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Veröffentlichungsversion / Published Version
Zeitschriftenartikel / journal article

Empfohlene Zitierung / Suggested Citation:
Zhou, Y. (2022). Development over Time in Cognitive Function among European 55-69-Year-Olds from 2006 to 2015, and Differences of Region, Gender, and Education. *Comparative Population Studies - Zeitschrift für Bevölkerungswissenschaft*, *47*, 119-142. https://doi.org/10.12765/CPoS-2022-04

Comparative Population Studies
Vol. 47 (2022): 119-142 (Date of release: 29.03.2022)

Development over Time in Cognitive Function among European 55-69-Year-Olds from 2006 to 2015, and Differences of Region, Gender, and Education

Ying Zhou

Abstract: With populations rapidly aging, the development over time in the cognitive function among the elderly approaching or reaching retirement is important for successful aging at work and planning pension policies. However, few studies in this field focus on this age group. This study characterizes time trends in cognitive function among 55-69-year-old Europeans from 2006 to 2015, and compares these trends by region, gender, and education. This study analyzes 40,689 subjects in Waves 2, 4, 5 and 6 of the Survey of Health, Aging and Retirement in Europe (SHARE) covering ten countries. Cognitive function was measured by Recall and Verbal Fluency. Educational levels were classified by quartiles. A Generalized Estimating Equation (GEE) model was used to explore the association between cognitive function and development over time after controlling for confounders. Further stratification analysis using GEE models was conducted, stratified by region, gender and education. Cognitive function improved significantly in southern and central Europe over the observed timeframe, whereas it did not in northern Europe. Those with relative low levels of formal education displayed the most rapid increases in cognitive function in southern and central Europe. Among those with lower education in southern Europe, males' cognitive function improved more quickly than females'. The improvement of cognitive function at ages 55-69 in southern and central Europe may contribute to continuing engagement with productive activities in old age. Educational interventions for people with lower levels of education may be most effective in achieving such engagement. This paper extends the literature on the development over time in the cognitive function among the elderly close to retirement age in Europe by analysing southern, central and northern Europe, as well as differences by region, gender and education. The results may provide evidence for planning pension policies and educational interventions.

Keywords: Aging · Cognitive function · Education · Flynn effect

Federal Institute for Population Research 2022

URL: www.comparativepopulationstudies.de
DOI: https://doi.org/10.12765/CPoS-2022-04
URN: urn:nbn:de:bib-cpos-2022-04en0

1 Introduction and review

As populations rapidly age, public policies in many countries now encourage working into increasingly higher ages, so as to help manage the increased costs of government retirement pension and health care (*Fisher et al.* 2016, 2017). By legislation, about half of the OECD countries will increase their retirement age to approximately 66 years on average by 2060 (*OECD* 2017). Moreover, financial incentives are now widely provided to delay retirement (*Fisher et al.* 2016).

However, poor health – including cognitive health – is one of the leading causes of early and unplanned retirement (*Fisher et al.* 2016). Although age-related cognitive decline begins in early adulthood (*Salthouse* 2010b), a study of the United States found that between the ages of 55 and 69, approximately 10 percent of workers experienced steep cognitive decline (*Belbase et al.* 2015). These workers experiencing steep cognitive decline were more likely to have lower performance at work, to "downshift" to a less cognitively demanding job, or to retire earlier than workers not experiencing cognitive decline (*Belbase et al.* 2015; *Fisher et al.* 2017). The cognitive functioning among older adults at work, particularly during periods approaching or reaching retirement, is a critical factor to successfully aging at work, especially in cognitively-demanding jobs, such as professional, managerial, technical and other cognitively complex jobs (*Fisher et al.* 2017).

Therefore, the development of cognitive function over time is a public health concern, particularly for the 55-69 age group.

1.1 Current research on trends in cognitive function

Past research analysing the trends of cognitive function remains inconsistent regarding the theory ("success of success" hypothesis versus "failure of success" hypothesis, "Flynn-effect" versus "Anti-Flynn-effect"), as well as in study results and conclusions.

On the one hand, the "success of success" hypothesis states that there exist factors which may improve the cognitive function of a population over time, postpone the onset of disability, and thereby result in more people living longer and healthier lives (*Fries* 1980). These positive factors for younger generations include higher education, better cardiovascular risk factor profiles (i.e. lower blood pressure and total cholesterol levels, less smoking, and more physical activity), better nutrition, and the improved treatment of cardiovascular diseases and diabetes (*Pietschnig/Voracek* 2015; *Ahrenfeldt et al.* 2018). Moreover, according to the "cognitive reserve" hypothesis, more recent generations have also more experience in jobs that require considerable cognitive investment, which leads to increases in neuronal development and consequently serves as a buffer against cognitive decline (*Fisher et al.* 2017). Recent studies have shown more recent birth years are associated with better cognitive function in Europe (*Ahrenfeldt et al.* 2018), and with slower rates of age-related cognitive decline and a lower risk of incident cognitive impairment in the United States (*Downer et al.* 2019; *Vonk et al.* 2019). The Berlin Aging Study reports that later-born cohort (in 2013-14, mean age of 75 years old) showed higher levels of cognitive performance than their counterparts born 20 years earlier (*Gerstorf et al.* 2015). In addition, the tendency toward a cumulation of advantages or disadvantages, the so-called "Matthew effect", is observed in human aging and life-course patterns within cohorts, as well as between cohorts (*Dannefer* 1987, 2003). If a larger proportion of younger generations is exposed to more factors beneficial to cognitive function, taking the "Matthew effect" into consideration, their cognitive development over time at older ages may also develop positively.

The increase of cognitive abilities from one generation to the next, the so called "Flynn effect", has been reported in both developed countries (including the United States, 15 European nations, Japan, South Korea, Australia, Canada, and New Zealand) and developing countries (including China, India, Brazil, Dominica, Saudi Arabia, and Sudan) (*Flynn* 2012, 1987; *Pietschnig/Voracek* 2015). A meta-analysis has estimated a global increase of 3 IQ points per decade on average from 1909 to 2013 (*Pietschnig/Voracek* 2015).

