JECH Online First, published on February 9, 2018 as 10.1136/jech-2017-209979

Trends and determinants of the Flynn effect in cognitive functioning among older individuals in 10 European countries

Philipp Hessel,[1] Jonas M Kinge,[2,3] Vegard Skirbekk,[4,5] Ursula M Staudinger[5]

► Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/jech-2017-209979).

[1]Alberto Lleras Camargo School of Government, University of the Andes, Bogotá, Colombia
[2]Departmet of Health Management and Health Economics, University of Oslo, Oslo, Norway
[3]Department of Epidemiology, Norwegian Institute of Public Health, Oslo, Norway
[4]Centre for Fertility and Health, Norwegian Institute of Public Health, Oslo, Norway
[5]Robert N. Butler Aging Center, Columbia University, Mailman School of Public Health, New York City, United States

Correspondence to
Philipp Hessel, Alberto Lleras Camargo School of Government, University of the Andes, Bogotá 111711, Colombia; p.hessel@uniandes.edu.co

Received 13 September 2017
Revised 18 January 2018
Accepted 24 January 2018

To cite: Hessel P, Kinge JM, Skirbekk V, *et al*. *J Epidemiol Community Health* Epub ahead of print: [*please include* Day Month Year]. doi:10.1136/jech-2017-209979

ABSTRACT

Background Although cognitive performance levels in old age have increased in most countries, recent evidence documents a slowing down or even decline in cohort gains in highly developed countries. The aim of this study was to assess trends and determinants in secular cohort gains in cognitive functioning among older individuals and whether cohort gains are levelling off in most advanced countries.

Methods Data for individuals aged between 50 and 84 years from the Survey of Health, Ageing and Retirement in Europe in 10 European countries between 2004 and 2013 (n=92 739) were used to assess country and age-specific changes in immediate word recall. Multivariate random intercept models were used to assess associations between secular cohort changes in immediate word recall, initial performance levels and changes in country-level socio-demographic characteristics.

Results Performance in immediate word recall improved in all countries between 2004 and 2013 (from 4.40 to 5.08 words, P<0.05). However, secular cohort gains were significantly smaller in countries with initially higher performance levels (coeff.=−0.554, 95% CI −0.682 to −0.426). Changes in socio-demographic and health conditions, including decreases in cardiovascular disease, physical activity and educational achievement, were associated with larger secular cohort gains.

Conclusions Results may either reflect that some countries are approaching the limits of cognitive plasticity, are slowing in their progress or that societal structures have not yet been optimised to improve cognitive abilities in midlife and beyond, or a combination of these interpretations.

INTRODUCTION

Given current age-specific distributions of disease and functional capacities, population ageing represents a major challenge to health systems and the economy. While poor cognitive functioning at older ages is a particular concern, a key question is whether successive cohorts will continue to be cognitively healthier than their predecessors.[1] If the age of onset of cognitive impairment can be postponed at a higher speed than increases in life expectancy, future cohorts of older individuals may be able to be productive for a longer time and require fewer care resources as current cohorts.[2] In contrast, if cognitive abilities do not increase at least at the speed of increases in life expectancy, the sustainability of social security systems would be severely affected in the face of an increasing share of older individuals.

Indeed, a large body of literature that goes back to 1930[3 4] has documented that later-born cohorts performed better at various cognitive measures from the early 20th century until the early 21st century—a phenomena also known as the Flynn effect.[5–10] Originally, the Flynn effect was used to describe such cohort improvements for cognitive functioning in young adulthood. Only recently has it been investigated with adults after age 50.[7] However, to date no systematic comparative evidence exists that allows to determine whether secular cohort gains in cognitive functioning in later life exist in different countries to the same degree and what affects such changes or the lack thereof.

On the one hand, several pieces of evidence suggest that secular cohort gains in cognition are likely to continue. For example, improvements in educational attainment of later-born cohorts, less likelihood of insufficient nutrition,[11] reductions in tobacco use in many countries[12] and more complex and mentally stimulating work experiences have been found to increase cognitive performance along cohort lines.[8] Evidence also suggests that cognitive health has improved well into the second half of life,[13] including a decline in the prevalence of dementia in Europe and the USA.[14 15]

On the other hand, secular cohort gains in cognitive functioning may differ between countries or even level off. Thus, stalling or decreasing levels of functioning among older adults have been identified in highly developed countries such as Norway, Finland and France in recent years.[16–18] This stagnation or even decline has also been reported for cognitive abilities among younger cohorts.[19] Different reasons for this trend have been discussed such as the levelling off in the extension of participation in tertiary education in some countries,[20] increasing levels of obesity and overweight which may negatively affecting functional capacities, such as cognitive performance through elevated risks of cardiovascular disease (CVD) and diabetes,[21] or relatedly, the spreading of a sedentary lifestyle may negatively affect cognition.[22] In addition, classical experimental work on the plasticity of cognitive performance has demonstrated that there are most likely biology-related limits to its modifiability which are reached more quickly in later life.[23]

Using longitudinal data of 10 European countries from the Survey of Health, Ageing and

Retirement in Europe (SHARE) from 2004 to 2013, the aim of this study was to investigate trends and determinants of secular cohort changes in cognitive performance among older individuals. Specifically, we investigated whether secular cohort gains in cognitive performance between 2004 and 2013 varied systematically between countries according to their initial performance levels and whether levels and changes in socio-demographic conditions of countries might mediate such differences.

