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The magnitude, generality, and determinants of Flynn effects on forms of declarative memory and visuospatial ability: Time-sequential analyses of data from a Swedish cohort study

Michael Rönnlund [a,]*, Lars-Göran Nilsson [b,c]

[a] *Department of Psychology, Umeå University, S-901 87, Sweden*
[b] *Department of Psychology, Stockholm University, Sweden*
[c] *Stockholm Brain Institute, Sweden*

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Abstract

To estimate Flynn effects (FEs) on forms of declarative memory (episodic, semantic) and visuospatial ability (Block Design) time-sequential analyses of data for Swedish adult samples (35–80 years) assessed on either of four occasions (1989, 1994, 1999, 2004; $n=2995$) were conducted. The results demonstrated cognitive gains across occasions, regardless of age, with no evidence of narrowing gender gaps. Across the entire range of birth cohorts (1909–1969) the estimated gain approached 1 SD unit. Over most cohorts the gains were largest for semantic memory, with a tendency of decelerating gains on the memory factors, but not on Block Design, across more recent cohorts (1954–1969). Together, differences in education, body height, and sibsize predicted virtually all (>94%) of the time-related differences in cognitive performance. Whereas education emerged as the main factor, the need to consider changes multiple factors to account for FEs is underscored. Their relative influence likely depends on which constellations of ability factors and stages in ontogenetic and societal development are considered.

Keywords: Flynn effect; Cohort; Memory; Visuospatial ability

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1. Introduction

Substantial increments in cognitive test performances took place during the 20th century as judged from large scales studies by Flynn (1984, 1987). The studies were indicative of a mean-level rate of gain of at least Δ3 IQ points/decade in many countries, including USA, Great Britain, and Australia on tests such as the WAIS and Raven's matrices.

Even though Flynn effects (FEs) have been observed in variety of other industrialized countries including Denmark (Teasdale & Owen, 1989), Japan (Lynn, 1982; 1987; Lynn & Hampson, 1986), Estonia (Must, Must, & Raudik, 2003), Spain (Colom, Andrés Pueyo, & Juan-Espinoza, 1998), and, more recently, in developing countries (e.g., Kenya; Daley, Whaley, Sigman, & Neumann, 2003; Dominica; Meisenberg, Lawless, Lambert, & Newton, 2005), the underlying mechanisms are not fully understood (e.g., Neisser, 1998; Neisser et al., 1996; Rodgers, 1999).

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* Corresponding author. Fax: +46907866695.
E-mail address: michael.ronnlund@psy.umu.se (M. Rönnlund).

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1.1. Theoretical accounts

A major account attributes the FEs to improved nutrition (Lynn, 1990a, 1998, see also Colom, Lluis-Font, & Andrés-Pueyo, 2005; Sigman, 2000; Sigman & Whaley, 1998), which, for example, is assumed to account for the marked cohort-related increase in body height during the 20th century (Malina, 1979; Martorell, 1998). Given a similar growth trend for neural substrates underlying cognitive performance (for evidence pertaining to brain size, see Storfer, 1999), later-born individuals may have a cognitive advantage over those born earlier.

An alternative account attributes the effect to increased cognitive stimulation (e.g., Greenfield, 1998; Williams, 1998) driven, for example, by changes in educational systems (Blair, Gamson, Thorne, & Baker, 2005; Teasdale & Owen, 1987, 1989), large scale social (e.g., urbanization; Schooler, 1998), and family structure (Williams, 1998). Specifically, later-born as compared with earlier-born cohorts were more educated, more often lived in cities, and were, on average, brought up in smaller families. The positive relation between education and cognitive test performance is firmly established and part of it is likely due to a direct influence from education to performance (Ceci & Gilstrap, 2000; Sternberg, Grigorenko, & Bundy, 2001). As regard the family-size factor, psychological theories (e.g., Blake, 1981; Zajonc, 2001; Zajonc & Markus, 1975) predict that a smaller sibsize should promote intellectual development to the extent that the degree of attention/cognitive stimulation that the child receives from caregivers should increase. Thus, more recent generations may be privileged compared to earlier ones with regard to factors promoting the stimulation and growth of intellectual capital.

1.2. Cohort or period effects?

Most proponents of the nutritional and stimulation accounts seem to share the assumptions a) that widespread changes in environmental factors underlie the FEs, and, b) that the factors were influential during a limited ontogenetic time-window (childhood/youth). Thus, the Flynn effect is conceived of as a cohort effect.

Disregarding methodological artefacts, which seem unlikely to account for the FEs, the possibility remains that they are better characterized as period effects (Rodgers, 1999). To the extent that individuals were exposed to more test-like items in school, working life, and popular press with historical time (i.e., regardless of age), the hypothesis that FEs are attributable to test sophistication/altered test-taking strategies (Brand, 1987; Brand, Freshwater, & Dockrell, 1989) could, for example, be framed in terms of period-related influences (e.g., Owens, 1966). In a similar vein, increased information flow via TV and other media could, if involved, exert its influence across age cohorts, and, hence be regarded as a period factor.

From observations of positive time-lag differences alone, on which the most of the evidence rests, we cannot discriminate between a cohort or period interpretation as the two factors are perfectly confounded. In the general developmental model Schaie (1965) considered the intricate confound of age, period, and cohort in various designs (e.g., cross-sectional, longitudinal, time lag). To tease the influences apart he recommended the use of a design that allows for sequential analyses (e.g., time- and cohort-sequential).

Based on such analyses of data from the Seattle Longitudinal Study (SLS) Schaie et al. (e.g., Schaie, 1994; Schaie & Hertzog, 1983; Schaie, Labouvie, & Beuch, 1973; for a summary, see Schaie, 1996) actually demonstrated Flynn-like effects on primary mental abilities before they were more systematically examined by Lynn and Flynn in the 1980s (cf. also Tuddenham, 1948). By virtue of the design, gains prior to the advent of intelligence testing could actually be inferred. Schaie et al. interpreted the gains mainly as reflective of cohort factors. Presumably because maturational effects were in focus, systematic analyses the determinants of the cohort-related gains were not undertaken. In recent works, Schaie (1996) and Schaie, Willis, and Pennak (2005) designate changes in educational attainment and practice as important factors behind the trends, though.

In general, existing evidence regarding the relation between FEs and cohort factors is indirect. For example, observations that gains in body height or school attendance in the population were in parallel with IQ gains in the investigated samples (Colom et al., 2005; Lynn, 1990a; Sundet, Barlaug, & Torjussen, 2004) are interesting. However, to provide substantive evidence that variations in the hypothesized constructs have explanatory power, the associations with cognitive measures and the extent to which the former account for the time-lag differences in cognition should be examined (e.g., Teasdale & Owen, 1987). Obviously, this requires that data on both sets of measures (i.e., cognitive measures and markers of constructs hypothesized to drive the FEs) are obtained at the individual level.

1.3. Generality of Flynn effects

Apart from the overarching issue of what factors cause the FEs, several issues pertaining to the generality of the effect remains unresolved (cf. Rodgers, 1999). Three will be discussed below.

First, to what extent do FEs vary in magnitude across cognitive ability domains? Much evidence pertains to tests designed to measure Spearman's *g* (e.g., Raven's Matrices) or aggregate IQs that cannot be used to address this issue. However, a pattern discernible from comparisons across tests (e.g., Flynn, 1987; Raven, 2000) and between subtests/factors within test batteries (e.g., Flynn, 1987; Lynn, 1990b), is that larger gains occurred in fluid as compared with crystallized intelligence (Horn & Cattell, 1966; cf. Flynn, 1994, but see Uttl & van Alstine, 2003).

Intuitively, this pattern seems to favor explanations involving biological factors (e.g., nutrition) over explanations based on cultural factors. Specifically, fluid intelligence is assumed to be more reflective of biological factors than crystallized measures. However, there is evidence that education, for example, promotes performance on measures of fluid as well as crystallized intelligence (e.g., Ceci, 1991; Gustafsson, 2001). Finally, it is worth noting that some measures appear to be resistant to FEs. For instance, data in Schaie (1996) indicate no or only minor cohort gains on measures of perceptual speed and numeric ability. Thus, FEs are not omnipresent, neither within the (broad) fluid nor the crystallized task domain.

Second, are there gender differences in the magnitude of FEs? Undoubtedly, significant changes took place with regard to women's rights during the 20th century, resulting in increased opportunities of attaining higher education and employment. Given these facts, an interesting question is whether FEs are gender invariant or not.