On the other hand, according to the "failure of success" hypothesis, reduced age-specific mortality and longer lifespans might increase the prevalence of chronic conditions including cognitive impairment, leading to worse overall cognitive health of the elderly population (*Fries* 1980). Studies examining trends in cognitive function showed an increase over time in prevalent cognitive impairment in the Netherlands (*van den Kommer et al.* 2018) and the United States (*Downer et al.* 2019), and in prevalence of dementia in Japan (*Sekita et al.* 2010) and Sweden (*Mathillas et al.* 2011). These studies investigating cognitive impairment and dementia usually focus on the population aged 65+, 75+, or 85+. However, little is known about the cognitive functioning and its development over time for the elderly approaching or reaching retirement (55-69 years old), despite research revealing that some workers experience steep cognitive decline over this period (*Belbase et al.* 2015).

The plateauing or decline of cognitive abilities from one generation to the next, the so-called "negative Flynn effect" or "anti-Flynn effect", has been reported in European countries including Norway (*Sundet et al.* 2004), Denmark (*Teasdale/Owen* 2008), the Netherlands (*Woodley/Meisenberg* 2013), Finland (*Dutton/Lynn* 2013), France (*Dutton/Lynn* 2015), and Britain (*Shayer/Ginsburg* 2009). However, the majority of research on the negative Flynn effect used samples of under-20-year-olds (*Dutton et al.* 2016; *Sundet et al.* 2004; *Teasdale/Owen* 2008; *Shayer/Ginsburg* 2009; *Woodley/Meisenberg* 2013; *Dutton/Lynn* 2013, 2015).

Taking dynamic time periods, geographic areas, and gender into consideration, the trends in the cognitive function studies are more complicated, since development over time in cognitive function may vary among different population subgroups of geographic regions, genders, and further potential factors (*Prince et al.* 2016; *Dutton et al.* 2016; *Vonk et al.* 2019). Studies of both Denmark and Norway found early gains of the Flynn effect, followed by stagnation through the 1990s in both countries, and a slight decline since the late 1990s in Denmark (*Teasdale/Owen* 2005; *Sundet et al.* 2004). A recent study indicated greater increases in cognitive performance for southern Europeans (compared to central and northern Europe) and for females (compared to males) (*Weber et al.* 2017). However, the authors noted that further research is required for the inconclusive and statistically insignificant findings, namely that males had larger gains than females in southern Europe, whereas females had larger gains in northern and central Europe (*Weber et al.* 2017). Moreover, the study did not analyse nor adjust for educational levels explicitly.

However, in addition to region and gender, education appears to be one of the key factors for time trends in cognitive ability in some countries, while not appearing influential in others (*Neisser* 1998; *Teasdale/Owen* 2005). More education in Europe may help cognitive levels, with a long-term effect through the pathways of occupation, social interaction, and lifestyle choices (*Bennett et al.* 2014; *Banks/Mazzonna* 2012; *Alley et al.* 2007; *Pavlova/Silbereisen* 2012; *Schneeweis et al.* 2014). Well-educated people are more likely to achieve higher earnings and income, to engage in greater social and cultural participation, and to have more healthy habits and lifestyles, which may prevent the age-related cognitive decline (*Banks/Mazzonna* 2012; *Rowe/Kahn* 1997). Moreover, people with higher education have more opportunities to work jobs demanding higher cognitive ability, and the "use it or lose it" hypothesis seems to be supported by results across studies (*Fisher et al.* 2017). Yet it remains unclear whether and how education moderates the trajectory of cognitive change (*Lenehan et al.* 2015; *Alley et al.* 2007). Some of the inconsistency in previous evidence may lie in the threshold of education for its effect (*Lenehan et al.* 2015).

1.2 Novel contributions of this study

First, this study focuses on the age group of 55-69. As mentioned above, the cognitive ability and its trends for this age group has a considerable influence on sustained productive work in old age and desired retirement timing. Moreover, this age group is less affected by sample attrition related to death or other health conditions than older adults. However, most research examining time trends in cognitive limitations or dementia focuses on persons 70 years of age or older (*Langa* 2015; *Choi et al.* 2018); while the majority studies which found the anti-Flynn effect examined those younger than 20 years old (*Larson et al.* 2013; *Alley et al.* 2007; *Dutton/Lynn* 2013; *Teasdale/Owen* 2005).

Second, this study investigates trends in cognitive function considering region, gender, and education by using a large representative European sample covering a total of ten countries in three European regions over nine years. The countries are Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, Spain, Sweden, and Switzerland.

Third, this study applies a new approach to operationalising education, which elsewhere has been successfully applied to time trend investigation by examining the relative rank of educational attainment or socio-economic status in proportion to the overall distribution (*Choi et al.* 2018; *Bound et al.* 2015). In contrast, the conventional classification of educational attainment by credentials or International Standard Classification of Education (ISCED) may lead to less comparable subgroups in the study of time trends, because the high educational group (ISCED ≥ 5) has grown over time, and the low educational group (ISCED ≤ 2) has shrunk and is becoming an increasingly vulnerable segment of the population (*Bound et al.* 2015).

Insufficient numbers of participants with low or high education levels may limit statistical power and lead to bias (*Lenehan et al.* 2015). Furthermore, relying only on years of education may cloud international comparisons, as each country has its own system with varying programme durations and differing types of certification, such as vocational and academic degrees.

1.3 Research question

This study aims to investigate changes in cognitive function over time at ages 55-69 in Europe and the differences linked to region, gender, and education. This study seeks to provide evidence whether and how cognitive performance becomes better over time at the population level for the elderly close to retirement ages in Europe. These results may contribute to the maintenance of productive activities in old age.

