gender equality. Instead, our findings demonstrate that a gender-specific cognitive performance pattern exists and that in societies with greater gender equity (see ref. 20 for a discussion), we should expect that women have a relative strength in some cognitive functions (e.g., episodic memory) and men in others (e.g., numeracy).

Our results also have important policy implications. Although we find that both men and women do cognitively worse in regions with lower GDP, greater mortality, larger family size, and lower educational levels, women, in particular, tend to underperform in such contexts. To potentially avoid underperformance in a large part of a country's population, policy makers could direct resources toward improving living conditions and, perhaps more importantly, ensuring equal educational opportunities for men and women.

Materials and Methods

Data. We use data from SHARE (22). SHARE is a European multidisciplinary and cross-national study conducted for the first time in 2004/05, with 28,000 participants in 11 countries. The survey was expanded to 14 countries with about 32,000 participants in 2006/07. Thirteen of the 14 national samples are representative of the participating countries' noninstitutionalized population, ≥50 y of age (22).

Here we use data from the second wave, conducted in 2006/07, on about 17,000 men and 14,000 women, 50–84 y of age, living in 13 European countries, who were interviewed and tested individually (22, 30). Demographic information was collected, and cognitive performance was evaluated with tasks assessing episodic memory, numeracy, and category fluency (see *SI Materials and Methods* for more details). For the descriptive analysis, we clustered the 13 European countries into three geographical regions (23, 24): Northern Europe (Denmark, Sweden), Central Europe (Austria, Belgium, Czech Republic, France, Germany, The Netherlands, Poland, Switzerland), and Southern Europe (Greece, Italy, Spain). An overview of the samples is provided in Table 1, and specific information on sample selection, nonresponse, and data collection can be found in ref. 22.

Statistical Analyses and Detailed Results. To investigate gender and birth cohort differences in episodic memory, numeracy, and category fluency within three geographical European regions, a series of multilevel linear models, Pearson's correlation coefficients, and *t* tests were computed. In all cross-sectional analysis, calibrated survey design weights were included to account for sampling probability and nonresponse.

Cognitive gender differences across birth cohorts and regions. For all cognitive tasks, we find that the performance is higher in Northern Europe compared with Central and Southern Europe and that later birth cohorts perform at a higher level than earlier birth cohorts. However, whereas women seem to perform at a higher level than men on the episodic memory task, this is not true for numeracy and category fluency (Fig. 1). The effects of gender and birth cohort on cognitive performance were investigated in multilevel analyses (31), computed separately for each cognitive task and region (Fig. 1 and Table S1).

Focusing on episodic memory performance (Fig. 1 *A*–*C* and Tables S1 and S2), the results show that women perform at a higher level than men in Northern and Central Europe, whereas there is no gender difference in Southern Europe. The absence of a significant variation of gender across birth cohorts (i.e., a nonsignificant random slope, which can be interpreted analogously as a nonsignificant interaction) in Northern Europe indicates that women, regardless of birth cohort, outperform their male counterparts (see Table S2 for raw mean differences, indicator of significance, pooled SD, and Cohen's *d*). In contrast, there is a significant variation of gender across birth cohorts in Central Europe, demonstrating that, although younger women perform at a higher level than their male counterparts, there are no gender differences in earlier cohorts (Table S2). In Southern Europe, the significant variation of gender across birth cohorts demonstrates that, whereas there are no gender differences for most birth cohorts, men outperform women in the earliest birth cohort (Table S2).

On the numeracy task (Fig.1 *D*–*F* and Tables S1 and S2), the main effects of gender and birth cohort are significant in all three regions, showing that men perform at a higher level than women and that later cohorts perform at a higher level than earlier cohorts. In addition, in Central and Southern Europe, there is significant variation of gender across birth cohorts, indicating that men's advantage over women is even larger in earlier cohorts than it is in later cohorts (Table S2). In Northern Europe, the male advantage is smaller and of similar magnitude across all birth cohorts, with Cohen's *d* ranging from −0.3 to −0.48 (Table S2).