Individual-level characteristics such as higher education, healthier behaviours and labour force participation have been shown to be positively associated with cognitive functioning.[24 25] According to the lifespan perspective,[26] positive developments in those dimensions are prone to help making better use of the developmental cognitive potential than in individuals that are lacking such resources. Nevertheless, evidence from individual-level studies does not allow to make predictions about future trends in cognitive functioning as it does not take into account secular trends in the underlying behavioural factors, for example, trends in educational or labour force participation. A cohort perspective therefore can add to our understanding of trends and determinants of cognitive functioning as it takes into account both the association between various socio-demographic characteristics and cognitive functioning, as well as trends in the socio-demographic characteristics itself.

METHODS

Data sources

Data for this study came from SHARE.[27] Data are representative of the non-institutionalised population aged ≥50 years in each participating country. For the purpose of this analysis, we used data from the first (2004/2005) and fifth wave (2013), enabling us to analyse secular cohort changes in cognitive performance over nearly a decade in the 10 countries participating in both waves (Austria, Belgium, Denmark, France, Germany, the Netherlands, Sweden, and Switzerland, Italy and Spain). In addition to SHARE, we also used data from the European Union's statistical office (Eurostat) (see table 1). Out of a total of 97 213 age-eligible observations in waves 1 and 5, 4474 observations were omitted due to missing data on at least one of the covariates.

Measures

Cognitive functioning was measured by immediate word recall, an important predictor of cognitive impairment and dementia.[28] It was measured by the immediate 10-word recall test, consisting of the words butter, arm, letter, queen, ticket, grass, corner, stone, book and stick. To conduct the test, the list of words was read out to the participant in his or her language who was then asked to immediately recall the words. The respondents then had 60 s to recall as many words as he or she could remember.

To assess the extent to which other key societal trends are associated with secular cohort changes in immediate word recall, we selected covariates linked with cognitive performance such as educational levels, complex and mentally stimulating work experience,[8] caloric intake or body mass index (BMI) and sedentary lifestyles,[22] prevalence of CVD[29] and overall levels of economic development.[30] We included the following individual-level characteristics: (a) overweight defined as a BMI of ≥25; (b) prevalence of CVD indexed by an item that asked whether a respondent had suffered a stroke, heart attack or cerebral vascular disease; (c) engagement in physical activities, measured by asking respondents whether they ever engage in activities that require a low or moderate level of energy; (d) educational achievement in terms of highest educational level obtained; (e) economic activity rates; as well as (f) gross domestic product (GDP) per capita as a country-level indicator. These measures were calculated for 2004/2005 and 2013 in order to take into account possible changes in these covariates.

Table 1 Overview of variables used in study

Variable	Definition	Source
Immediate word recall	Number of words correctly recalled in the 10 words list learning test	SHARE
Overweight	Percentage of individuals with body mass index ≥25	SHARE
Cardiovascular disease	Percentage of individuals reporting to ever been diagnosed with a heart attack, stroke or cerebral vascular disease	SHARE
Physically inactive	Percentage of individuals reporting to never or hardly ever engaging in activities that require a low or moderate level of energy such as gardening, cleaning the car or doing a walk	SHARE
Economic activity rate	Percentage of individuals reporting to be currently employed or self-employed compared with being either unemployed, retired, permanently sick or disabled or home maker	SHARE
Education	Percentage of individuals reporting primary, secondary or tertiary education as their highest degree obtained according to the International Standard Classification of Education	SHARE
GDP	GDP per capita in euro in constant prices	Eurostat

All variables except for GDP were calculated by country, sex and 5-year age group strata for ages 50–84 using individual-level data from the SHARE.
GDP, gross domestic product; SHARE, Survey of Health, Ageing and Retirement in Europe.

To assess trends and determinants of secular cohort changes in immediate word recall, based on individual-level data from SHARE, we calculated means by country, sex and 5-year age groups between ages 50 and 84 separately for waves 1 (2004/2005) and 5 (2013) for all variables using calibrated survey weights. To derive measures of secular cohort changes within each country, sex and 5-year age group stratum, we subtracted the means in 2013 from those in 2004/2005. For GDP per capita, we used the country-specific and year-specific values derived from Eurostat.