2 Data and methods

2.1 Sample

This study uses data of people between the ages of 55 and 69 in Waves 2, 4, 5, and 6 of the SHARE survey, a longitudinal, nationally representative, population-based, international, and harmonized survey (*Börsch-Supan et al.* 2013). Wave 1 was excluded because education was measured differently than in subsequent waves. Wave 3 was also excluded because it focused on respondents' life histories. Wave 7 was excluded because it was designed to focus on both life history and panel information, and the panel information was collected by a shorter, condensed set of questions from the regular panel questionnaire. Thus, Verbal Fluency in Wave 7, one of the key variables in this study, has a great deal of missing values because it was only asked for respondents who participated in SHARELIFE in Wave 3. This study included only those countries which participated in all selected waves, except for the Netherlands due to differences in its mixed mode experiment in Wave 6 compared to the regular SHARE waves for other countries. Thus, ten countries were included in the analysis: Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, Spain, Sweden, and Switzerland. Although some waves covered two calendar years, the first calendar year was used as the survey year, namely the years 2006, 2011, 2013, and 2015 for Waves 2, 4, 5, and 6, respectively. Italy and Spain were assigned to the category of southern Europe; Austria, Belgium, Czech Republic, France, Germany, and Switzerland were grouped together as central Europe; Denmark and Sweden were listed as northern Europe.

2.2 Cognitive function measures

SHARE uses temporal orientation, numeracy, immediate and delayed recall testing, and verbal fluency to measure cognitive function. This study focuses on recall tests and verbal fluency for four reasons. First, episodic recall tests and semantic verbal fluency are sensitive to cognitive aging (*Souchay et al.* 2000; *Tomer/Levin* 1993). Second, recall and verbal fluency reflect two key dimensions of cognitive performance separately, namely fluid intelligence/working memory and crystallized intelligence/knowledge (*Arpino/Bordone* 2014; *Salthouse* 2006; *Weber et al.* 2017). Crystallized intelligence refers to an individual's store of knowledge and learned operation; fluid intelligence refers to the ability to think logically and solve novel problems independently of acquired knowledge, and is highly related to working memory (*Nisbett et al.* 2012; *Arpino/Bordone* 2014; *Salthouse* 2006; *Horn/Cattell* 1967; *Jaeggi et al.* 2008). Third, the temporal orientation in SHARE had a skewed distribution and thus was strongly affected by ceiling and floor effects. Fourth, the ordinal variable resulting from the numeracy test had limited variability, and the numeracy tests had a high number of missing values in Wave 6 (*Adam et al.* 2013; *Mehrbrodt et al.* 2019).

The recall test was used to assess episodic memory performance. The respondent listened to a list of ten words, and immediately did a recall test (immediate recall test), followed by another after a delay (delayed recall test). The number of words the respondent recalled correctly was recorded, ranging from 0 to 10 for both tests. The Recall variable is the average score of the immediate and delayed recall tests.

Verbal fluency was used to assess executive function. Respondents were asked to list animals, and the number of animals the respondent said correctly in one minute was counted and stored as the raw variable of verbal fluency. Outliers were defined as the values more than 2.5 standard deviations away from the mean per wave. These outliers were replaced by the wave-specific maximum values within 2.5 standard deviations. Thus, the verbal fluency without outliers ranged from 0 to approximately 40. Additionally, the variable was multiplied by 0.25, so that it had a comparable scale of 0 to approximately 10, similar to the Recall variable.

2.3 Educational level

For an international comparison of education, the ISCED 1997 was used with categories ranging from 0 to 6, with higher categories indicating higher levels of formal education. In order to improve comparability across groups over time, the ISCED 1997 grades were multiplied by years of education and further categorized into groups of "low", "middle", and "high" Adjusted Educational Levels for each survey wave. These three groups are made up of the bottom 25 percent (lowest to first quartile Q1), middle 50 percent (first quartile Q1 to third quartile Q3), and top 25 percent (third quartile Q3 to highest) for each survey wave.

2.4 Modelling strategies and statistical analysis

Generalized Estimating Equation (GEE) models were estimated using a linear link function with normally distributed error terms and an unstructured covariance matrix to account for the dependency of observations between waves. The GEE model is also capable of handling missing values and unbalanced cases and is fairly robust with large sample sizes in particular.

Separate GEE models for Recall and Verbal Fluency were run to explore their association with the time trend measured by the numeric survey year, adjusting for gender, region, education, and the interactions of gender-by-survey year, education-by-survey year, and region-by-survey year. The adjustment was conducted further for age at interview and whether the subject had participated in SHARE for the first time. In subsequent stratification analyses the association between cognitive function and time was further investigated by GEE models stratified by region, gender, and education.

A sensitivity analysis was conducted for the other common correlation structures (autoregressive, exchangeable, and independent). The goodness of fit statistic Quasilikelihood under the Independence Model Information Criterion (QIC) was used for the GEE model comparison (*Hardin/Hilbe* 2013). Moreover, a sensitivity analysis was conducted to include Wave 7. Finally, in order to investigate differences and similarities between the two operationalizations of education, the conventional classification of education by ISCED (ISCED-97 = 0-2, 3-4, 5-6 as low, middle, and high levels of education) was additionally applied in a separate analysis.

All analyses were performed in SAS 9.4 (SAS Institute, Cary NC).

3 Results

The sample comprised 40,689 subjects with a mean age of approximately 62; roughly 54 percent of whom were female and 46 percent were male (see Table 1). From Wave 2 to Wave 6, the scores for Recall and Verbal Fluency increased on average. The proportions of low, middle, and high Adjusted Educational Level were approximately 25 percent, 50 percent, and 25 percent for each survey wave as defined, although these were not as precise as defined due to the tied values. The proportion of subjects who participated in the SHARE survey for the first time decreased over time (see Table 1).

Figure 1 illustrates the mean values and 95 percent confidence intervals for Recall and Verbal Fluency, showing a consistent increase of Verbal Fluency over time for each European region, and of Recall over time in central Europe. A less consistent trend of increase of Recall can also be found in northern and southern Europe. Overall, central Europe shows higher cognitive function than southern Europe, while northern Europe has the highest values. However, the differences between regions are shrinking due to different speeds of increase over time.