Turning to performance on the category fluency task (Fig. 1 *G*–*I* and Tables S1 and S2), although performance is lower in earlier birth cohorts than in later birth cohorts, men and women perform on a similar level across birth cohorts in Northern Europe, as evidenced by a lack of gender effect and nonsignificant variation of gender across birth cohorts. Nonsignificant *t* tests and small Cohen's *d* support these results (Table S2). In contrast, there is a main effect of gender, together with significant variation of gender across

Table 1. Description of participating men and women, including summary statistics on shares of women, and performance means (SD) on measures of episodic memory, numeracy, category fluency, and years of education

European regions	Sample size	Share of women (%)	Episodic memory		Numeracy		Category fluency		Years of education	
			Women	Men	Women	Men	Women	Men	Women	Men
Northern Europe	4,974	51.9	4.62 (1.97)	4.10 (1.89)	3.49 (1.06)	3.91 (1.06)	23.10 (7.27)	23.29 (7.23)	11.83 (3.72)	12.32 (3.85)
Central Europe	18,300	54.0	3.73 (2.01)	3.42 (1.88)	3.28 (1.13)	3.67 (1.13)	19.75 (7. 63)	20.62 (7.47)	10.91 (3.64)	12.01 (3.98)
Southern Europe	7,819	54.0	2.94 (1.98)	2.96 (1.86)	2.65 (1.06)	3.18 (1.07)	14.36 (6.78)	15.78 (7.33)	7.38 (4.28)	8.62 (4.79)

birth cohorts in Central and Southern Europe. In Central Europe, men show a tendency ($P < 0.10$) toward higher performance in most birth cohorts and significantly so for birth cohort 1927–1932 (75–79 y). In Southern Europe, men perform at a higher level than women in most birth cohorts, with the exception of birth cohorts 1947–1952 and 1927–1932 (55–59 and 75–79 y). Taken together, these analyses demonstrate that the pattern and magnitude of gender differences in cognitive performances vary across geographical regions and birth cohorts.

Education and cognitive gender differences. The gender differences are not only present in cognitive performance, but they are also observed in discrepancies between men and women in level of education (Table 1). To evaluate the extent to which educational differences are associated with cognitive gender differences, we compute difference scores for education [women's average level of education ($M_{W\ educ}$) minus men's average level of education ($M_{M\ educ}$)] and cognitive performance [women's average episodic memory/numeracy/category fluency performance ($M_{W\ cogn}$) minus men's average memory/numeracy/category fluency performance ($M_{M\ cogn}$)] separately for each birth cohort within each region. As can be seen in Fig. 2, there are significant and positive correlation coefficients between the gender differences in level of education and the gender differences in cognitive performance in all three cognitive tasks. These positive correlation coefficients indicate that there are larger differences favoring women in episodic memory performance in birth cohorts with less of a male advantage in education ($r = 0.74$, $P < 0.001$). For numeracy, smaller educational differences are associated with a smaller male advantage ($r = 0.54$, $P = 0.01$). Finally, for category fluency, little or no educational differences are associated with less or no gender differences ($r = 0.62$, $P = 0.003$).