Generally, data pertaining to FEs are severely biased with regard to gender composition as much of the evidence pertains to conscripts. A notable exception to the lack of female conscript data is from Israel (Flynn, 1998). Analyses of these data revealed similar time-related gains in male and females from the early 1970s to 1984. However, data from Estonia (Must et al., 2003) demonstrated significantly larger time-lag differences for girls (1930s–1980s). Also, studies of 13-year Swedish children (Emanuelsson & Svensson, 1990; Emanuelsson, Reuterberg, & Svensson, 1993) observed a larger gain (1960 to 1990) for girls in verbal and spatial test performance. Thus, the evidence is somewhat mixed. In particular for intellectual factors were males and females have been found to differ (e.g., Maccoby & Jacklin, 1974), the potential presence of gender-related trends in FEs should be of great interest.

Third, do FEs generalize across age? As noted, a major source of data concern conscripts with a minimal age variation. Data for children in various ages constitute another source (e.g., Brand et al., 1989; Flynn, 1987; 1990; Lynn & Hampson, 1986). However, little research seems to have examined more systematically the magnitude of FEs as a function of age of the children (for a recent *within-subject* analyses, see Kanaya, Ceci, & Scullin, 2005).

Even less is known concerning FEs in adult age. This is an important omission, in particular as time by age interactions may be expected to emerge. Specifically, with improved health-care, the expected life-length has increased dramatically during the 20th century. Thus, at a given age-level a factor such as terminal decline/drop (i.e. steeper linear/curvilinear decline in cognitive functions associated with impending death (e.g., Riegel & Riegel, 1972; Small, Fratiglioni, von Strauss, & Bäckman, 2003) should, for example, be less influential for more recent cohorts. In other word, later-born, elderly in particular, may be expected to benefit from two sources of historical variation: a) improvements related to (cohort) factors with an early impact (childhood/youth) and b) period-related changes with regard to health-care. Under the assumption that cohort gains are approximately linear as much evidence seem to suggest, one might, thus, expect larger FEs in older individuals.

Data from the SLS (Schaie, 1996; Schaie et al., 2005) indeed seem to lend support of the predicted pattern of larger time-lag differences for older adults, on a verbal meaning factor in particular. A similar observation of larger gains in groups of older as compared with younger adults was made by Uttl and van Alstine (2003) in a meta-analysis of age differences in WAIS vocabulary (which the author's attributed to cohort factors).

1.4. The present study

The present study addressed the three issues pertaining to the generality of FEs (i.e., across cognitive abilities, gender and age) from viewpoint of time-sequential analyses of data from the Swedish Betula Prospective Cohort Study (Nilsson et al., 1997, 2004; see Method section for a further description).

The main focus is on forms of declarative long-term memory. In the literature we find little evidence pertaining to this important class of intellectual abilities, episodic memory in particular (see Schaie, 1994, 1996 for evidence of a positive cohort gradient on a factor mainly reflecting two recall measures). Episodic memory is concerned with encoding and retrieval of personally experienced events, whereas our semantic memory factor reflected measures required retrieval of world knowledge devoid of spatio-temporal study context (Nyberg, 1994, Nyberg et al., 2003; cf. Nyberg & Tulving, 1996; Tulving, 1972).

The semantic measures should mainly reflect crystallized intelligence, which, as noted, seems to exhibit weaker FEs than fluid intelligence. By contrast, episodic measures emphasize learning of novel associations and are, in common with measures of Gv or Gf, more "vulnerable" for example to effects of aging (Horn & Hofer, 1992; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005). Thus, the FEs for episodic memory might be expected to be comparable to measures of Gv/Gf. The inclusion of the Block Design Test (from WAIS-R; Wechsler, 1981) which reflects visuospatial ability (mainly Gv; Kaufman, 2001) allowed for a test of this prediction.

Turning to gender, mean-level differences have been observed on each of the cognitive factors considered. More specifically, women tend to outperform men on episodic measures (e.g., Herlitz, Nilsson, & Bäckman, 1997; Lewin, Wolgers, & Herlitz, 2001; Maitland, Herlitz, Nyberg, Bäckman, & Nilsson, 2004) and on measures of semantic memory that requires rapid retrieval, such as word fluency (Herlitz et al., 1997; Maitland et al., 2004), whereas a reversed difference, in favor of males, has been observed on the Block Design test (Rönnlund & Nilsson, 2006). Thus, in present focus is whether the male–female gaps observed on the cognitive factors are narrowing (e.g., Feingold, 1988; see also Voyer, Voyer, & Bryden, 1995 for partial support of this hypothesis) or persist over time.

Finally, we considered the relation between time-lag differences in cognition and variations in cohort makers pertaining to extant theoretical accounts of Flynn effects. These were assumed to reflect changes in a) nutrition, using body height as an anthropometric marker (cf., Lynn, 1990a, b, 1998; Martorell, 1998), b) family structure (sibsize), and, c) the educational system (years of schooling). In particular, this allowed for testing the hypothesis that changes in multiple factors accumulate to produce the FEs (Jensen, 1998, Dickens & Flynn, 2001).

Few studies have considered the influence of the three factors within the same study (e.g., Daley, Whaley, Sigman, & Neumann, 2003) and, to our knowledge, only one considered their relative influence (i.e., in the same analyses; Meisenberg, Lawless, Lambert, & Newton, 2006). Basically, the latter study failed to find much support for the notions that physical growth or variations in family structure contributed to the cognitive gains in a Dominican sample. Increased formal schooling was suggested to have some impact, but most of the variance in cognitive performance (Raven's Matrices and a vocabulary test) remained unexplained. A limitation of the study is that it was based on a cross-sectional design using young–old comparisons to estimate time-lag effects (which confounds age and cohort membership).

2. Method

The data emanated from an ongoing Swedish study of memory, health, and aging, the Betula prospective cohort study (Nilsson et al., 1997, 2004). For an overview of the full design, further details concerning assessment of health/cognition, and social variables, see Nilsson et al. (1997) and Nilsson (1999). For a summary of major findings up to 2006, see Nilsson (2006). More recent publications concern cognitive changes at the mean level (e.g., Rönnlund & Nilsson, 2006; Rönnlund et al., 2005), inter-individual differences in rate of change (de Frias, Lövdén, Lindenberger, & Nilsson, 2007; Lövdén et al., 2004), genetic influences on memory (Nilsson et al., 2006) and brain function and structure Lind, Ingvar et al., 2006, Lind, Larsson et al., 2006, Lind, Persson et al., 2006; Persson et al., 2006), and the role of gene-environment interactions in cognitive changes (e.g., Sundström et al., 2004), to provide examples.

2.1. Sample characteristics and design

The first test occasion (Time 1 or T_1) took place in 1988–1990. On this occasion Sample 1 (S1) that involved 1000 individuals was assessed. The participants were recruited by means of stratified random sampling from the population registry in Umeå, a city in Northern Sweden with about 110 000 inhabitants, that served as the target population. S1 consisted of 100 individuals in each of 10 age groups (35, 40, 45, 50, 55, 60, 65, 70, 75, and 80 years at date of test) with a gender distribution matching that of the target population in each group. Exclusion criteria were a) dementia diagnosis, b) mental retardation, and c) another native tongue than Swedish.

The data collection required two years for completion. Consequently, the ten groups differed from 1908–1910 (80-year olds) to 1953–1955 (35-year olds) with regard to birth year. A second, third, and fourth test occasion was undertaken five (1993–1995), ten (1998 to 2000), and 15 years later (2003–2005), occasions on which a follow-up assessment of S1 was made.

Of main concern at present, new samples matched in regard to age (i.e., 35–80 years) with S1 at T_1, were included at T_2, T_3, and T_4. Consequently, participants in the new samples differed systematically (i.e., 5, 15, or 15 years) from those in S1 with regard to cohort membership. The same means of sampling (i.e., stratified random), and exclusion criteria as were adopted for S1 were adopted for the new samples. For financial reasons the sample size was cut to half at T_3 and T_4 such that about 50 individuals per age/cohort were assessed rather than 100 as was the case for S1 at T_1 and S2 at T_2.

Table 1 provides an outline of the time-sequential (Schaie, 1965) design of the study, including age, time of measurement, and (mean) birth year of the included groups.