Table 2 shows the results of the two overall models for the association of cognitive function and time after controlling for age, gender, region, education, their interaction, and whether the subject had participated in SHARE for the first time.

Gender: Females had statistically significantly better Recall than males ($ß = 0.44$, $p < 0.0001$). There was a general improvement in cognitive function over time (Recall: $ß = 0.02$, $p < 0.0001$; Verbal Fluency: $ß = 0.04$, $p < 0.0001$). However, there was no significant overall difference in the trend between the two genders (Recall: $ß = 0.00$, $p = 0.322$; Verbal Fluency: $ß = 0.01$, $p = 0.176$).

Tab. 1: Demography, cognitive function, educational level, and other characteristics for the sample in SHARE

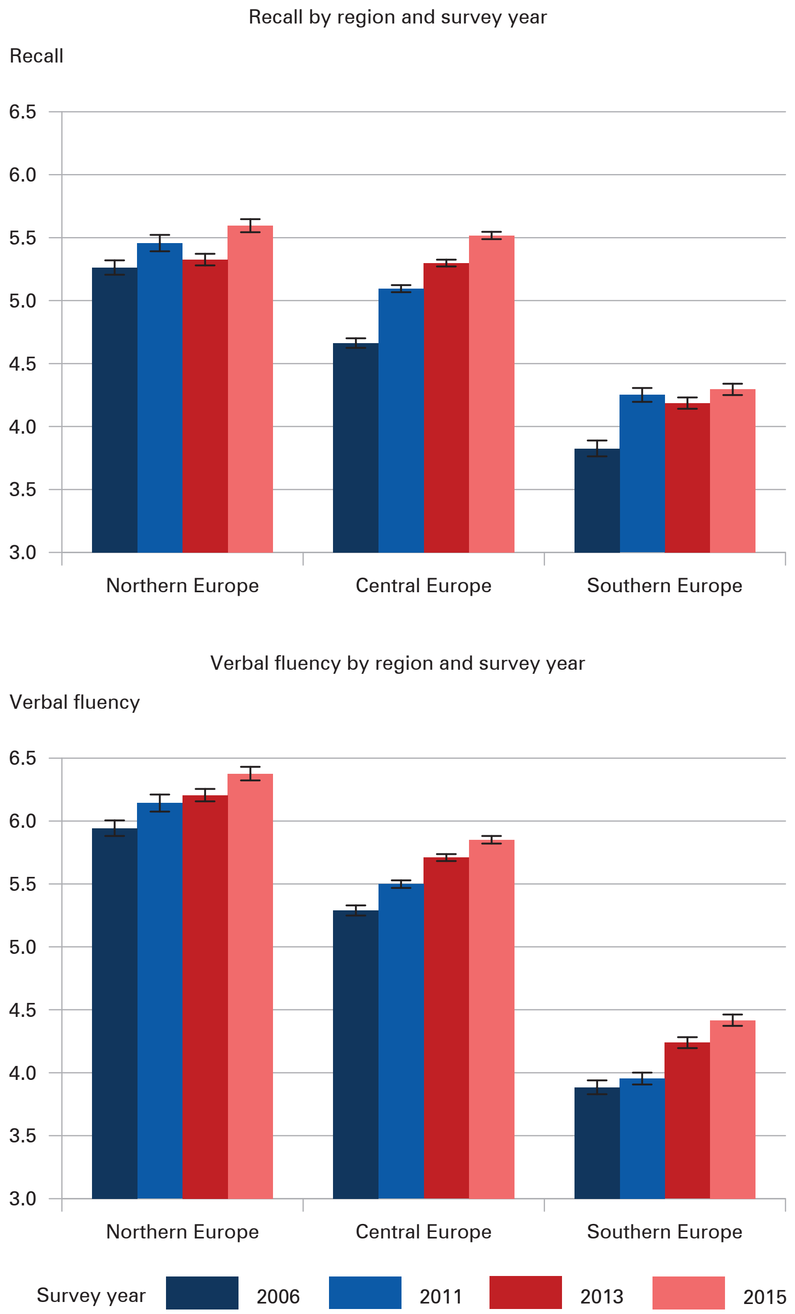
	Wave 2		Wave 4		Wave 5		Wave 6	
	n	(%)	n	(%)	n	(%)	n	(%)
N	12556		19338		24464		21151	
Age	61.7	(4.27)	61.9	(4.22)	62.2	(4.21)	62.4	(4.25)
Gender								
Female	6778	(54.0)	10562	(54.6)	13268	(54.2)	11666	(55.2)
Male	5778	(46.0)	8776	(45.4)	11196	(45.8)	9485	(44.8)
Country								
Austria	649	(5.2)	2549	(13.2)	2128	(8.7)	1578	(7.5)
Belgium	1553	(12.4)	2597	(13.4)	2814	(11.5)	2883	(13.6)
Czech Republic	1442	(11.5)	3067	(15.9)	3094	(12.6)	2515	(11.9)
Denmark	1233	(9.8)	1122	(5.8)	2162	(8.8)	1932	(9.1)
France	1361	(10.8)	2767	(14.3)	2322	(9.5)	1905	(9.0)
Germany	1429	(11.4)	886	(4.6)	2731	(11.2)	2181	(10.3)
Italy	1591	(12.7)	1789	(9.3)	2280	(9.3)	2489	(11.8)
Spain	1048	(8.3)	1629	(8.4)	3018	(12.3)	2483	(11.7)
Sweden	1536	(12.2)	1026	(5.3)	2308	(9.4)	1705	(8.1)
Switzerland	714	(5.7)	1906	(9.9)	1607	(6.6)	1480	(7.0)
Recall	4.6	(1.67)	5.0	(1.69)	5.1	(1.71)	5.2	(1.70)
Verbal fluency	5.1	(1.79)	5.3	(1.80)	5.5	(1.82)	5.6	(1.82)
Adjusted Educational Level								
Low	3179	(26.0)	4001	(25.6)	5214	(26.9)	3889	(26.5)
Middle	5895	(48.3)	7697	(49.2)	9267	(47.9)	7098	(48.3)
High	3143	(25.7)	3946	(25.2)	4879	(25.2)	3707	(25.2)
Participate in SHARE-survey								
First time	5786	(46.1)	13175	(68.1)	10664	(43.6)	3827	(18.1)
Not the first time	6770	(53.9)	6163	(31.9)	13800	(56.4)	17324	(81.9)