Statistical analysis

Changes in immediate word recall over time were compared for each country, sex and age group. Multivariate analyses of the association between change in immediate word recall between 2004/2005 and 2013, initial performance levels in 2004/2005 and covariates were conducted using linear regression models including random-intercepts for country, sex and age group to allow for differences in cognitive performance and socio-demographic characteristics between countries, sexes and age groups.[31] The model can be formally written as

$$Y_{csa} = Y_{csat} - Y_{csat-1} = \beta_0 + \beta_1 Y_{csat-1} + \beta_2 \boldsymbol{X}_{csat-1} + \beta_3 \left(\boldsymbol{X}_{csat} - \boldsymbol{X}_{csat-1}\right) + \mu_{csa} + \varepsilon_{csat}$$

where Y_{csa} represents the change in immediate word recall between time t–1 (2004/2005) and t (2013) within country c, sex s and age group a. β_0 represents the mean in immediate word

recall in the population, Y_{csat-1} represents immediate word recall within a country, sex and age group strata at time t–1 (2004/2005). $\boldsymbol{X}_{csat-1}$ is a vector of country, sex and age-specific covariates, with the exception of GDP which is a country-level indicator, at time t–1 . 2004/2005). $\boldsymbol{X}_{csat} - \boldsymbol{X}_{csat-1}$ represents the change in the vector of covariates within each country, sex and age group strata between t–1 and t. The model thus controls for levels of covariates in 2004/2005 as well as their change between 2004/2005 and 2013. Finally, μ_{csa} is a random intercept for each country, sex and age group, while ε_{csat} is the error term.[31]

RESULTS

Descriptive statistics averaging across ages 50–84 and sexes are shown in table 2. Average performance in the immediate word recall test at ages 50–84 improved in all countries between 2004 and 2013 with an average increase of 0.68 words recalled. Largest improvements among occurred in France (0.98), Italy (0.92) and Spain (0.84). In contrast, average performance among men and women increased least in Denmark (0.51), Germany (0.25) and Sweden (0.46). Educational levels as well as economic activity rates and GDP increased in all countries even though to different degrees. Trends in prevalence of CVD, overweight and physical inactivity varied between countries. Online supplementary appendix table 1 shows the distribution of the performance in the word recall test for each country.

Figure 1 shows secular changes in immediate word recall between 2004/2005 and 2013 within each 5-year age group and separately for men and women, comparing the three countries with the highest average levels of immediate word recall in 2004 (Germany, Denmark and Switzerland) with the three countries having the lowest average levels (Italy, Spain and France). As expected, changes in average immediate word recall were significantly larger among countries with initially lower performance levels across all age groups ($P<0.05$). For example, between 2004/2005 and 2013 average scores in the 10-word recall test among men aged 50–54 improved by 0.81 points (from 4.18 to 4.99) in initially lowest performing countries, but only improved by 0.39 points (from 4.97 to 5.36) in initially highest performing countries. Among women, over the same period, average scores in the immediate word recall test improved by 0.51 points (from 5.24 to 5.75) in the highest performing countries and by 0.86 points (from 4.51 to 5.37) in the initially lowest performing countries. By 2013, average levels of immediate word recall among the initially lowest performing countries improved up to a level similar or above average levels in highest performing countries in 2004.

Figure 2 shows secular changes in immediate word recall between 2004 and 2013 relative to average performance in 2004. As indicated by the regression lines, within all age groups there is a negative association between average performance in 2004 and secular cohort change in cognitive functioning over time. Hence, age groups performing better in the immediate word recall test in 2004 showed smaller gains over time. We used linear multilevel models with random intercepts for country, sex and age group to assess the association between levels of immediate word recall in 2004 with secular cohort change over the period 2004–2013. As table 3 shows, average immediate word recall performance in 2004 was significantly negatively associated with secular cohort change over time. A 1-word higher average performance in the 10-word recall test in 2004 was associated with a 0.554-word (95% CI −0.682 to −0.426) smaller change between 2004 and 2013.