Assessment of the degree to which the final samples were representative of the target population and the Swedish population in general was indicative of a high degree of representativeness (Nilsson et al., 1997). With regard to cognitive ability, performance on the Block Design test (Wechsler, 1981) revealed a slightly higher mean for S1 as compared with the US norms, regardless of age (Rönnlund & Nilsson, 2006). This possibly reflects a time-lag effect (the US norms were established about 10 years earlier) and/or an adult population difference (see Lynn & Vanhanen, 2002). Thus, as judged from several comparisons the population validity of the included sample appears to be adequate, which, for example, renders potential migration effects less likely to have an impact on the results.

2.2. Participants

A descriptive summary of participant characteristics relevant for the purposes of the present article (gender distribution, *M*, SDs body height, sibsize, and years of formal education across age; note that some minor internal attrition was evident on the latter variables; Table 4) is provided in Table 2.

Inspection of the marginal means indicate a successive increase in body height, a decrease in sibsize, and increased number of years of schooling, respectively, over the 15-year period.

A series of 4 (Time) × 10 (Age) × 2 (Gender) Analyses of Variance (ANOVAs) revealed significant effects of time for all three variables; for body height, $F(9, 2888)=6.14$, MSE=37.54, partial η^2 (henceforth η^2)=.006; for sibsize, $F(9, 2864)=23.42$, MSE=6.18, $\eta^2=.024$, and for years of schooling, $F(9, 2877)=364.57$, MSE=11.24, $\eta^2=.310$.

Table 1
Design of the study, including age, mean time of measurement, and birth cohort of the studied groups

Age	Time of measurement			
	Time 1	Time 2	Time 3	Time 4
35	1954	1959	1964	1969
40	1949	1954	1959	1964
45	1944	1949	1954	1959
50	1939	1944	1949	1954
55	1934	1939	1944	1949
60	1929	1934	1939	1944
65	1924	1929	1934	1939
70	1919	1924	1929	1934
75	1914	1919	1924	1929
80	1909	1914	1919	1924

Note. Time 1=1989, Time 2=1994, Time 3=1999, Time 4=2003.

Moreover, main effects of age were observed; for body height, $F(9, 2870)=45.55$, $\eta^2=.125$, for sibsize, $F(9, 2843)=34.29$, $\eta^2=.098$, and for years of schooling, $F(9, 2856)=143.15$, $\eta^2=.311$, consistent with shorter body height, larger sibsize, and less formal schooling within older as compared with younger groups.

Gender, finally, was naturally related to body height, $F(1, 2888)=3097.83$, MSE=37.54, $\eta^2=.518$, but neither to sibsize nor years of schooling. The only significant interaction among the aforementioned factors was a time by age interaction for years of schooling, $F(27, 2877)=3.42$, MSE=11.24, $\eta^2=.031$, which appears to reflect a somewhat larger cohort-related increment in years of schooling across the middle-age/young–old groups (cohorts born around World War II) as compared with other groups.

For sake of comparison of the magnitude of time/cohort effects among the three cohort factors, and for sake of a subsequent comparison with the trends on the cognitive variables, values on each variable were transformed to *z*-scores based on data for S1 at T_1. Note that simply averaging the obtained values over birth cohorts would yield a good approximation of cohort-related effects for a variable such as sibsize which is usually fixed in childhood. By contrast, for body height some changes are expected to occur past peak level in form of shrinkage (due to thinning of the cartilage between bones of the vertebral column). As a result, the participants from the early-born cohorts are shorter, partly due to cohort membership and partly due to age-related shrinkage. In a time-sequential design such age-related influence may be controlled for by restricting the comparisons to successive birth cohorts assessed at the same age. Thus, for example, the difference in body height between the 1954 and 1959 cohorts (see Table 1) may be estimated from differences among 35-year-old measured at T_1 and 35-year-olds measured at T_2, as well as from differences among 40- and 45-year-olds assessed at T_2 versus T_3, and T_3 versus T_4, respectively.[1] More formally, cohort differences, $\mathrm{Cd}_{i)} = \sum_j^1 \left(M_{ij+1}M_{ij}\right))/a$, where M_{ij} is the unweighted mean[2] for Cohort *i* at age *j*, and *a* is the number of

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[1] This estimate should be compared by that obtained by a direct comparison of the 1909 and the 1969 cohorts that yield a difference of 1 *z*. Consequently, it can be estimated that about 60% of the mean-level height difference between the earliest and most recent-born groups reflects cohort-related influences and 40% age-related shrinkage and/or effects of selective survival.

[2] In the case of body height, the z scores were transformed separately for men and women before computing the cohort gradients.

Table 2
Descriptive summary (*M*; SDs within parenthesis) of the background variables as a function of age, time of measurement (T_1–T_4), and gender

	Variable											
	Body height (cm)				Sibsize				Education (years of schooling)			
Age	Time 1 (f/m)	Time 2 (f/m)	Time 3 (f/m)	Time 4 (f/m)	Time 1 (f/m)	Time 2 (f/m)	Time 3 (f/m)	Time 4 (f/m)	Time 1 (f/m)	Time 2 (f/m)	Time 3 (f/m)	Time 4 (f/m)
35	166.9/180.5 (6.8/7.3)	165.5/179.8 (7.1/6.8)	166.2/179.0 (6.2/6.7)	166.0/180.5 (4.7/6.2)	2.8/3.6 (1.5/1.8)	3.3/3.2 (1.6/1.7)	3.4/2.9 (1.6/1.4)	2.4/2.6 (0.8/0.8)	14.2/13.7 (2.6/2.6)	12.8/12.9 (2.5/2.6)	14.4/14.4 (2.0 /3.4)	14.7/14.4 (3.2 /3.8)
40	164.7/177.7 (5.2/7.1)	166.6/180.3 (7.1/6.3)	167.0/179.6 (7.9/6.4)	168.6/178.9 (6.1/6.7)	3.8/3.5 (2.0/1.9)	3.6/2.9 (1.5/1.5)	2.8/3.0 (1.1/1.3)	3.1/3.0 (2.3/1.4)	13.7 /14.0 (3.2/3.8)	13.3/ 12.8 (3.1 /2. 9)	13.1 /14.2 (2.3 /5.1)	13.6/12.4 (2.7/2.3)
45	164.4/178.6 (5.8/6.3)	166.6/177.4 (6.7/7.8)	168.5/179.7 (6.2/7.0)	165.3/178.0 (5.4/5.3)	3.7/3.1 (2.2/1.6)	3.4/3.9 (1.8/2.5)	3.6/3.0 (1.9/1.5)	3.6/2.6 (2.0/1.2)	12.6 /12.9 (3.8/4.7)	13.9/13.6 (3.3/3.5)	14.1/13.1 (2.6/3.5)	14.4/14.4 (2.3/3.5)
50	163.3/175.3 (4.9 /6.8)	164.5/176.7 (6.4/6.8)	162.2/179.8 (6.1/6.3)	164.9/177.7 (6.2/6.1)	3.8/4.8 (2.1/2.7)	3.7/4.0 (2.2/2.9)	3.1/3.1 (2.1/1.4)	2.9/3.5 (1.7/1.7)	10.2 /10.7 (3.4 /4.2)	11.2/11.9 (3.5/4.1)	13.5 /13.3 (4.2/3.2)	13.1/14.2 (2.7 /3.9)
55	163.6/174.1 (6.1/7.4)	162.8/176.5 (5.3/4.7)	164.9/177.4 (7.5 /6.8)	164.1/178.4 (5.1/7.6)	4.9/4.7 (2.9/2.6)	4.1/4.4 (2.6/2.5)	3.4/3.5 (1.5/1.7)	3.0/3.8 (1.4/2.2)	9.1/8.8 (3.6/2. 8)	10.8/10.2 (4.2/3.3)	11.6/12.1 (4.0/4.5)	12.7/12.0 (4.1/2.7)
60	161.4/174.9 (5.8/6.1)	164.1/174.8 (5.5/6.0)	162.8/174.5 (4.2/3.9)	163.9/175.6 (6.9/5.6)	4.5/4.8 (2.6/3.0)	3.9/4.6 (2.2/3.0)	3.3/4.9 (1.4/3.3)	2.8/3.5 (1.6/1.8)	8.9 /8.8 (3.3/3.2)	9.9/9.8 (4.0/3.5)	9.9/9.8 (3.7/3.3)	12.4/11.6 (4.4/4.0)
65	161.0/175.2 (5.1/6.1)	161.2/175.3 (5.3/6.6)	161.3/176.8 (5.4/4.9)	164.1/177.7 (5.0/5.7)	5.4/5.5 (3.3/3.3)	4.2/5.1 (2.9/3.2)	4.3/4.0 (2.6/2.8)	4.1/4.6 (3.1/2.5)	7.5/9.0 (1.8/3.7)	8.1/8.5 (2.3/3.8)	7.5/8.2 (1.7/2.9)	11.6/10.2 (3.6/4.1)
70	160.3/174.7 (5.6/6.1)	160.0/174.5 (5.6/4.8)	162.5/173.9 (5.3/5.6)	160.6/174.5 (5.6/4.7)	5.4/4.9 (3.2/3.0)	4.9/5.2 (2.9/3.0)	4.7/5.4 (2.6/3.5)	4.9/4.0 (3.2/2.3)	7.6/8.8 (2.8/3.6)	7.6/8.1 (2.9/3.9)	7.9/7.3 (2.3/2.1)	10.0/9.2 (4.2/3.6)
75	158.2/174.9 (6.9/6.5)	157.9/176.5 (6.2/5.9)	158.8/176.5 (4.5/5.8)	159.5/173.3 (4.8/6.6)	6.7/6.2 (3.5/3.0)	5.5/5.1 (2.8/2.8)	4.2/4.0 (2.7/1.6)	5.0/5.0 (2.9/3.2)	7.2/7.8 (2.2/3.3)	7.8/8.7 (3.8/4.4)	6.8/8.2 (1.6/3.1)	7.6/8.2 (2.4/3.4)
80	159.4/171.1 (6.0/6.4)	157.9/171.2 (5.6/7.3)	159.2/172.5 (5.2/5.7)	159.2/174.0 (5.3/6.2)	5.2/6.5 (3.0/3.4)	6.2/6.9 (2.8/3.3)	5.3/6.0 (2.7/3.0)	4.0/5.0 (2.6/3.0)	7.5/7.1 (2.9/3.5)	6.8/7.2 (2.7/3.5)	7.3/7.6 (2.9/4.0)	9.0/8.2 (3.1/3.4)
Total	162.3/175.7 (6.3/7.0)	162.6/176.3 (6.7/6.8)	163.4/176.9 (6.7/6.3)	166.0/176.8 (6.1/6.5)	4.6/4.7 (2.9/2.9)	4.3/4.4 (2.6/2.8)	3.8/4.0 (2.2/2.5)	3.6/3.8 (2.4/2.3)	9.8/10.1 (3.9/4.2)	10.0/10.5 (4.1/4.1)	10.6/10.8 (4.6/4.5)	12.0/11.5 (4.0/4.1)