Regional development index. The extent to which differences in living conditions and cognitive stimulation can help to explain variability in the magnitude of gender differences across birth cohorts and regions was further investigated by means of a RDI. We used GDP per capita and average family size (TFR) as proxies for living conditions. Country- and birth cohort-specific GDP and TFR information was collected from the years each of the participants was 25 y old and then averaged over cohort groups (i.e., 1923–1927, 1928–1932…1953–1957). We added infant mortality and life expectancy as indicators of health and nutrition, from when each participant was 37 y old (the earliest time point in which data were available for all countries). Furthermore, we included country- and birth cohort-specific information on each country's educational distribution every fifth year (i.e., 1970, 1975…2005), that is, for when each birth cohort was 45–49 y of age, by considering the shares of secondary educated [International Standard Classification of Education (ISCED) 2–4] and tertiary educated (ISCED 5–6) inhabitants (32, 33). We applied a principal components analysis on the variables to construct the RDI (*SI Materials and Methods*), which aims to capture country- and birth cohort-specific information about the standard of living and cognitive stimulation when the participants were between 25 and 49 y of age. As an example, for an individual born in 1950 in Sweden, the RDI is 3.05 (10th decile), whereas it is −0.15 (6th decile) for a same-age individual from Spain.

Regional development index and cognitive gender differences. In the next step, we applied multilevel linear models (31), with participants as level 1 units and countries as level 2 units, to identify to what extent participants' individual age, gender, and education level are associated with cognitive performance and also to what extent the RDI (group-mean centered) influences the performance. In these analyses, we also considered interactions between gender and the participants' education level (in years of education) and between gender and the RDI. Significant random slopes of RDI and gender were included for all three measures. We used dummy coding for the variable birth cohort with reference category 1952/57 (age 50–54 y).

As can be seen in Table S3 and demonstrated in earlier analyses, cognitive performance is significantly influenced by birth cohort, gender, and the participant's level of education in all three cognitive tasks. Beyond these effects, cognitive performance is also significantly associated with the RDI, so that a higher RDI is associated with higher episodic memory and category fluency performance for both women and men (Table S3). Importantly, and evidenced by the significant interactions between the RDI and gender in episodic memory and numeracy, an increase in the RDI is relatively more important for women than for men (Table S3 and Fig. S1). In line with this, significant interactions between a participant's level of education and gender on episodic memory and category fluency demonstrate that women's cognitive performance, relative to that of men, benefits from increases in level of education.

To further explore and illustrate the relationship between the RDI and cognitive gender differences, we computed the average episodic memory/numeracy/ category fluency performance for each RDI decile (Fig. S1). Fig. S1 shows descriptively that higher RDI is associated with better cognitive performance and that women's performance appears to increase more than men's with higher RDI, although it should be noted that the effect of RDI on cognitive performance for both men and women is inflated by the effect of age, as later birth cohorts typically have higher RDI.

PSYCHOLOGICAL AND COGNITIVE SCIENCES

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Supporting Information

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SI Materials and Methods

Cognitive Assessment. The three cognitive tasks used to assess different dimensions of cognitive performance are described below (1).

Episodic memory. Participants were told: "A little while ago, I read you a list of words and you repeated the ones you could remember. Please tell me any of the words that you can remember now?" Retention interval between encoding and retrieval was approximately 5 min. One minute was allocated to recall the remembered words.

Numeracy. Participants were asked: "If the chance of getting a disease is 10 percent, how many people out of one thousand would be expected to get the disease?" If the first item was answered incorrectly, the participant was asked the following question, after which the numeracy test was stopped, irrespective of whether this answer was correct or not: "In a sale, a shop is selling all items at half price. Before the sale, a sofa costs 300 (local currency). How much will it cost in the sale?" If the first item was answered correctly, a second question was posed: "A second hand car dealer is selling a car for 6,000 (local currency). This is two-thirds of what it cost new. How much did the car cost new?" Only if both numeracy items were answered correctly, was the participant asked to answer a last question: "Let's say you have 2,000 (local currency) in a savings account. The account earns ten percent interest each year. How much would you have in the account at the end of two years?" The numeracy score ranged from 1 (the participant did not answer correctly any of the math questions) to 5 (the participant answered all of the math questions correctly).

Category fluency. Participants were told: "Now, I would like you to name as many different animals as you can think of. You have one minute to do this. Ready, go." Valid answers were any members of the animal kingdom, real or mythical, specific species' names, any accompanying breeds within the species, as well as male, female, and infant names within the species. Proper nouns were considered incorrect.