Table 2 Descriptive statistics

	Immediate word recall (mean)		Overweight (%)		Cardiovascular disease (%)		Physically inactive (%)		Labour force participation rate (%)		Primary educated (%)		Secondary educated (%)		Tertiary educated (%)		GDP (per capita)	
	2004	Change 2004–2013	2004	Change 2004–2013	2004	Change 2004–2013	2004	Change 2004–2013	2004	Change 2004–2013	2004	Change 2004–2013	2004	Change 2004–2013	2004	Change 2004–2013	2004	Change 2004–2013
Average	4.41	0.68	55.07	0.66	18.63	−3.09	15.18	−1.42	22.81	4.27	35.42	−9.11	48.42	0.47	16.16	8.63	30500	8100
Austria	4.86	0.74	57.02	1.98	17.43	−0.76	14.95	−0.41	17.79	5.86	22.02	−9.30	59.16	7.89	18.82	1.42	29600	8900
Belgium	4.35	0.78	55.77	−0.05	21.86	−6.26	19.01	−2.93	16.29	5.13	33.28	−9.39	45.19	−0.05	21.52	9.45	28700	7200
Denmark	4.87	0.51	49.55	1.97	17.49	−1.10	14.61	−3.96	28.37	1.06	24.22	−6.04	49.93	−3.44	25.85	9.48	37400	8800
France	4.01	0.98	54.34	2.43	23.54	−6.95	19.09	−4.88	19.53	4.36	51.45	−13.56	32.29	6.38	16.25	7.18	27300	4900
Germany	4.95	0.25	57.27	4.72	18.38	0.51	12.08	0.31	23.87	5.94	0.91	1.85	75.38	−5.11	23.71	3.26	27900	8100
Italy	3.48	0.92	57.57	−4.03	16.92	−2.79	24.12	0.47	17.80	4.35	65.12	−11.08	30.02	6.91	4.86	4.17	25000	1500
The Netherlands	4.67	0.59	56.50	−1.00	18.97	−2.51	13.56	−2.92	22.39	6.19	22.73	−6.63	60.18	−0.96	17.09	7.59	32200	7100
Spain	3.17	0.84	60.78	−1.59	14.09	1.20	19.05	0.87	20.32	3.73	68.14	−6.49	23.98	4.38	7.87	2.11	20100	2300
Sweden	4.71	0.46	52.21	0.50	24.04	−8.27	10.82	−4.29	31.16	3.01	43.09	−19.63	38.45	7.22	18.46	12.41	34200	10200
Switzerland	5.00	0.69	49.72	1.71	13.58	−4.01	4.50	3.55	30.54	3.05	23.21	−10.78	69.64	−18.50	7.15	29.28	42600	22000

Except for GDP all variables were calculated using data from the Survey of Health, Ageing and Retirement in Europe. While the information in this table shows means by country for all ages between 50 and 84 combined, for the statistical analyses information for all variables, except for GDP, was derived for each country and 5-year age-group strata separately.
GDP, gross domestic product.

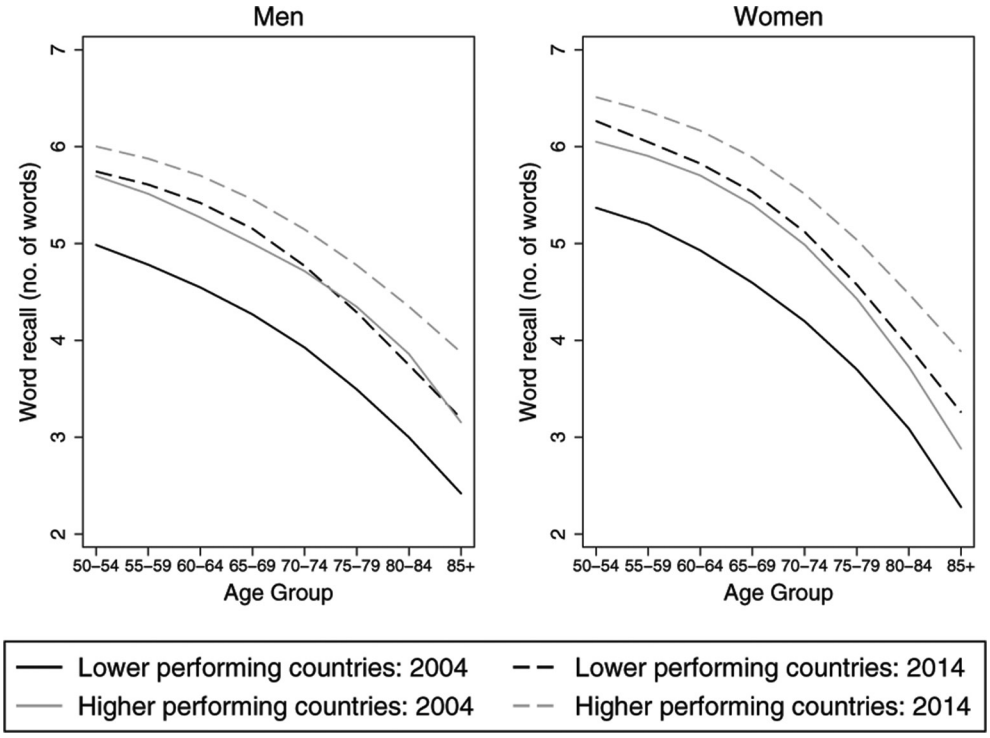

Figure 1 Changes in immediate word recall at ages 50+ among men and women in 10 European countries between 2004/2005 and 2013 according to performance levels in 2004/2005. The figure compares smoothed means in immediate word recall scores for 5-year age groups between ages 50 and 84 in 2004/2005 and 2013 separately for the three highest and three lowest performing countries in 2004/2005. Estimates shown in the figure were derived using a linear smoothing interpolation.