observations available for each cohort; Schaie, 1965). Cumulative summation of the obtained estimates across birth cohorts (i.e., $C2-C1$; $C3-C2$;...$C13-C12$, where $C1=1909$ cohort and $C13=1969$ cohort) yields the cohort gradients depicted in Fig. 1.

The cohort gradients confirm the presence of substantial differences on each of the variables. Over the entire range of cohort the size of the effects amounts to about 0.6, −1.2, and 1.3 *z*-score units for body height [for similar estimates for Swedish cohorts, see Schmidt et al. (1995) and Dey, Rothenberg, Sundh, Bosaeus, and Steen (2001)], sibsize, and years of schooling, respectively.

2.3. *Cognitive measures*

The cognitive data were collected during two test sessions (i.e., on each of the four test occasions). Each session lasted 11/2–2 h. Participants were requested to use corrective lenses or hearing aids, if used, during testing, and they were tested individually. For additional details concerning the materials presented below see Nilsson et al. (1997).

2.4. *Episodic memory*

2.4.1. *Recall of actions/sentences*

Following presentation of 16 verbal commands (e.g., point at the book, lift the cup) that were enacted by the participants (actions) or encoded verbally (sentences; see Rönnlund, Nyberg, Bäckman, & Nilsson, 2003) the participants were requested to recall orally as many as possible, in any order. Number of sentences recalled (with correct verb and noun) in the two conditions served as dependent measures.

2.4.2. *Cued recall of nouns*

Following a brief retention interval, participants recalled as many nouns as possible from the enacted/nonenacted sentences. Four categories to which each noun belonged served as cues to remember the nouns. Number of nouns recalled from the enacted and nonenacted sentences served as the dependent measures.

2.4.3. *Recognition of nouns*

The participants were presented with a list of 32 nouns. Half of these were from the enacted/nonenacted sentences studied previously, with eight nouns from each condition and 16 nouns that served as foils. Number of hits minus false alarms for nouns in the nonenacted condition served as the outcome measure.

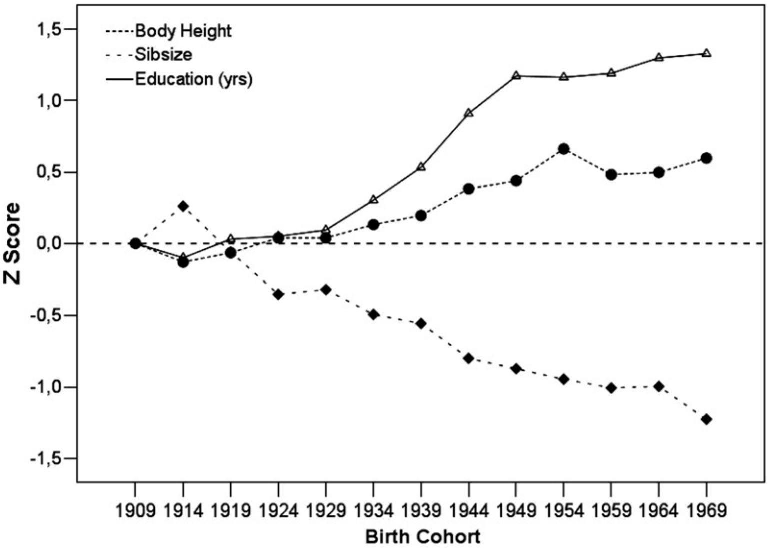

Fig. 1. Cumulative changes (*z*-scores) across birth cohorts (1909–1969) for body height, sibsize, and education (years of schooling).

2.5. Semantic memory

2.5.1. Vocabulary

Vocabulary was assessed by a 30-item multiple-choice synonym test (SRB:1, Dureman, 1960) in which the synonym of each target was to be picked among five alternatives. Seven minutes were allotted for completing the test.

2.5.2. Word fluency

Word fluency was assessed in three tests in which the participants was requested to say aloud as many words as possible in one minute, given the restrictions: a) initial letters A, b) initial letters M and five letters, and, c) professions with the initial letter B.

2.6. Visuospatial ability

2.6.1. Block Design Test (BDT)

In this test the participants arranged a set of four, or nine, two-colored blocks so as to duplicate a maximum of ten target patterns presented in order of ascending difficulty. The test was administered and scored in accord with the WAIS-R manual (Wechsler, 1981).

2.7. Factorial model and data reduction

The BDT total raw score was analyzed as a manifest variable. However, the memory measures were subjected to a confirmatory factor analyses. The measurement model was a bi-factorial (episodic/semantic) model with correlated factors (see Nyberg, 1994; Nyberg et al., 2003 for comparisons with competing models) in which the five recall/recognition measures were assumed to load on an episodic factor and the vocabulary test and the verbal fluency tests were assumed to reflect a semantic factor (breaking out vocabulary, as a measure of knowledge separate from the word fluency measures; cf., Nyberg et al. (2003) did not yield much difference to the results). Correlated measurement errors were allowed for the episodic tests that were based on a common study episode (i.e., enacted and nonenacted sentences) and the letter fluency tasks (Fluency A and M). The analyses were performed on data for S1 at T_1 ($n=1000$) using AMOS 7.0 (Arbuckle, 2006). As judged from various indices the fit of the model was appropriate, $\chi^2(21)=47.50$, $p<.001$, GFI=.993, RMSEA=.036 and the factor loadings were all highly significant ($p<.001$, range: .52–.82 for standardized loadings).

Factor scores were computed from the obtained factor regression weights over test occasions. A few ($n=21$) cases were detected for which data one or a few of the memory tests were missing. In these cases, regression-based imputation provided in AMOS was used to compute the factor scores.

Noteworthy is that models involving the present memory measures/factors met several criteria of metric invariance in cross-sectional (Nyberg et al., 2003) and longitudinal comparisons (Lövdén et al., 2004; cf. Wicherts et al., 2004). Five-year test–retest correlations (S1 T_1–T_2, $n=824$, screened for dementia) for the factor scores used at present were .85 and .90, respectively, for the semantic and episodic factor. The corresponding value for the BDT was .81 (Rönnlund & Nilsson, 2006). Thus, even as judged from conservative estimates (the stability coefficients reflect meaningful inter-individual differences in change in addition to error; cf. Lövdén et al., 2004) the cognitive variables show high test–retest reliabilities and are comparable in this regard.