Regional Development Index. We collected country- and birth cohort-specific indicators of gross domestic product (GDP) per capita (2), total fertility rate (TFR) (3, 4), educational distribution (5, 6), infant mortality rates (7), and life expectancy (8). GDP and TFR information was collected from the years when each of the participants was 25 y old and then averaged over cohort groups (i.e., 1923–1927, 1928–1932…1953–1957). We also included country- and birth cohort-specific information on each country's educational distribution every fifth year (i.e., 1970, 1975…2005), that is, for when each birth cohort was 45–49 y of age, by considering the shares of secondary educated [International Standard Classification of Education (ISCED) 2–4] and tertiary educated (ISCED 5–6) inhabitants. In addition, country-specific infant mortality rates and life expectancy at birth were collected from the years each of the participants was 37 y old, which was the earliest time infant mortality rates for all countries and birth cohorts were available.

Next, we log-transformed GDP and infant mortality rates, due to positively skewed distributions, and applied principal components analysis on the standardized variables (unit variance and zero centered). The first factor, which we hereafter call regional development index (RDI), explained 68.6% of the total variation. This factor captures country- and birth cohort-specific information about health, standard of living, and cognitive stimulation when the participants were between 25 and 49 y of age. The RDI ranges from −5.7 to 3.93. Educational distribution, GDP, and life expectancy contribute positively to RDI, whereas TFR and infant mortality rate load negatively (TFR, −0.36; infant mortality, −0.46; GDP, 0.47; secondary educated, 0.29; tertiary educated, 0.43; life expectancy, 0.41). As an example, the RDI is 3.05 (10th decile) for an individual from Sweden born in 1950, whereas it is −0.15 (6th decile) for a same-age individual from Spain.

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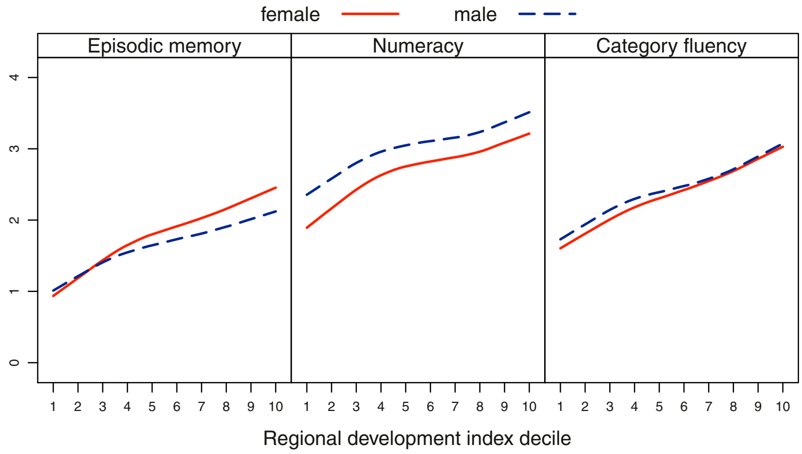

Fig. S1. Associations between the RDI decile and cognitive performance (average level of episodic memory/numeracy/category fluency performance in SD units as a function of RDI decile), descriptively showing that higher RDI is associated with better cognitive performance and that women's performance appears to increase more than men's with higher RDI. Note that the effect of RDI on cognitive performance for both men and women is inflated by the effect of age, as later birth cohorts typically have higher RDI. Multilevel modeling (Table S3) show that higher RDI is related to higher episodic memory and category fluency performance and that women's more than men's episodic memory and numeracy performance benefit from improvements in RDI. Curves are smoothed by using local regressions (LOESS).