Neither prevalence of overweight in 2004 nor changes between 2004 and 2013 were associated with changes in immediate word recall. Increases in prevalence of CVD were associated with significantly smaller cohort gains in immediate word recall. Prevalence of physical inactivity in 2004 as well as increases in inactivity over time were significantly associated with lower average changes in immediate word recall for both sexes. Although countries with a higher share of individuals aged 50–84 participating in the labour market showed higher average levels of immediate word recall, increases in the former were not significantly associated with improvements in immediate word recall. Increases in the share of individuals with secondary as well as tertiary education were significantly associated with cohort improvements in immediate word recall. There was no significant association between levels or change in GDP and changes in immediate word recall.

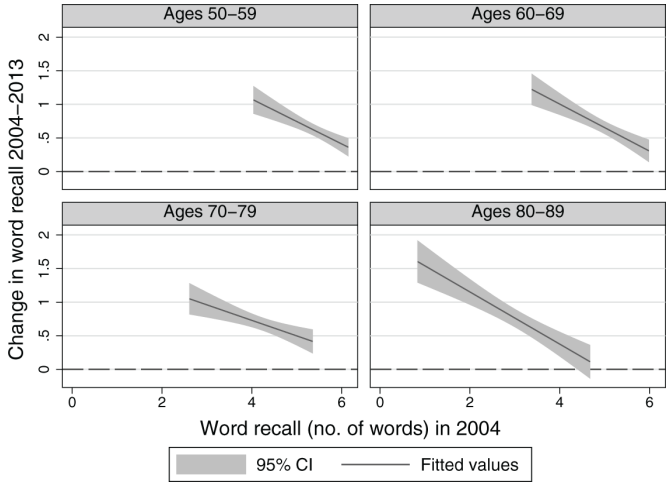

Figure 2 Changes in immediate word recall at ages 50+ among men and women in 10 European countries between 2004/2005 and 2013 relative to performance levels in 2004/2005. The figure shows the change in mean immediate word recall in a given age group and country in relationship to the change within the same age group and country between 2004/2005 and 2013.

The association between levels of immediate word recall in 2004 and secular cohort change over the period 2004–2013 was stronger among men than among women ($P<0.05$). However, no significant interaction existed between sex and any of the remaining covariates.

DISCUSSION

Summary

The major aim of this study was to investigate population-level trends and determinants in secular cohort gains in cognition using a sample of 10 European countries. Specifically, we investigated whether secular cohort gains in immediate word recall were slowing down in initially better performing countries compared with initially worse performing countries. Our findings show that cohort gains occurred in all countries. However, these gains were significantly greater in initially lower performing countries. Furthermore, our results suggest that decreases in the prevalence of CVD and physical inactivity as well as increases in educational achievement were positively associated with secular cohort gains in cognitive functioning.

Interpretation of findings

In line with studies demonstrating that later-born cohorts generally show higher levels of cognitive performance than their

Table 3 Multilevel model: determinants of secular cohort changes in immediate word recall at ages 50–84 in 10 European countries 2004–2013

	Change in average immediate word recall performance between 2004 and 2013 by country, sex and 5-year age groups		
Outcome	**Coefficient**	**95% CI**	**P value**
Immediate word recall: 2004	−0.554	−0.682 to −0.426	<0.05
Baseline levels: 2004			
Overweight (%)	0.002	−0.004 to −0.007	0.539
CVD (%)	−0.011	−0.019 to −0.003	<0.05
Physically inactive (%)	−0.027	−0.034 to −0.020	<0.05
Economic activity rate (%)	0.003	0.001 to −0.004	<0.05
Education (ref.: primary)			
Secondary (%)	0.004	0.000 to −0.008	<0.05
Tertiary (%)	−0.002	−0.009 to −0.004	0.464
GDP per capita (log)	−0.295	−1.047 to −0.456	0.441
Change: 2004–2013			
Overweight (%)	−0.003	−0.008 to −0.003	0.355
CVD (%)	−0.009	−0.018 to −0.001	<0.05
Physically inactive (%)	−0.023	−0.032 to −0.015	<0.05
Economic activity rate (%)	0.004	−0.001 to −0.009	0.151
Education (ref.: primary)			
Secondary (%)	0.006	0.003 to −0.009	<0.05
Tertiary (%)	0.006	0.002 to −0.010	<0.05
GDP per capita (log)	0.832	−0.797 to −2.460	0.317
Constant	6.112	−1.359 to −13.583	0.109
N		140	

Results are from a linear multilevel model including random intercepts for country, age group and sex. The dependent variable is the change in word recall between 2004/2005 and 2013 within each country, sex and age group strata. The regression coefficient for each covariate refers to the association between the latter and average change in the number of words on the 10-word recall test over time across all strata. Results are substantially similar when using fixed effects for country, sex and age groups instead of random effects, as well as when omitting indicators of baseline levels in 2004.
CVD, cardiovascular disease; GDP, gross domestic product.

predecessors,[7 8 32] all countries in our sample enjoyed secular cohort gains in cognitive functioning.