3. Results

First we consider the time-related patterns for the cognitive variables. Second, cohort gradients are estimated. Finally, the relations between time-related differences in the cognitive factors and variations in the cohort markers are examined. The α-level was set to .01 throughout, motivated by the large sample size.

3.1. Time-related trends for the cognitive factors

The episodic and semantic factor scores and the BDT (raw) score were transformed to *z*-scores to allow for comparisons of the time-/cohort-related trends across the measures. Table 3 presents the mean and standard deviation for each variable as a function of test occasion, age, and gender.

4 (test occasion) × 10 (age) × 2 (gender) ANOVAs showed a main effect of test occasion for each of the cognitive variables, in line with the pattern of time-related gains discernible from Table 3; for episodic memory, $F(3, 2915)=5.47$, MSE = .61, partial $\eta^2=.006$; for semantic memory, $F(3, 2915)=9.00$, MSE = .68, $\eta^2=.009$, and for BDT, $F(3, 2911)=6.33$, MSE = .65, $\eta^2=.006$ (all ps $<.01$).

In addition, there results demonstrated effects of age, with lower scores for older groups (for episodic memory and BDT in particular; for episodic memory, $F(9, 2915)=151.66$, MSE = .61, $\eta^2=.32$; for semantic memory, $F(9, 2915)=83.56$, MSE = .68, $\eta^2=.20$, and for BDT, $F(9, 2911)=160.41$, MSE = .65, $\eta^2=.33$ (all ps $<.01$).

Moreover, a main effect of gender turned out significant across the measures; for episodic memory, $F(1, 2915)=80.84$, $\eta^2=.027$; for semantic memory; $F(1, 2915)=61.13$, $\eta^2=.021$, and for visuospatial ability, $F(1, 2911)=31.46$, $\eta^2=.011$. The latter effects reflect a female advantage for episodic and semantic memory and a reversed trend for BDT, respectively.

The only tendency for a gender by time interaction was for semantic memory ($p=.083$) consistent with a widening female advantage over time (mean *z* difference at $T_1=0.16$; $T_2=0.18$; $T_3=.30$; $T_4=.40$ *z*).

Finally, no time by age interactions were observed (ps $>.50$). The high similarity of age-related differences across test occasions, despite a systematic increase with regard to average performance levels, is evident from inspection of Fig. 2a–c.

3.2. Cohort gradients

The same rationale used to compute gradients for the cohort markers (see *participants*) was applied to the cognitive variables. The cumulative patterns of changes birth that emerge are displayed in Fig. 3.

In agreement with the lack of significant age by time interactions, the cohort gradients are indicative of successively higher mean-level performances. The estimated gain over the entire range of cohorts is substantial, approaching 1 *z* for semantic memory and BDT and about 0.6 *z* scores on the episodic factor.

Across a most cohorts (1909–1949) the upward trend is strongest for semantic memory. A tendency of deceleration is discernible for semantic as well as episodic memory for cohorts born in 1954 and thereafter, whereas a reversed tendency is observed for the BDT with pronounced gains across more recent cohorts.

3.3. Predictors of time-related differences in cognitive performance

Having established the presence of significant mean-level gain on the cognitive factors we finally examined the extent to which the gains were predictable from variations in the three cohort markers (body height, sibsize, and years of schooling).

Zero-order and partial correlations (controlling for gender and age) between the cognitive variable, the cohort markers and time of measurement are provided in Table 4, together with information concerning the *n*s and measures of deviations from normality (skewness, kurtosis) of the variables.

The values in Table 4 confirm a positive association between scores on the three cognitive factors and test year revealed by ANOVAs. The cognitive variables are, as can be seen substantially correlated. Further, each of the cohort factors (body height, sibsize, and years of schooling) is significantly related to the cognitive factors. Measures pertaining to the distribution of values indicate certain skewness and kurtosis for sibsize, but values do not reach common criteria (<-2 or >2) of problematic deviations from normality.

To appreciate the extent to which the cohort makers predicted the time-lag effects in cognitive performances, simple and hierarchic regression analyses were performed. In the simple analyses test year was regressed on each of the measures (following age, and gender).

Table 3
Descriptive summary (*M*; SDs within parenthesis) of the cognitive factors as a function of age, time of measurement and gender

	Cognitive factor					
	Episodic memory				Semantic memory	
Age	Time 1 f/m	Time 2 f/m	Time 3 f/m	Time 4 f/m	Time 1 f/m	Time 2 f/m
35	.87/.64 (.87/.81)	.87/.55 (.82/.73)	1.00/.46 (.53/.64)	1.00/.72 (.78/.58)	.69/.48 (.83/.85)	.61/.45 (.79/.70)
40	.85/.38 (.68/.70)	.97/.63 (.66/.84)	.83/.59 (.74/.78)	.81/.31 (.76/.77)	.72/.30 (.67/.72)	.79/.49 (.60/.70)
45	.60/.43 (.70/.76)	.70/.48 (.88/.83)	.99/.49 (.73/.76)	.80/.71 (.65/.53)	.45/.39 (.71/.84)	.61/.34 (.87/.78)
50	.57/.16 (.78/.83)	.50/.25 (.65/.81)	.82/.41 (.70/.68)	.61/.34 (.78/.80)	.52/.24 (.70/.80)	.45/.22 (.81/.81)
55	.32/.08 (.82/.79)	.33/.10 (.92/.76)	.52/.14 (.76/.75)	.52/−.02 (.67/.81)	.25/.18 (.95/.89)	.31/.10 (.88/.81)
60	.14/−.19 (.76/.74)	.15/−.03 (.81/.69)	.12/−.04 (.64/.72)	.43/.14 (.75/.89)	.20/−.16 (.85/.86)	.22/−.01 (.80/.88)
65	−.15/−.36 (.80/.91)	−.03/−.20 (.71/.73)	−.30/−.02 (.73/.54)	.05/.00 (.71/.65)	−.18/−.24 (.89/1.00)	.01/−.09 (.74/.78)
70	−.46/−.37 (.83/.81)	−.28/−.61 (.69/.72)	.01/−.70 (1.01/.80)	.11/−.56 (.80/1.01)	−.45/−.22 (.84/.91)	−.25/−.38 (.84/.80)
75	−.80/−.87 (.86/.88)	−.48/−.82 (.91/.81)	−.62/−.82 (.73/.88)	−.73/−.62 (.62/.67)	−.76/−.79 (.93/.98)	−.28/−.59 (.92/.93)
80	−.89/−1.12 (.94/.94)	−.94/−.95 (.87/.77)	−.69/−1.06 (.82/.74)	−.57/−1.02 (.78/.68)	−.71/−1.02 (1.01/1.04)	−.82/−.71 (.92/.96)
Total	.10/−.11 (1.02/.97)	.14/.00 (.99/.94)	.28−.06 (.96/.92)	.31/.00 (.91/92)	.07/−.08 (1.00/.99)	.14/.02 (.95/.90)

Thus, the unstandardized regression coefficients indicate the annual gain in *z*-score units. These were .010, .014, and .012, respectively, for episodic memory, semantic memory, and the BDT (these are linear time terms; the inclusion of quadratic and cubic terms did not contribute with additional variance).

Next, analyses involving each cognitive variable as the criterion and the cohort markers as the predictors were conducted. The predictors were entered in five steps. The order was motivated by the hypothesized developmental sequence according to which the underlying constructs may be assumed to exert their influence. More specifically, nutritional changes, as reflected by body height, were assumed to exert the earliest influence, whereas the influence with regard to education was assumed to emerge last ontogentically.[3]

In the final step, test year was entered to examine if it still accounted for variance in performance beyond that accounted for by the other variables. Examination of Tolerance-values (>.40 in all cases) and Variance Inflation Factors (VIFs) revealed no indication of multicolinearity.

The results are summarized in Table 5. For illustrative purposes the reduction of the time-related variance (%SOS, for shared over simple effect; Lindenberger & Pötter, 1998, computed by entry of test year following each step in separate analyses) is provided (last column of each factor).