Source: Own calculations, based on data from SHARE

Region: There were statistically significant regional differences, with northern Europe showing higher cognitive function than southern and central Europe (central vs. northern Europe: Recall: ß = -0.56, $p < 0.0001$; Verbal Fluency: ß = -0.57, $p < 0.0001$; southern vs. northern Europe: Recall: ß = -0.97, $p < 0.0001$; Verbal Fluency: ß = -1.73, $p < 0.0001$). However, southern Europe experienced faster improvements in Recall (ß = 0.03, $p < 0.0001$) and Verbal Fluency (ß = 0.02, $p = 0.0009$) than northern Europe; in central Europe Recall and Verbal Fluency also improved more quickly than in northern Europe (Recall: ß = 0.07, $p < 0.0001$; Verbal Fluency: ß = 0.02, $p = 0.0006$).

Education: In comparison to those with relative low levels of education, people with middle and higher levels of education had higher cognitive function (Middle vs. Low educational levels: Recall: ß = 0.65, $p < 0.0001$; Verbal Fluency: ß = 0.61, $p < 0.0001$; High vs. Low educational level: Recall: ß = 1.18, $p < 0.0001$; Verbal Fluency: ß = 1.22, $p < 0.0001$). Nevertheless, those with lower levels of education

Fig. 1: Bar chart for mean values of cognitive function with 95 percent confidence interval by region and survey year



Source: Own calculations, based on data from SHARE

Tab. 2: Overall models: Association of the cognitive function and time after controlling for gender, region, education, their interactions, and potential confounders in SHARE by GEE models[1]

	Recall	Verbal Fluency
Intercept	7.14***	7.84***
Gender (Female)[2]	0.44***	0.00
Survey year	0.02***	0.04***
Survey year*Gender (Female)[2]	0.00	0.01
Region (Central Europe)[3]	-0.56***	-0.57***
Region (Southern Europe)[3]	-0.97***	-1.73***
Survey year * Region (Central Europe)[3]	0.07***	0.02***
Survey year * Region (Southern Europe)[3]	0.03***	0.02***
Adjusted educational level (Middle)[4]	0.65***	0.61***
Adjusted educational level (High)[4]	1.18***	1.22***
Survey year * Adjusted educational level (Middle)[4]	-0.01***	-0.01
Survey year * Adjusted educational level (High)[4]	0.00	-0.02***
Age	-0.05***	-0.04***
Participate in SHARE-survey for the 1st time	-0.18***	-0.13***

1 *** p<=0.01; ** p<=0.05; *p<=0.1.

2 Male is the reference group for gender.

3 Regions: Southern Europe: Italy, Spain; Central Europe: Austria, Belgium, Czech Republic, France, Germany, Switzerland; Northern Europe: Denmark, Sweden (reference group).

4 Adjusted educational level: low: lowest-Q1 (reference group); Middle: Q1-Q3; High: Q3-highest.

Source: Own calculations, based on data from SHARE

improved their Recall faster than those with middle educational levels did (ß = -0.01, p = 0.005), and improved their Verbal Fluency more quickly than the highly-educated (ß = -0.02, p = 0.006).

The models are stratified by regions in Table 3 (Columns I and IV), permitting us to study the differences in regional time trends. The models reveal that cognitive function improved significantly in southern and central Europe (southern Europe: Recall: ß = 0.08, p < 0.0001; Verbal fluency: ß = 0.07, p < 0.0001; central Europe: Recall: ß = 0.09, p < 0.0001; Verbal fluency: ß = 0.06, p < 0.0001), whereas in northern Europe Recall has stagnated (ß = -0.02, p = 0.145) and Verbal Fluency improved somewhat, but not statistically significantly according to a significance level of 0.05 (ß = 0.02, p = 0.066). Moreover, in southern Europe, the interaction of time-by-gender showed that males tended to benefit more from improving cognitive function than females (Recall: ß = -0.02, p = 0.003; Verbal fluency: ß = -0.01, p = 0.081). Additionally, in southern and central Europe, those with lower education levels tended to improve their cognitive function faster than the other educational groups, as most of the coefficients for the time-by-education interaction

Tab. 3: Stratification analyses: Association of cognitive function and time in SHARE by GEE models, stratified by region, and further stratified by gender[1]

	Recall			Verbal Fluency		
	Overall (I)	Female (II)	Male (III)	Overall (IV)	Female (V)	Male (VI)
Southern Europe[2]						
Intercept	5.67***	6.22***	5.32***	5.55***	5.66***	5.25***
Middle Education[3]	1.01***	0.95***	1.06***	0.58***	0.61***	0.55***
High Education[3]	1.69***	1.71***	1.69***	1.00***	0.94***	1.04***
Survey year	0.08***	0.05***	0.09***	0.07***	0.05***	0.07***
Survey year * Middle Education[3]	-0.03***	-0.02*	-0.04***	-0.01	0.00	-0.01
Survey year * High Education[3]	-0.05***	-0.04**	-0.07***	0.00	0.01	-0.02
Gender (Female)[4]	0.27***			-0.13**		
Survey year * Gender (Female)[4]	-0.02***			-0.01*		
Central Europe[2]						
Intercept	6.81***	7.31***	6.77***	7.30***	7.51***	7.10***
Middle Education[3]	0.54***	0.56***	0.50***	0.72***	0.71***	0.74***
High Education[3]	1.12***	1.12***	1.12***	1.41***	1.39***	1.43***
Survey year	0.09***	0.08***	0.10***	0.06***	0.07***	0.07***
Survey year * Middle Education[3]	-0.01**	-0.01	-0.02**	-0.01**	-0.01	-0.02**
Survey year * High Education[3]	0.00	0.00	-0.01	-0.03***	-0.02*	-0.05***
Gender (Female)[4]	0.46***			0.05		
Survey year * Gender (Female)[4]	0.00			0.01**		
Northern Europe[2]						
Intercept	7.01***	7.80***	6.74***	8.42***	8.99***	7.76***
Middle Education[3]	0.43***	0.40***	0.46***	0.41***	0.46***	0.36***
High Education[3]	0.78***	0.86***	0.67***	0.91***	0.91***	0.91***