While the key factors contributing to secular improvements in cognitive functioning among younger cohorts have been educational expansions, improved hygiene as well as reduced infectious disease prevalence in younger adulthood,[7 32] this study demonstrated that increases in secondary education, reductions in CVD and physical inactivity were significantly associated with secular cohort improvements in cognitive functioning among older individuals.

There exists extensive evidence on all of these factors to protect cognitive functioning in later life. For example, higher levels of education and lower levels of CVD have been linked with reduced incidence of Alzheimer's dementia and bolstered cognitive functioning in later life.[25] Also, the importance of physical activity for healthy cognitive ageing has been confirmed by experimental work.[33]

Neither levels of economic development nor changes therein did affect changes in late-life cognitive performance between cohorts. Thus, it seems that economic conditions per se do not improve cognitive functioning but concrete activities that mediate such improvements.

Although cognitive performance at older ages improved in all countries, we found that countries with initially higher levels of cognition showed less gain or even stability across 10 years. Similarly, women changed more than men and also started from a lower level. One of the reasons why cognitive performance may be stalling at older ages in the originally higher performing countries may be the continued high prevalence of CVD in combination with lower mortality due to CVD,[34] raising the number of individuals who survived cardiovascular diseases but may suffer negative physical and cognitive consequences. Another reason why gains in cognitive performance have been larger in initially lower performing countries may be that those countries witnessed the largest relative reductions in the share of individuals with only primary education, considered one of the central drivers of the so-called Flynn effect.[8]

Furthermore, cohort gains in cognitive functioning may be stalling in higher performing countries because societal structures addressing midlife and beyond may have not yet been optimised to provide for rich physical, social and intellectual stimulation to the same degree as it has been accomplished for the first decades of life. For instance, lifelong-learning regimes need more systematic development and implementation across all levels of education. Patterns of economic activity and work settings need yet to be optimised with regard to the maintenance of cognitive health. Finally, the broad implementation of volunteering activities including proper training is yet to be accomplished, and certain subpopulations continue to be not represented in volunteering settings.[35]

Lastly, there are two additional mutually non-exclusive interpretations of our results that deserve consideration. The first is that we cannot rule out the possibility that cohort improvements in initially higher performing countries follow a slower pace that cannot be captured in the course of 10 years but may be observed after 20 years of societal change. Second, older cohorts in high-performing countries may indeed be approaching the biological limits of plasticity, that is, restrictions set by biological factors such as neurological and physiological constraints. Indeed, there is experimental evidence that supports this notion of limits of cognitive plasticity.[23]

Limitations

Despite several strengths of this study, a number of limitations should be acknowledged. Focusing on memory functioning as indicator of cognitive functioning may be considered a limitation as it covers only one facet of cognitive ageing, although a crucial one with regard to cognitive ageing.[36] The association between latent factors of episodic memory and indicators of fluid intelligence has been found to be substantive.[37] In this context, it is also important to note that a study using Estonian data showed that the Flynn effect—with the exception of numerical reasoning—pretty much generalised across different subtests of cognitive functioning.[38] Furthermore, cognitive test performances may be influenced by a 'ceiling effect'. Hence, it may be the case that individuals in the best performing countries were close to the upper boundaries of performance, that is, recalling all 10 words. However, even in the overall highest performing country Switzerland the mean number of words recalled was only 5.09, with merely around 3.5% of individuals correctly recalling 9 or 10 words. Thus, it is unlikely that

ceiling effects affected the results. Also, 'retest' or 'practice' effects (increased procedural knowledge, decreased test anxiety, shorter 'warm-up' phase) and selective attrition (poor performers may be more likely to drop out, which potentially could bias the results) may have compromised the findings of this panel study. In particular, initially lower performing individuals may have benefited disproportionally from practice effects. In our SHARE sample of wave 5 (2013), around 40% of individuals had already taken the immediate word recall test at a previous wave. Omitting this group from the analyses did not substantially affect the results.

CONCLUSIONS

Absolute differences in word recall among older adults across European countries have been decreasing. Our findings suggest that with increasing socioeconomic development among European countries cohort improvements in word recall are levelling off. Or at least they are slowing down in countries that have been enjoying higher levels of socioeconomic development for longer. Although we do not know yet whether the underlying factors of this trend are biological or sociostructural, or possibly a combination thereof, monitoring potential limits of the plasticity of ageing is important with regard to the social security and health system implications of population ageing.

