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.

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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,

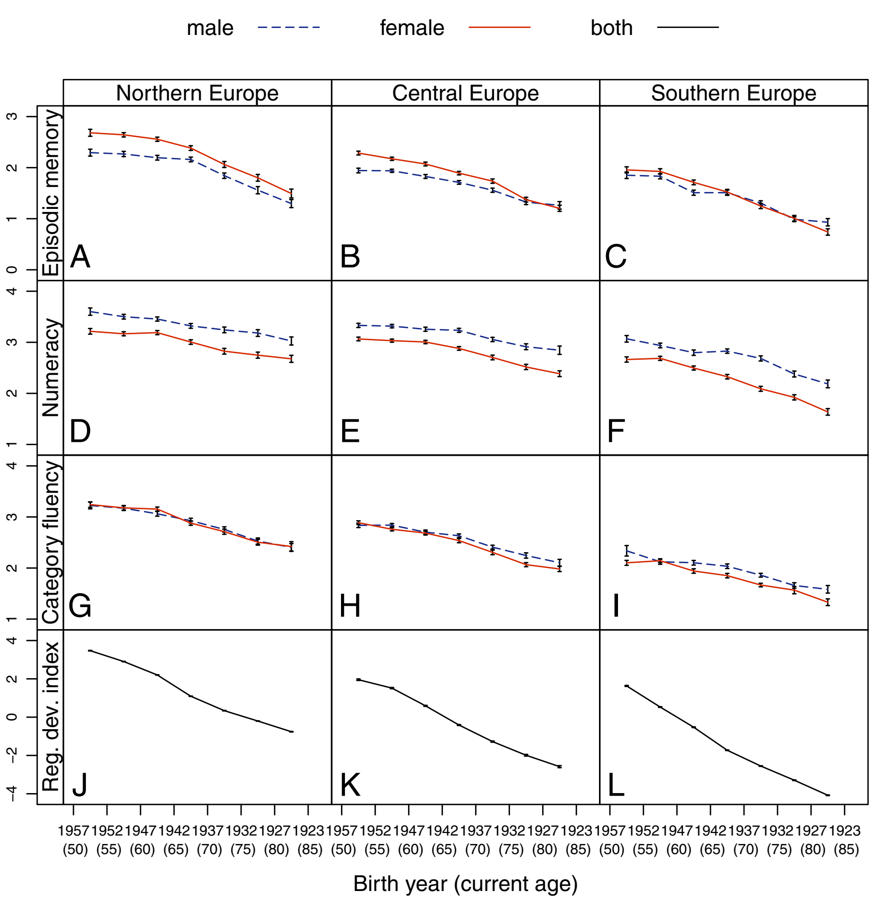

Fig. 1. Mean standardized performances (±SEM) in episodic memory (*A–C*), numeracy (*D–F*), and category fluency (*G–I*) per 5-y birth cohort by gender for Northern, Central, and Southern Europe. (*J–L*) Mean RDI (±SEM) per 5-y birth cohort for Northern, Central, and Southern Europe. As can be seen in *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.

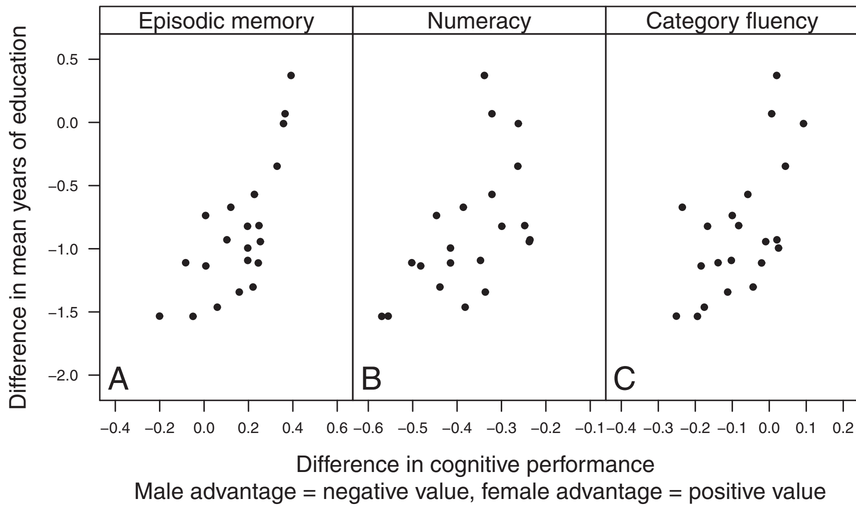

Fig. 2. Association between difference score for education (women's average level of education minus men's average level of education) and difference score in cognitive performance (women's average standardized episodic memory/numeracy/category fluency performance minus men's average standardized memory/numeracy/ 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.

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