Tab. 3: Continuation

	Recall			Verbal Fluency		
	Overall (I)	Female (II)	Male (III)	Overall (IV)	Female (V)	Male (VI)
Survey year	-0.02	0.00	-0.03**	0.02*	0.03*	0.02
Survey year * Middle Education[3]	0.02*	0.01	0.03*	0.01	0.00	0.01
Survey year * High Education[3]	0.04***	0.01	0.06***	0.02	0.02	0.01
Gender (Female)[4]	0.59***			0.01		
Survey year * Gender (Female)[4]	0.01			0.01		

1 *** p<=0.01; ** p<=0.05; *p<=0.1. Models are further adjusted by age and whether the subject participated in the SHARE survey for the first time.

2 Regions: Southern Europe: Italy, Spain; Central Europe: Austria, Belgium, Czech Republic, France, Germany, Switzerland; Northern Europe: Denmark, Sweden.

3 Adjusted educational level: low: lowest-Q1 (reference group); Middle: Q1-Q3; High: Q3-highest.

4 Male is the reference group for gender.

Source: Own calculations, based on data from SHARE

Tab. 4: Stratification analysis: Association of the cognitive function and time in SHARE by GEE models, stratified by region and education[1]

	Recall				Verbal Fluency			
	Overall[2]	Low Education[3]	Middle Education[3]	High Education[3]	Overall[2]	Low Education[3]	Middle Education[3]	High Education[3]
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Southern Europe[4]								
Intercept	5.67***	6.42***	5.87***	6.52***	5.55***	5.59***	5.60***	8.15***
Gender (Female)[5]	0.27***	0.27***	0.23**	0.35*	-0.13**	-0.16**	-0.04	-0.24
Survey year	0.08***	0.08***	0.04***	0.02	0.07***	0.07***	0.05***	0.05***
Survey year * Gender[5]	-0.02***	-0.03***	-0.01	-0.01	-0.01*	-0.02**	-0.01	0.00
Middle Education[3]	1.01***				0.58***			
High Education[3]	1.69***				1.00***			
Survey year * Middle Education[3]	-0.03***				-0.01			
Survey year * High Education[3]	-0.05***				0.00			
Central Europe[4]								
Intercept	6.81***	7.57***	7.28***	7.75***	7.30***	7.44***	8.02***	8.71***
Gender (Female)[5]	0.46***	0.40***	0.49***	0.42***	0.05	0.06	0.05	0.05
Survey year	0.09***	0.10***	0.07***	0.08***	0.06***	0.07***	0.05***	0.03***
Survey year * Gender[5]	0.00	-0.01	0.00	0.01	0.01**	0.00	0.01*	0.02**
Middle Education[3]	0.54***				0.72***			
High Education[3]	1.12***				1.41***			
Survey year * Middle Education[3]	-0.01**				-0.01**			
Survey year * High Education[3]	0.00				-0.03***			
Northern Europe[4]								
Intercept	7.01***	7.16***	7.49***	7.61***	8.42***	9.60***	8.65***	9.07***
Gender (Female)[5]	0.59***	0.54***	0.47***	0.73***	0.01	-0.06	0.07	0.00
Survey year	-0.02	-0.03	0.00	0.03***	0.02*	0.03	0.04***	0.03***
Survey year * Gender[5]	0.01	0.03	0.02	-0.01	0.01	0.01	-0.01	0.02

Tab. 4: Continuation

	Recall				Verbal Fluency			
	Overall[2]	Low Education[3]	Middle Education[3]	High Education[3]	Overall[2]	Low Education[3]	Middle Education[3]	High Education[3]
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Middle Education[3]	0.43***				0.41***			
High Education[3]	0.78***				0.91***			
Survey year * Middle Education[3]	0.02*				0.01			
Survey year * High Education[3]	0.04***				0.02			

1 *** p<=0.01; ** p<=0.05; *p<=0.1. Models are further adjusted by age and whether the subject participated in the SHARE survey for the first time.

2 The overall model is the same as that in the Table 3. It is listed here again for easier comparison with other models.

3 Adjusted educational level: low: lowest-Q1 (reference group); Middle: Q1-Q3; High: Q3-highest.

4 Region: Southern Europe: Italy, Spain; Central Europe: Austria, Belgium, Czech Republic, France, Germany, Switzerland; Northern Europe: Denmark, Sweden.

5 Male is the reference group for gender.

Source: Own calculations, based on data from SHARE

were statistically significantly negative values, and none of these coefficients were statistically significantly positive values.

Further stratification analysis by region and education, shown in Table 4, confirmed a statistically significant interaction of time and gender favoring males with lower education levels in southern Europe (Table 4). (Column II, interaction time-by-gender for Recall: ß = -0.03, p = 0.002; Column VI, for Verbal fluency: ß = -0.02, p = 0.039).

The sensitivity analysis regarding the correlation structures (autoregressive, exchangeable, and independent correlation structures) resulted in consistent parameter estimations and inference p-values, as well as similar goodness of fit statistics (QICs). Results remained stable when the data of Wave 7 was included, despite a large number of missing values for Verbal Fluency. The sensitivity analysis using the conventional classification of education by ISCED produced similar results, but was not able to show the interaction of survey year and educational level consistently (data not shown).