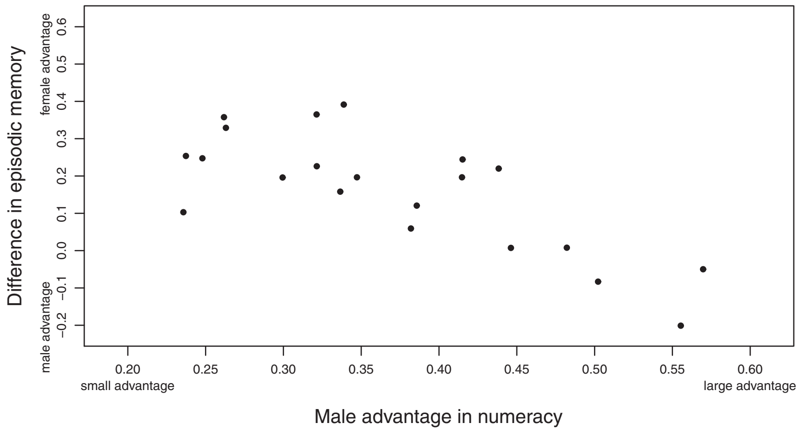

Fig. S2. The association between the difference score in episodic memory (women's average standardized level of episodic memory minus men's average standardized level of episodic memory) and the difference score in numeracy (men's average standardized level of numeracy minus women's average standardized level of numeracy), $r = -0.76$; $P < 0.001$, demonstrating that in birth cohorts in which women have a large advantage in episodic memory (high value on y axis), gender differences favoring men in numeracy are relatively small (low value on x axis).

Table S1. Results from multilevel analysis investigating the effects of gender and birth cohorts in episodic memory, numeracy, and category fluency separately for Northern, Central, and Southern Europe

Factor	Episodic memory, Northern Europe	Numeracy, Northern Europe	Category fluency, Northern Europe	Episodic memory, Central Europe	Numeracy, Central Europe	Category fluency, Central Europe	Episodic memory, Southern Europe	Numeracy, Southern Europe	Category fluency, Southern Europe
Fixed effects: estimates									
Intercept	3.847***	3.836***	22.46***	3.232***	3.595***	19.870***	2.778***	3.094***	15.307***
Gender (f)	0.558***	−0.414***	0.002	0.336***	−0.38***	−0.675**	0.06	−0.493***	−1.219***
Birth cohort random effects: variances									
Intercept	0.481	0.043	4.955	0.277	0.045	4.279	0.453	0.112	3.754
Gender (f)	0.019	0.004	0.041	0.057	0.008	0.263	0.34	0.017	0.318
Residual	3.301	1.073	48.118	3.448	1.21	52.66	3.19	1.011	45.51
LR	4.86	3.29	0.78	31.62	19.97	14.88	15.61	22.92	7.12

We carried out likelihood ratio tests (LR) to test if gender differences vary significantly across birth cohorts (e.g., significance of random slope gender), where a likelihood ratio statistics >5.991 with 2 df signals a significant gender variation.

Significance levels: $*P \leq 0.05$; $**P \leq 0.01$; $***P \leq 0.001$.

Table S2. Testing the hypothesis (H0: there are no gender differences in episodic memory, numeracy, and category fluency) for Northern, Central, and Southern Europe