As can be seen, all steps 2–4 contribute with significant increments in variance accounted for on the episodic and semantic memory factors. Of particular interest, the cumulative percentage of time-related variance accounted for by the predictors (%SOS) increased from about 20% following entry of body height (step 2) to around 50% following entry of sibsize (step 3), approached 100% following entry of years of schooling (step 4). For the BDT a similar increment in % SOS is observed following step 2 (body height), but sibsize does not contribute significantly to variance in cognition beyond body height. In common with the memory factors education added substantially to the % SOS in step 4 (>94%; as for the memory factors, the variance accounted for by test year in the final step was non-significant), though.

The regression weights show that schooling was by far the strongest predictor of performance, throughout. Otherwise, the significance of weights obtained from the final equation confirmed that each cohort factor contributed with unique variance, except for sibsize in the case of BDT, in line with the prior observations.

4. Discussion

The results add to the bulk of evidence of substantial Flynn effects (e.g., Flynn, 1984, 1987) on cognitive test performance during the past century. The findings extend prior research by demonstrating FEs for episodic memory in addition to effects on semantic memory (crystallized intelligence) and visuospatial ability (Block Design) and by demonstrating that the effect generalize across age and gender. Finally, the analyses

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[3] As noted by a reviewer, cognitive birth-order/sibsize effects may also reflect biological factors. McKeown (1970) for example argued that there should be a negative relation between birth-weight and litter size due to retarded fetal growth and early delivery with a large sibsize. Thus, one could speculate that sibsize should be first. We acknowledge the potential presence of an early (pre-/postnatal) influence on the sibsize-cognition relationship but stick to the position that body height should be *more* indicative of early/biological factors than sibsize (re-analyses based on altered assumptions revealed similar results as those reported with regard to the significance of ΔR^2).

		Visuospatial ability (Block Design)			
Time 3 f/m	Time 4 f/m	Time 1 f/m	Time 2 f/m	Time 3 f/m	Time 4 f/m
.76/.35 (.50/.58)	.75/.66 (.71/.66)	.71/.85 (.91/.85)	.71/.94 (.86/.83)	.86/.89 (1.01/.75)	1.06/1.31 (.65/.79)
.66/.50 (.64/.77)	.75/.06 (.66/.66)	.47/.62 (.81/.72)	.71/.79 (.97/.86)	.66/.97 (.79/.91)	.80/.87 (.89/.90)
.93/.41 (.82/.83)	.69/.70 (.69/.62)	.27/.92 (.87/.71)	.29/.52 (.88/.93)	.79/.74 (.88/.88)	.54/.99 (.97/.66)
.68/.36 (.62/.74)	.77/.30 (.92/.80)	.41/.31 (.79/.82)	.38/.57 (.78/.71)	.37/.57 (.73/.85)	.09/.70 (.97/.81)
.49/.11 (.74/.62)	.54/−.02 (.72/.89)	.31/.36 (.93/.78)	−.09/.40 (.91/.83)	.17/.28 (.81/.76)	.42/.16 (.81/.91)
.20/−.01 (.84/.73)	.56/.20 (.86/1.13)	−.04/−.02 (.74/.73)	−.13/.17 (.77/.75)	.00/.00 (.60/.92)	−.01/.21 (1.08/.77)
−.06/.12 (.72/.71)	.34/.16 (.85/.73)	−.39/−.19 (.69/.96)	−.37/−.20 (.72/.80)	−.29/.03 (.64/.77)	−21/.23 (.90/.81)
.13/−.64 (.93/.94)	.24/−.44 (.82/1.02)	−.63/−.04 (.72/.82)	−.61/−.49 (.76/.72)	−.72/−.51 (.65/.78)	−.46/−.42 (1.02/.87)
−.53/−.56 (.81/.93)	−.50/−.38 (.79/.80)	−.87/−.78 (.74/.79)	−.67/−.71 (.77/.80)	−.85/−.55 (.63/.72)	−.87/−.41 (.78/.76)
−.39/−.82 (.87/.83)	−.14/−.85 (.92/.73)	−1.06/−1.20 (.71/.71)	−1.05/−.81 (.72/.82)	−.70/−1.06 (.73/.82)	−.67/−.72 (.76/.61)
.29/−.02 (.88/89)	.40/.03 (.88/.94)	−.09./.09 (.99/1.00)	−.12/.18 (.99/.99)	.03/.13 (.97/1.04)	.08/.29 (1.07/1.01)

of predictors of the time-lag effect have implications for theoretical accounts of FEs. Major aspects of the results are discussed below.

4.1. Overall pattern of gains

In spite of the impressive cognitive gains, it might be noted their overall magnitude, that corresponds to around 1.5 ΔIQ/decade overall, is smaller than estimates by Flynn (1984, 1987, 1999; cf. also Schaie et al., 2005). As such, the result in line with other indices that FEs were more modest in Sweden (Emanuelsson & Svensson, 1990; Emanuelsson et al., 1993) and other Scandinavian countries, including Norway and Denmark (Sundet et al., 2004; Teasdale & Owen, 2000) in comparison with other European countries (e.g., Colom et al., 2005) and the US.

A likely explanation is the early expansion of the welfare systems in Scandinavian countries, including early improved medical care, and an early expansion of the educational system (six-year compulsory school dates as far back as 1842 in Sweden). In addition, Swedish citizens may have been spared some of the cultural, social and material inefficiencies associated with World War II. Thus, the Swedish population may have reached a fairly high level early with somewhat more modest subsequent gains as a result. At this point, Finland that was heavily struck by the war, would, as noted by a reviewer, be interesting for purposes of comparison, but, to our knowledge, evidence regarding FEs in Finland is not yet available.

4.2. Ability specific patterns

Apart from the finding of substantial gains across the cognitive measures, the cohort-related patterns revealed a tendency of ability specific patterns. Specifically, the results deviate from the trend of larger gains for (broad) fluid as compared with crystallized tests (e.g., Flynn, 1994) with the overall magnitude being largest for semantic memory (mainly reflecting crystallized aspects). The gains in visuospatial performance (Block Design) were also substantial, but not larger than gains on the semantic factor. Considering the trends in more detail, a reversed trend of larger gains on the visuospatial task than on the semantic and episodic factors (for which gains across the 1954 to 1969 cohorts appear small) is discernible, though, much in line with prior indications (e.g., Teasdale & Owen, 2000). Also, the tendency of diminished FEs (1954–1969) on the memory factors appears to be in line with the aforementioned Swedish data (for 1970–1990 cohorts). From viewpoint of the data for memory, the present results constitute the first indication that Sweden underwent a period with large FEs (cf. Norway; Flynn, 1987) before a tendency of decelerated gains.

Interestingly, two recent Scandinavian studies (Norway; Sundet et al., 2004; Denmark; Teasdale & Owen, 2005) are not only indicative of deceleration, but a stagnation of the FEs (in cohorts born 1970s and onwards), even a slight recent trend of loss in the latter case, which the authors discussed in relation to changes in school attendance, instrumentation serving as a potentially confounding factor.[4] Future data from the Betula study should be able to tell whether the apparent end of the Flynn effect observed in Norway and Denmark generalizes to Sweden. In such a case, an interesting question is

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[4] Immigration is, as pointed out by a reviewer, another factor to consider (cf. Lynn & Vanhanen, 2002; te Nijenhuis, de Jong, Evers, and van der Flier, 2004).

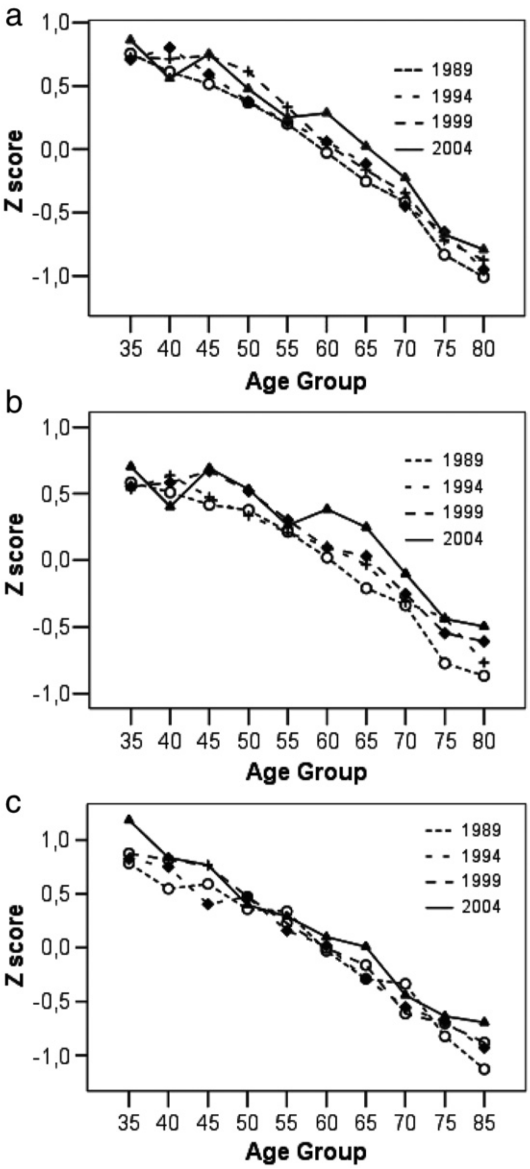

Fig. 2. a–c. Cross-sectional age gradients (z-scores) across test year for episodic memory (a), semantic memory (b), and visuospatial ability (Block Design).

whether the diminished FEs signals the approach of a genetically determined upper limit or only that the factors that have driven them thus far have lost their fuel; perhaps they will be replaced by others.