4 Discussion

This study has three important results. First, cognitive function among 55-69-year-olds improved significantly from 2006 to 2015 in southern and central Europe, whereas it did not in northern Europe, although there was already a generally higher level in northern Europe to begin with. Thus, the gap between European regions is getting smaller. Second, in southern and central Europe, the group with relative low education, starting from the lowest level of cognitive function, tended to improve its cognitive functions more quickly than the middle and higher educational groups did. Thus, the gap between the relative low educational group and other educational groups is growing smaller. Third, among those with lower education in southern Europe, males improved their cognitive functions more quickly than females. More generally, in southern Europe, males seemed to benefit more than females in terms of improvement of cognitive function after controlling for education.

The disparity of regions, education, and genders over time may be explained by the threshold theory, as *Lyketsos et al*. tried to interpret the benefit of education for preventing cognitive decline in adulthood (i.e. beyond a certain "dose" of education, such as 8 years of schooling, additional years of education are no longer associated with less cognitive decline) (*Lenehan et al.* 2015; *Lyketsos et al.* 1999). Once the biological limits or environmental threshold on the improvement of cognitive function are reached or approaching, gains of cognitive ability might arrive at or get close to saturation and the improvements may yield diminishing returns, cease, or even reverse (*Weede* 2006; *Rindermann* 2008; *Pietschnig/Voracek* 2015; *Dutton et al.* 2016). In other words, the "success of success" or "failure of success" hypotheses alone may not explain the complete picture of time trends in cognitive function.

4.1 Regional disparities

The findings of this study suggest that 55-69-year-old adults in southern and central Europe stay at the Flynn effect phase, whereas the same age group in northern Europe stays at the anti-Flynn effect phase. *Flynn et al.* have summarized that some Scandinavian nations had robust intelligence gains in the twentieth century but peaked around 1990 and may have gone into mild decline since then (*Flynn* 2012). If we look at the trends in cognitive function dynamically, the Flynn effect in southern and central Europe indicates that these countries may have the potential for further improvement on cognitive function from one generation to the next, whereas the anti-effect in northern Europe suggests that these countries may have arrived at or be approaching the maximum plateau. A recent study showed improvements in cognitive function for those aged 50+ in all European regions (*Ahrenfeldt et al.* 2018). However, more closely examining those aged 55-69 in that study, southern and central Europeans had considerable improvements of cognitive function, whereas northern Europeans didn't (*Ahrenfeldt et al.* 2018). The mortality selection and different survival patterns for the oldest among the old (*Hülür et al.* 2013; *Gerstorf et al*. 2015) may explain the inconsistency between the present study and theirs. Furthermore, the finding of the present study is consistent with some previous studies on trends in cognitive function (*Pietschnig/Voracek* 2015; *Sundet et al.* 2004), but inconsistent with others (*Dutton/Lynn* 2015; *Weber et al.* 2017). The inconsistency may result from the age groups of the samples, the measures and analysis of cognitive function, and other potential influencing factors. Nonetheless, a major strength of the present study is that it provides evidence from three European regions with internationally comparable data and approaches.

Cognitive health is a key prerequisite for deciding the age at which people retire, although the decision of when to retire is complex and often based on many factors including macroeconomic, family, work-related, and individual factors (*Fisher et al.* 2016, 2017). This study indicates that increases of the retirement age may be reasonable in southern and central European countries from the perspective of cognitive health.

4.2 Educational disparities

A threshold for the cognitive health benefits of education may explain the association between education and the rates of cognitive change. According to a review paper published in 2000, the majority of the studies between 1985 and 1999 reported protective effects of education on the rate of cognitive decline (*Anstey/Christensen* 2000). In contrast, another review paper published in 2015 indicated that the majority of the studies from 2000 to 2015 reported no such protective effects (*Lenehan et al.* 2015). The beneficial impact of education on cognitive decline may no longer be observable as education levels extend beyond a certain threshold, such as an eight-year threshold (*Lyketsos et al.* 1999; *Lenehan et al.* 2015). Having eight years or less of formal education was reported to be associated with greater cognitive decline. However, having nine years of education or more was unrelated to any further reduction of cognitive decline (*Lyketsos et al.* 1999).

In line with this threshold explanation, this study indicates that most benefits of the Flynn effect in those with the least education are probably due to the fact that those people with the lowest education levels had the lowest baseline values for cognitive function, and these remained lower than the threshold throughout the analysis period in southern and central Europe. Consequently, those with low education in these regions have disproportionally improved their cognitive function over time. On the other hand, this was not observed in northern Europe. A possible explanation is that the majority of the northern Europeans attained the maximum cognitive reserve capacity with increasing levels of education as the norm (*Lenehan et al*. 2015).

Interestingly, previous studies have revealed that school reform in England led to improvements in old-age memory of people with less education (*Banks/Mazzonna* 2012). Other studies also found that the early gains of the Flynn effect in Denmark and Norway were primarily at the low end of the cognitive test score distributions, which were attributed to the developments of educational system (e.g. improved pre-school care, starting school earlier and leaving later, and improved special education for physically or mentally disabled children) (*Teasdale/Owen* 2005; *Sundet et al.* 2004). Support for active aging was recommended to target less-educated and other disadvantaged groups in Germany (*Pavlova/Silbereisen* 2012). In a review paper, *Lenehan et al.* suggested that less-educated groups were an under-researched subgroup for the effect of education on the rate of cognitive function, and they assumed that this subgroup could benefit most from education-based intervention approaches (*Lenehan et al.* 2015).

Consistently, the findings of this study provide further evidence that in the context of limited resources, it may be worth prioritizing those with relative low educational levels when it comes to education-based intervention approaches in southern and central Europe. This would also hold true for developing countries, since a continuing Flynn effect has been observed or has begun to be observed in the developing world (*Flynn* 2012; *Nisbett et al.* 2012).

4.3 Gender disparities

An explanation for the greater improvement of cognitive function in males in southern Europe may be the larger biological vulnerability, variability, and flexibility of cognitive function for males (*Halpern* 2012). Some types of mental retardation are X-linked and are therefore more prevalent in males (*Halpern* 2012). Moreover, previous studies have found that males show greater age-related decline than females, independent of whether males or females outperform for the parameter of cognitive function (*Maylor et al.* 2007). In other words, 55-69-year-old males may have lower baselines, and a larger potential to improve, particularly in those groups in southern Europe with the lowest educational levels.