What is already known on this subject?

- Studies based on single countries or regions therein have shown improvements in cognitive functioning and reductions in prevalence of dementia among later-born cohorts.
- Recent studies in some highly developed European countries have shown that secular cohort improvements in cognitive functioning have stopped to exist.
- No study has assessed whether countries may be approaching upper boundaries of cohort improvements in cognitive ageing and what determines cohort changes at later life.

What this study adds?

- Cognitive functioning levels have improved in all countries.
- Participation in education as well as physical activity positively contributed to cohort improvements.
- Largest improvements in cognitive functioning in the last decade were observed in countries with initially lower performance levels, while improvements in initially higher performing countries are significantly smaller or close to zero.
- To prevent stalling of improvements in cognitive functioning, societal structure structures may have to be optimised to allow older individuals to maximise participation in social, economic and physical activities.

Contributors VS had the idea for the study. UMS developed the conceptual framework. JMK did the initial analysis. PH performed the final analyses of the data and compiled the figures and tables. All authors interpreted the results and contributed to writing the final version of the manuscript.

Funding This paper uses data from SHARE waves 1 and 5 (DOIs: 10.6103/SHARE.w1.600, 10.6103/SHARE.w2.600, 10.6103/SHARE.w5.600). The SHARE data collection has been primarily funded by the European Commission through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193, COMPARE: CIT5-CT-2005-028857, SHARELIFE: CIT4-CT-2006-028812) and FP7 (SHARE-PREP: no. 211909, SHARE-LEAP: no. 227822, SHARE M4: N°261982). 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) and from various national funding sources is gratefully acknowledged (see http://www.share-project.org . This work was partly supported by the Research Council of Norway through its Centres of Excellence funding scheme, project number 262700 and through grant "The burden of obesity in Norway: morbidity, mortality,health service use, and productivity loss" project number 250335/F20. PH was supported by a David E Bell Fellowship from the Harvard Center for Population and Development Studies.

Patient consent Detail has been removed from this these case descriptions to ensure anonymity. The editors and reviewers have seen the detailed information available and are satisfied that the information backs up the case the authors are making.

Ethics approval The study uses publicly available survey data which were collected after obtaining ethical approval from national review boards and consent of participants.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement Additional data are available on the journal's homepage.

REFERENCES

1 Chatterji S, Byles J, Cutler D, *et al*. Health, functioning, and disability in older adults--present status and future implications. *Lancet* 2015;385:563–75.
2 Parker MG, Thorslund M. Health trends in the elderly population: getting better and getting worse. *Gerontologist* 2007;47:150–8.
3 Lynn R. What has caused the Flynn effect? Secular increases in the Development Quotients of infants. *Intelligence* 2009;37:16–24.
4 Runquist EA. Intelligence test scores and school marks in 1928 and 1933. *School & Society* 1936;43:301–4.
5 Wongupparaj P, Kumari V, Morris RG. A Cross-Temporal Meta-Analysis of Raven's Progressive Matrices: Age groups and developing versus developed countries. *Intelligence* 2015;49:1–9.
6 Karlsson P, Thorvaldsson V, Skoog I, *et al*. Birth cohort differences in fluid cognition in old age: comparisons of trends in levels and change trajectories over 30 years in three population-based samples. *Psychol Aging* 2015;30:83–94.
7 Skirbekk V, Stonawski M, Bonsang E, *et al*. The Flynn effect and population aging. *Intelligence* 2013;41:169–77.
8 Flynn J. *Are We Getting Smarter? Rising IQ in the Twenty-First Century*. Cambridge, UK: Cambridge University Press, 2012.
9 Flynn JR. Massive IQ gains in 14 nations: What IQ tests really measure. *Psychol Bull* 1987;101:171–91.
10 Pietschnig J, Voracek M. One Century of Global IQ Gains: A Formal Meta-Analysis of the Flynn Effect (1909-2013). *Perspect Psychol Sci* 2015;10:282–306.
11 Morley JE. Cognition and nutrition. *Curr Opin Clin Nutr Metab Care* 2014;17:1–4.
12 Anstey KJ, Kingston A, Kiely KM, *et al*. The influence of smoking, sedentary lifestyle and obesity on cognitive impairment-free life expectancy. *Int J Epidemiol* 2014;43:1874–83.
13 Jagger C, Matthews FE, Wohland P, *et al*. A comparison of health expectancies over two decades in England: results of the Cognitive Function and Ageing Study I and II. *Lancet* 2016;387:779–86.
14 Langa KM, Larson EB, Crimmins EM, *et al*. A Comparison of the Prevalence of Dementia in the United States in 2000 and 2012. *JAMA Internal Medicine* 2016.
15 Wu YT, Fratiglioni L, Matthews FE, *et al*. Dementia in western Europe: epidemiological evidence and implications for policy making. *Lancet Neurol* 2016;15:116–24.
16 Moe JO, Hagen TP. Trends and variation in mild disability and functional limitations among older adults in Norway, 1986-2008. *Eur J Ageing* 2011;8:49–61.
17 Dutton E, Lynn R. A negative Flynn Effect in France, 1999 to 2008–9. *Intelligence* 2015;51:67–70.
18 Dutton E, Lynn R. A negative Flynn effect in Finland, 1997–2009. *Intelligence* 2013;41:817–20.
19 Sundet JM, Barlaug DG, Torjussen TM. The end of the Flynn effect?A study of secular trends in mean intelligence test scores of Norwegian conscripts during half a century. *Intelligence* 2004;32:349–62.
20 Teasdale TW, Owen DR. A long-term rise and recent decline in intelligence test performance: The Flynn Effect in reverse. *Pers Individ Dif* 2005;39:837–43.
21 Ng M, Fleming T, Robinson M, *et al*. Global, regional and national prevalence of overweight and obesity in children and adults 1980-2013: A systematic analysis. *Lancet* 2014;384:766.
22 Elias MF, Elias PK, Sullivan LM, *et al*. Obesity, diabetes and cognitive deficit: The Framingham Heart Study. *Neurobiol Aging* 2005;26 Suppl 1:11–16.