4.3. Are gender gaps narrowing?

The results confirmed the presence of a female advantage on episodic and semantic memory and a male advantage on the BDT, as observed in previous studies (Herlitz et al., 1997; Maitland et al., 2004; Rönnlund & Nilsson, 2006). Of major concern, the gender gaps for episodic memory and Block Design did not narrow across the 15-year period (cf. de Frias, Nilsson, & Herlitz, 2006). A possibility is that these differences reflect biological influences (e.g., hormonal influences; Hausman, Slabbekoorn, Van Goozen, Cohen-Kettenis, & Güntürkün, 2000) that are relatively immune to cultural/historical variation. Alternatively, part of the differences reflect persistent socio-cultural factors (e.g., Sharps, Price, & Williams, 1994), an issue that will likely be subject of continuing debate.

Interestingly, a tendency of a widening gender gap (i.e., a larger female advantage with advancing time) was observed on the semantic factor. At this point it is interesting to note that Emanuelsson et al. (Emanuelsson & Svensson, 1990; Emanuelsson et al., 1993) observed a growing gap in the same direction for 13-year children such that girls were more ahead of boys in 1990 as compared with 1960 (for a similar result, see Lynn & Hampson, 1986). Given the recent trends of higher levels of educational attainment for Swedish women as compared with men (SCB, 2006), one may speculate that a significant gender by time interaction will emerge in future analyses.

4.4. Flynn effects and adult age

Contrary to the hypothesis of different age trajectories with historical time (Schaie et al., 2005), we failed to detect any time by age interactions It could be argued that our analyses had little power to detect such influences as they might be expected to be manifest primarily in old age (e.g., effects of improved medical care). Also, a potential source of difference in outcome as compared to that of Schaie et al. (2005) is that the latter comparison pertained to an earlier historical time period (1956 and forward) presumably associated with more dramatic changes in regard to factors such as health care/life expectancy, which also hold for data in Uttl and van Alstine (2003).

In addition the data in Schaie et al. (2005) were obtained from within-group (longitudinal) comparisons. The present results were, by contrast, based on cross-sectional differences. This method may suffer from potential selectivity effects. Specifically, as a consequence of improved health care/increased life-length, old individuals from a more recent cohort may be less select at as compared with their counterparts from an earlier cohort. Given a positive correlation between selective survival and ability level/rate of change (e.g., Rabbitt, Lunn, & Wong, 2005), a comparison between old (same age) individuals from past and more recent

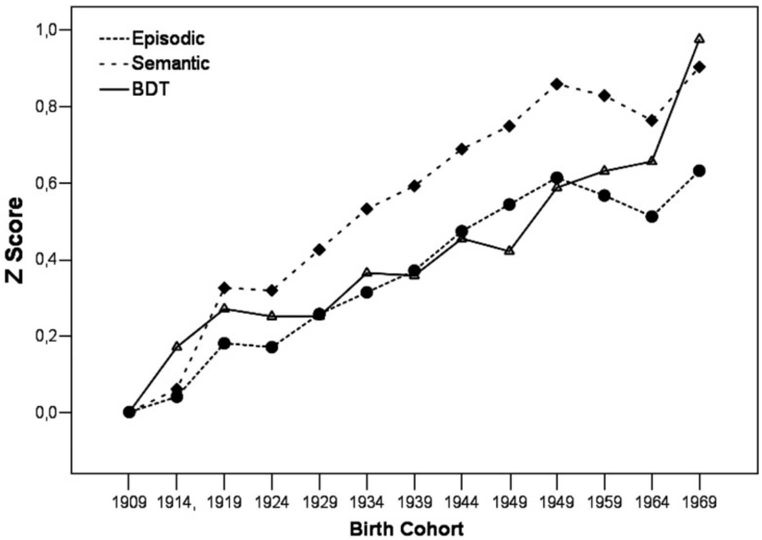

Fig. 3. Cumulative changes (z-scores) (1909–1969) on three cognitive factors (episodic memory, semantic memory, visuospatial ability) across birth cohorts.

cohort may thus be biased toward a smaller difference (perhaps yielding a net null effect if we assume some positive period influences). Thus, a longitudinal (or cohort-sequential) analysis may be preferred over the present analyses in this regard. Possibly, significant effect might emerge over an extended time window.[5] In any case, the present lack of time by interactions demonstrates the generality of the FEs.

Apart from underscoring the need to re-norm cognitive tests at frequent intervals, the finding that FEs generalize across adult age have implications with regard to the use of cross-sectional designs in cognitive aging research. Specifically, the simultaneous operation of cohort- and age-related influences will likely result in an overestimate of age-related decline on some measures (e.g., measures of Gv, Gf, and episodic memory) and underestimate a positive age-related influence on others (e.g., measures of semantic memory/crystallized intelligence; Rönnlund & Nilsson, 2006; Rönnlund et al., 2005; Schaie, 1996).

Of more practical concern, the finding that FEs persist in old age suggest that newer generations of elderly exhibit successively higher levels of cognitive performance, that may be well above yesterday's criteria of cognitive dysfunction (see Freedman, Aykan, & Martin, 2001). To the extent that these gains corresponds to an attenuation, or delay, of everyday functional inefficiencies resulting from age-related deficits certain cut-offs designating "oldness" (e.g., age of retirement, which typically occurs by age 65 in Sweden) may have to be reconsidered.

This touches upon the basic issue of whether FEs are accompanied by increased achievements in the population (cf. Cocodia et al., 2003; Flynn, 1987, 1998). Apart from evidence that more geniuses/patents et cetera emerge with FEs, it may be useful also to pay attention to groups expected to experience some cognitive deficits, such as older individuals. Findings that functional impairments of instrumental activities of daily living (IADLs; e.g., shopping for food, making phone calls), which are assumed to reflect a cognitive component (Rodgers, Oftesdal, & Herzog, 2003), have declined over time (Waidman & Liu, 2000) is consistent with the notion that FEs are accompanied by certain real-world achievements. These issues merit further attention.

4.5. The role of cohort factors

4.5.1. Body height

The magnitude of the estimated increment in body height over time/cohorts approached that of the cognitive variables. Despite the fact that the associations between height and cognition appear to be small, analyses indicated that about 20% of the time-lag gains across measures were predictable from the height gains alone. Thus, the hypothesis that changes in cognition and body growth reflect a common cause such as nutrition (Colom

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[5] If stagnation of FEs (e.g., Sundet et al., 2004) would turn out to be more permanent, future comparisons will likely yield a pattern of larger FEs in older cohorts regardless of period effects.