Banks et al. found that school reform in England improved executive function at old age only for males with less education (*Banks/Mazzonna* 2012). Schneeweis et al. similarly observed that the educational reforms in Europe had stronger protective effects on cognitive function and decline for males (*Schneeweis et al.* 2014). Both of these studies explained this as the positive financial returns and prolonged labor force participation only for males from the educational reforms (*Banks/Mazzonna* 2012; *Schneeweis et al.* 2014). This may also explain the present study's finding of greater increases in cognitive function favoring males in the group with lower education in southern Europe. Additionally, this study's analysis of education gives further insights into the regional gender differences based on *Weber's* papers (*Weber et al.* 2017). The larger gain for males in southern Europe which was observed by Weber et al. (*Weber et al.* 2017) may be attributed to the improvement in the lower educational group.

4.4 A more complete picture of disparity by region, gender, and education

On the whole, threshold theory may be able to explain the various rates of cognitive improvement throughout all Europe by region, education, and gender. Southern and central Europeans, people with lower education, and males may have larger potentials to improve their cognitive function than the corresponding comparison groups, thus also showing quicker improvements in the data. Conversely, the cognitive function of the corresponding comparison groups may be closer to biological limits (saturation), hence improvements happen more slowly, if at all. In addition, threshold theory may also cover other factors, such as living conditions and heathy behaviors, which may influence cognitive improvements over time as well. Further research is needed to investigate and further support this explanation.

4.5 Strengths and limitations

One of the major strengths of this study is that it investigated 55-69-year-olds, whose cognitive development over time is important for sustained productive work in old age and pension policies, but who have relatively rarely been investigated to date. Second, this study used SHARE datasets with large sample sizes covering numerous European countries with harmonized design and data (*Börsch-Supan et al.* 2013). Third, this study used a definition of education by quantiles, which decreased selection bias and increased comparability. Fourth, this study used the data of Waves 2, 4, 5 and 6, and considered the correlation of the same subject in its modelling strategy. This longitudinal approach can show a more precise picture than cross-sectional studies or studies with only two time points (*Lenehan et al.* 2015). Fifth, recall and verbal fluency are performance-based measures, thus avoiding the biases which may occur in self-reported measures.

This study also has limitations. First, the retest effect may influence the cognitive parameters (*Salthouse* 2010a). In order to minimize it, an adjustment for first-time participation was included in the statistical models. Second, the two parameters only partially cover the overall concept of cognitive function. Further studies are needed to investigate other parameters of cognitive function. However, our assessments of recall and verbal fluency can be regarded as two key dimensions of intelligence, fluid intelligence/working memory, and crystallized intelligence/knowledge (*Arpino/Bordone* 2014; *Salthouse* 2006; *Weber et al.* 2017). Third, as an observational study without a causal identification strategy, no causal relationship can be provided. Moreover, it is difficult to clearly distinguish the aging and cohort effects. Consideration must be taken when interpreting the results. Fourth, the overall effect sizes seem to be small. However, due to the division of values in our parameters for a comparable range, the true effect size might be larger than it seems to be. Moreover, the difficulty of setting criteria of clinical meaningfulness for the effect size is a general limitation in research using cognitive tests (*Halpern* 2012). Fifth, the relative rank of educational attainment is used to minimize the selection bias of educational groups over time. However, it is difficult to use another golden standard measurement to validate this approach. A sensitivity analysis using conventional classification of educational attainment was conducted to investigate the differences and similarities between the two operationalizations of education.

4.6 Conclusions

Older adults close to retirement age (55-69-year-olds) in southern and central Europe improved their cognitive function significantly from 2006 to 2015, whereas adults of the same age in northern Europe did not. Those with relative low levels of education in southern and central Europe improved their cognitive function most rapidly. Among those with lower education in southern Europe, males improved in cognitive function more quickly than females did. These results can be interpreted in line with threshold theory. Despite the complexity of the decisions about the retirement age, future increases of the retirement age may be reasonable in southern and central European countries from the perspective of cognitive function. It also may be worth prioritizing people with lower levels of formal education when it comes to education-based intervention approaches.

Acknowledgements

I would like to express my sincere thanks to Gabriele Doblhammer for her very valuable comments on this manuscript, and Renee Lueskow for her English editing service. This paper uses data from SHARE Waves 2, 4, 5, and 6, see *Börsch-Supan et al.* (2013) for methodological details. The SHARE data collection has been funded by the European Commission, DG RTD through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193, COMPARE: CIT5-CT-2005-028857, SHARELIFE: CIT4-CT-2006-028812), FP7 (SHARE-PREP: GA N°211909, SHARE-LEAP: GA N°227822, SHARE M4: GA N°261982, DASISH: GA N°283646) and Horizon 2020 (SHARE-DEV3: GA N°676536, SHARE-COHESION: GA N°870628, SERISS: GA N°654221, SSHOC: GA N°823782, SHARE-COVID19: GA N°101015924) and by DG Employment, Social Affairs & Inclusion through VS 2015/0195, VS 2016/0135, VS 2018/0285, VS 2019/0332, and VS 2020/0313. Additional funding from the German

Ministry of Education and Research, the Max Planck Society for the Advancement of Science, the U.S. National Institute on Aging (U01_AG09740-13S2, P01_AG005842, P01_AG08291, P30_AG12815, R21_AG025169, Y1-AG-4553-01, IAG_BSR06-11, OGHA_04-064, HHSN271201300071C, RAG052527A) and from various national funding sources is gratefully acknowledged (see www.share-project.org).

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Date of submission: 05.02.2020 *Date of acceptance: 05.11.2021*

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Comparative Population Studies

www.comparativepopulationstudies.de

ISSN: 1869-8980 (Print) – 1869-8999 (Internet)

Published by
Federal Institute for Population Research (BiB)
D-65180 Wiesbaden / Germany

Managing Publisher
Dr. Nikola Sander