Measure per region	Birth cohort 1952/57 (50–54) *Δ (SD) [d]*	Birth cohort 1947/52 (55–59) *Δ (SD) [d]*	Birth cohort 1942/47 (60–64) *Δ (SD) [d]*	Birth cohort 1937/42 (65–69) *Δ (SD) [d]*	Birth cohort 1932/37 (70–74) *Δ (SD) [d]*	Birth cohort 1927/32 (75–79) *Δ (SD) [d]*	Birth cohort 1923/27 (80–84) *Δ (SD) [d]*
Episodic memory							
Northern Europe	0.77*** (1.75) [0.44]	0.72*** (1.82) [0.4]	0.71*** (1.82) [0.39]	0.45*** (1.76) [0.25]	0.43*** (1.81) [0.24]	0.48** (1.90) [0.25]	0.39* (1.98) [0.2]
Central Europe	0.65*** (1.90) [0.34]	0.49*** (1.83) [0.27]	0.50*** (1.89) [0.27]	0.39*** (1.84) [0.21]	0.31*** (1.85) [0.17]	0.12 (1.82) [0.06]	−0.16 (1.87) [−0.09]
Southern Europe	0.24 (1.87) [0.13]	0.20 (1.93) [0.11]	0.39*** (1.81) [0.21]	0.02 (1.83) [0.01]	−0.10 (1.68) [−0.06]	0.01 (1.62) [0.01]	−0.40** (1.55) [−0.25]
Numeracy							
Northern Europe	−0.39*** (1.03) [−0.38]	−0.37*** (1.00) [−0.37]	−0.30*** (1.03) [−0.3]	−0.37*** (1.04) [−0.36]	−0.51*** (1.06) [−0.48]	−0.48*** (1.05) [−0.46]	−0.48*** (1.12) [−0.43]
Central Europe	−0.30*** (1.07) [−0.29]	−0.29*** (1.09) [−0.26]	−0.28*** (1.09) [−0.25]	−0.40*** (1.07) [−0.38]	−0.39*** (1.12) [−0.35]	−0.44*** (1.19) [−0.37]	−0.58*** (1.16) [−0.5]
Southern Europe	−0.45*** (0.99) [−0.45]	−0.27*** (0.97) [−0.28]	−0.35*** (1.02) [−0.34]	−0.56*** (1.03) [−0.54]	−0.66*** (1.04) [−0.64]	−0.52*** (1.04) [−0.5]	−0.64*** (0.95) [−0.67]
Category fluency							
Northern Europe	0.16 (6.91) [0.02]	0.05 (7.02) [0.01]	0.73 (7.09) [0.1]	−0.46 (6.80) [−0.07]	−0.34 (6.58) [−0.05]	−0.16 (6.57) [−0.02]	0.20 (7.60) [0.03]
Central Europe	0.34 (7.61) [0.05]	−0.65* (7.17) [−0.09]	−0.07 (7.58) [−0.01]	−0.80* (7.42) [−0.11]	−0.88* (6.99) [−0.13]	−1.37*** (6.56) [−0.21]	−1.09* (6.86) [−0.16]
Southern Europe	−1.84** (8.40) [−0.21]	0.16 (6.34) [0.03]	−1.30*** (6.24) [−0.21]	−1.44*** (6.15) [−0.23]	−1.52*** (5.18) [−0.29]	−0.78 (8.08) [−0.1]	−1.96** (6.14) [−0.31]

t tests are used to test the null hypothesis: values of raw mean differences Δ, (SD), and [effect size, Cohen's *d*] are reported. A positive *d* value indicates that women performed on a higher level than men. Significant differences: *10%, **5%, and ***1%.

Table S3. Multilevel linear regression models for episodic memory, numeracy, and category fluency

Factor	Episodic memory	Numeracy	Category fluency
Fixed effects: estimates (SE)			
Intercept	2.688 (0.23)***	2.802 (0.14)***	15.657 (0.67)***
Birth cohort 1947/52 (55–59 y)	−0.072 (0.04)*	−0.030 (0.02)†	−0.267 (0.14)*
Birth cohort 1942/47 (60–64 y)	−0.154 (0.05)**	−0.010 (0.02)	−0.360 (0.38)
Birth cohort 1937/42 (65–69 y)	−0.263 (0.08)***	−0.029 (0.06)	−0.509 (0.50)
Birth cohort 1932/37 (70–74 y)	−0.513 (0.10)***	−0.140 (0.05)**	−1.242 (0.64)†
Birth cohort 1927/32 (75–79 y)	−0.875 (0.11)***	−0.230 (0.08)**	−1.951 (0.77)*
Birth cohort 1923/27 (80–84 y)	−1.257 (0.13)***	−0.424 (0.08)***	−2.875 (0.96)**
Gender (f)	0.238 (0.09)*	−0.369 (0.08)***	−0.721 (0.30)*
Education	0.100 (0.01)***	0.084 (0.01)***	0.427 (0.05)***
RDI	0.080 (0.03)**	0.023 (0.02)	0.495 (0.18)**
Education x Gender (f)	0.021 (0.01)**	0.006 (0.01)	0.068 (0.02)**
RDI x Gender (f)	0.056 (0.01)***	0.026 (0.00)***	0.061 (0.05)
Country random effects: variances			
Intercept	0.175	0.095	5.167
RDI	0.003	0.001	0.112
Gender (f)	0.035	0.007	0.097
Residual	3.073	0.935	40.891
Sample size	29910	30101	29762