23 Kliegl R, Smith J, Baltes PB. Testing-the-limits and the study of adult age differences in cognitive plasticity of a mnemonic skill. *Dev Psychol* 1989;25:247–56.
24 Albert MS, Jones K, Savage CR, *et al*. Predictors of cognitive change in older persons: MacArthur studies of successful aging. *Psychol Aging* 1995;10:578–89.
25 Yaffe K, Fiocco AJ, Lindquist K, *et al*. Predictors of maintaining cognitive function in older adults: the Health ABC study. *Neurology* 2009;72:2029–35.
26 Baltes P, Lindenberger U, Staudinger U. *Life span theory in developmental psychology Handbook of child psychology: Theoretical models of human development*. Hoboken: NJ: John Wiley & Sons Inc, 2006:569–664.
27 Börsch-Supan A, Brandt M, Hunkler C, *et al*. Data Resource Profile: the Survey of Health, Ageing and Retirement in Europe (SHARE). *Int J Epidemiol* 2013;42:992–1001.
28 Purser JL, Fillenbaum GG, Pieper CF, *et al*. Mild cognitive impairment and 10-year trajectories of disability in the Iowa Established Populations for Epidemiologic Studies of the Elderly cohort. *J Am Geriatr Soc* 2005;53:1966–72.
29 Knopman D, Boland LL, Mosley T, *et al*. Cardiovascular risk factors and cognitive decline in middle-aged adults. *Neurology* 2001;56:42–8.
30 Zajenkowski M, Stolarski M, Meisenberg G. Openness, economic freedom and democracy moderate the relationship between national intelligence and GDP. *Pers Individ Dif* 2013;55:391–8.
31 Rabe-Hesketh S, Skrondal A. *Multilevel and longitudinal modeling using Stata*: STATA press, 2008.
32 Trahan LH, Stuebing KK, Fletcher JM, *et al*. The Flynn effect: A meta-analysis. *Psychol Bull* 2014;140:1332–60.
33 Voelcker-Rehage C, Godde B, Staudinger UM. Cardiovascular and coordination training differentially improve cognitive performance and neural processing in older adults. *Front Hum Neurosci* 2011;5:1–12.
34 Moran AE, Forouzanfar MH, Roth GA, *et al*. The global burden of ischemic heart disease in 1990 and 2010: the Global Burden of Disease 2010 study. *Circulation* 2014;129:1493–501.
35 Staudinger UM. Images of Aging: Outside and Inside Perspectives. *Annual Review of Gerontology and Geriatrics* 2015;35:187–209.
36 Verhaeghen P, Salthouse TA. Meta-analyses of age-cognition relations in adulthood: estimates of linear and nonlinear age effects and structural models. *Psychol Bull* 1997;122:231–49.
37 Lachman ME, Agrigoroaei S, Tun PA, *et al*. Monitoring cognitive functioning: psychometric properties of the brief test of adult cognition by telephone. *Assessment* 2014;21:404–17.
38 Shiu W, Beaujean AA, Must O, *et al*. An item-level examination of the Flynn effect on the National Intelligence Test in Estonia. *Intelligence* 2013;41:770–9.

Trends and determinants of the Flynn effect in cognitive functioning among older individuals in 10 European countries

Philipp Hessel, Jonas M Kinge, Vegard Skirbekk and Ursula M Staudinger

J Epidemiol Community Health published online February 9, 2018