RDI and gender differences vary significantly across countries (e.g., significance of random slope RDI and gender) for episodic memory, numeracy, and category fluency (verified with likelihood ratio tests). Birth cohort 1952/57 aged 50–54 years served as reference group. Random intercepts and slopes are allowed to covary.

Significance levels: †$P \leq 0.10$; *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

4

Conclusion

This chapter consists of three parts: the first one is a short summary of the content of this theses, the second one deals with the limitations of the methods and outcomes throughout the thesis, and the last one finally contains the contributions and impacts seen from an interdisciplinary perspective.

In this work new measures of aging were proposed that allow the consideration of physical and cognitive performance. The potential of countries with high shares of older but cognitively active population can be better measured using the cognition adjusted dependency ratio, which treats older adults with good cognitive capacity equal to the working population. Further, analyzing lower body performance (e.g. walking speed) by education highlights a gap in individual aging of up to 15 years for men and up to 10 years for women. Investigating determinants of aging, particularly cognitive aging, I showed that cognitive stimulations from the neighborhood are positively assigned with cognitive performance in addition to a positive individual education effect. However, with more cognitive stimulation from the peers and better regional development (e.g. economic development, infant mortality, life expectancy, and national education) during the life-cycle cognitive gender differences will increase favoring women in episodic memory and diminish in category fluency.

Some limitations of the four studies should be noted. The data source of this thesis relies on aging studies with self-reported health status as well as cognitive and physical performance tests. There might be cultural differences in response habits that could influence the gained results. Moreover, language differences could lead to some bias within the cognitive tests, as for instance some languages might have on average longer words than others. This is particularly important when the participants have to name as many animals as possible within one minute. Another limitation known as endogeneity can arise in models investigating the effect of education on cognitive aging. First, it is challenging to control for reverse causality between individual education and cognitive performance. Since I analyze cognitive performance of older adults, while education was gained in their younger days, the reverse causality is not expected to be an issue. Second, the education effect might be biased due to omitted variables, such as children are more likely to visit schools that are in their proximity. This effect of omitted variables cannot be completely eliminated, even using methods such as the instrumental variable approach.

To sum up, there is a huge variation in aging (e.g. physical and cognitive) across countries as well as within countries. New measures of aging considering performance enable more comparable investigations of population aging, and they can better address subgroup differences in individual aging. National education is an important determinant of aging next to individual education, but there are more influences on the national level that appear during the whole life-cycle. Nevertheless, my results show that variations in cognitive aging within and between countries might remain even after increasing education and achieving more equal societies.

Hence, developed countries particularly can expect higher shares of more active older adults in upcoming years. From a social perspective there will be more potential caregivers (for grandchildren and for older people) with good cognitive performance. Moreover, older adults are strongly involved in volunteer work, which yields an increased share of healthy volunteers. Tomorrow's older adults are supposed to be knowledgeable, emotionally stable and relatively healthy, to sum up a good resource for the labor market. Therefore the trend of aging populations might also be beneficial for economies thinking about the labor force potential. Though, that would ask for more flexible retirement ages and pension systems.