Table 4
Zero-order (top half of table) and partial correlations (controlling age and gender; bottom half of table) between cognitive variables, cohort variables and time of measurement

	1	2	3	4	5	6	7	8	9
1. Episodic memory	–	.91*	.61*	−.57*	−.12*	.13*	−.29*	.58*	.05*
2. Semantic memory	.88*	–	.60*	−.46*	−.10*	.13*	−.28*	.60*	.08*
3. Visuospatial ability	.44*	.48*	–	−.58*	.11*	.30*	−.23*	.52*	.06*
4. Age	−.62*	−.50*	−.58*	–	−.02	−.28*	.33*	−.55*	.00
5. Gender^{a}	−.12*	−.09*	.12*	−.62*	–	.71*	.02	.03	.04
6. Body height^{b}	.12*	.14*	.12*	−.50*	.74*	–	−.32*	.24*	.08*
7. Sibsize	−.13*	−.16*	−.06*	−.60*	.03	−.11*	–	−.32*	−.14*
8. Education	.41	.48*	.29*	−.56*	.02	.14*	−.18*	–	.14*
9. Test year	.08*	.10*	.07*	.00	.03	.07*	−.15*	.17*	–
N	2995	2995	2974	2995	2995	2968	2944	2957	–
M	.07	.09	.05	57.48	–	169.26	4.32	10.48	–
SD	.97	.95	1.01	14.36	–	9.46	2.67	4.28	–
Skewness	−.20	−.41	−.03	–	–	.62	1.34	.62	–
Kurtosis	−.24	.02	−.63	–	–	−.05	1.73	−.05	–

$^{*}p<.01$, ^{a}A negative sign indicates a female advantage, $^{b}M=162.80$, SD=6.51; $M=176.32$, SD=6.76 for females and males, respectively. Partial correlations for age and gender are when one is controlled (i.e., $r_{\text{age}\times y\cdot\text{gender}}$, or $r_{\text{gender}\times y\cdot\text{age}}$).

et al., 2005; Lynn 1990a; Lynn, 1998) received partial support.

4.5.2. Sibsize

The results confirmed a strong trend of a smaller sibsize over cohorts. There was also a significant association between sibsize and cognitive performance over and beyond other influences (cf. Holmgren, Molander, & Nilsson, 2006, submitted for publication). Sibsize predicted up to 30% of the time-related variance beyond variations in body height,[5] in line with the hypothesis that changes in family structure may have contributed to the FEs (Williams, 1998). Interestingly, the latter held true for the memory factors, but not Block Design for which sibsize did not turn out as a significant predictor. An explanation could be that effects of sibsize are mediated by early exposure to adult language and, thus, are attenuated on non-verbal measures (cf. Mercy & Steelman, 1982).

4.5.3. Education

In terms of magnitude (1.3 z) years of schooling was the cohort marker for which the largest change was apparent. Importantly, education also turned out as the strongest predictor of the time-lag gains, accounting for around 50% of the variance beyond that predicted from variations in height and sibsize. The fact that education emerged as the strongest predictor across all cognitive measures enforces the conclusion that education may exert influence on time-related patterns on (broad) fluid (visuospatial ability, episodic memory) as well as crystallized/semantic aspects of cognition (e.g., Schaie et al., 2005; Williams, 1998).

Table 5
Summary of hierarchic regression analyses of the cognitive factors

		Cognitive factor											
		Episodic memory				Semantic memory				Visuospatial ability (BDT)			
Step	Predictor	b/β^{a}	ΔR^2	ΣR^2	% SOS	b/β^{a}	ΔR^2	ΣR^2	% SOS	b/β^{a}	ΔR^2	ΣR^2	% SOS
1	Age	−.023/−.340**				−.011/−.163**				−.029/−.408**			
	Gender	−.362/−.186**		.347		−.346/−.182**		.227		.035/.017		.350	
2	Body height	.007/.071*	.009**	.356	21.2	.009/.088**	.014**	.241	18.6	.011/.102**	.009**	.359	24.8
3	Sibsize	−.017/−.046*	.009**	.364	51.8	−.021/−.059**	.015**	.255	47.9	.002/.005	.001	.360	39.8
4	Edu (years)	.086/.369**	.090**	.454	99.6	.107/.471**	.147**	.402	99.9	.065/.268**	.048**	.409	94.6
5	Test year	−.001/−.004	<.001	.454		.000/.002	<.001	.402		.003/.014	<.001	.409	

$^{*}p<.01$, **, $p<.001$. ^{a}The regression weights are from the final equation including all of the predictors. %SOS=Percentage shared over simple time effects.

Whereas the estimate of the cognition–education association must be considered as an upper-bound estimate due to a bidirectional relationship between cognitive level and education (Ceci, 1991; Ceci & Williams, 1997),[6] prior studies convincingly demonstrate a direct influence from educational to ability, that amount to about Δ1.8 IQ-units/school year (Ceci, 1991; see also Gustafsson, 2001). It is interesting to note that with the seven year difference at present (Table 1) the estimate by Ceci is sufficient to predict most of the cognitive gains observed at present, much in line with our argument. A particularly compelling piece of evidence that educational attainment has an effect on cognition is based on structural equation modelling of childhood measures and follow-up assessments in adulthood (Husén & Tuijnman, 1991).

Through which potential mechanisms could education elevate levels of cognitive performance? The hypothesis of a differential style of responding over time, toward more guessing and faster/more complete responding (Brand, 1987; Brand et al., 1989), presumably reflecting differences in educational practice, is not a plausible account. Specifically, eight of the ten cognitive tasks included as present required reproduction/recall rather than (two/multi-choice) recognition. For one of the remaining measures, scores were corrected for guessing.

Thus, schooling likely exerts its influence in a more general fashion than by altering test-taking/response strategies (encoding strategies could be a more important factor with regard to effects on episodic memory). Progression towards abstract reasoning with higher levels of educational attainment and over cohorts (possibly, accompanied by a shift in educational *practice* in the same direction; cf., Schaie et al., 2005) would presumably be beneficial across cognitive tasks. At the neural level, there are also indications that education may increase reserve capacity and alter brain activity in memory tasks in a more persistent fashion (Springer, McIntosh, Winocur, & Grady, 2005). More generally, cognitive stimulation offered by schooling and other factors may, in particular during a critical period, promote the development of the neural substrates underlying cognitive abilities (cf. Garlick, 2002; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005).

Given indications that school-related effects on cognition are a) temporally persistent and b) discernible at the neural level, we believe that they are more than superficial gains (cf. “head-start gains”, Lynn, 1990b). With regard to a third type of criterion of real (non-superficial) gains: transfer beyond the test-situation, there is as noted at least some positive evidence, even though specific role of education in this regard remains to be demonstrated.

An apparent difficulty with the argument that educational differences are a major factor behind the FEs, more generally, remains. Regardless of which cohort is considered, the minimum number of years in school (i.e. compulsory school) is 6 years. With a school start at age seven this means that cohorts differences in educational exposure will not appear before age 13. Yet, FEs in children below this age have been convincingly shown (e.g., Bocéréan, Fischer, & Flieller, 2003; Daley et al., 2003; Flynn, 1990; Lynn, 1990a; cf. Lynn, 1998).

A possibility is that the age at which the Flynn effect appears varies with socio-cultural context and that childhood data for the present samples would have revealed minimal FEs. In light of gains in Swedish 13-year-olds (Emanuelsson & Svensson, 1990; Emanuelsson et al., 1993) we regard this ad hoc argument implausible. Of more substantial concern, a comparison of FEs in children presupposes that the rate of cognitive maturation and peak level age is time invariant. Biologically, there is ample evidence that later-born cohorts matured faster, for example as judged from timing of puberty (Parent et al., 2003; Roche, 1979). This could be taken to suggest that part of the FEs in chidren might not be manifest at the peak level (cf. findings of a later catch-up in body growth for those who matured later due to a social disadvantage, Li, Manor, & Power, 2004). However, data in Schaie (1996), actually indicate a trend of *shift to a higher* cognitive peak level age with time. The possibility that Flynn effects are driven (in part) by a faster biological maturation (e.g., caused by nutrition) and prolonged neural growth (e.g., caused by cognitive stimulation) merits attention.

Thus, the need to consider changes in multiple factors (cf., Dickens & Flynn, 2001; Jensen, 1998) is underscored. First, we find it reasonable to predict that the relative contribution of causal factor varies across socio-cultural contexts. Changes in nutrition and child rearing practices may, for example, be more important for understanding the rapid gains currently observed in developing countries (Daley et al., 2003). The fact that Swedish height gains were smaller also as compared with most European countries (Schmidt et al., 1995) may, for example, restrict a restriction with regard to the impact of nutritional factors. Second, a reciprocal causal relationship likely exists among the environmental

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[6] Also the estimated influence from sibsize to cognition must also be considered as an upper-bound estimate given evidence that less cognitively able individuals have tended to have more children (e.g., Rodgers, Cleveland, van den Oord, & Rowe, 2000).

factors underlying FEs (cf. Dickens & Flynn, 2001; Lynn & Vanhanen, 2006). At the societal level, improved health-care and nutrition may, for example, serve to improve education via stimulating intellectual growth. In turn, educational attainment (e.g., via technological advances or direct knowledge) might serve to improve conditions with regard to nutrition and health-care. At the individual level education may affect wealth, family structure, factors that, in turn, will affect the milieu for the offspring in various ways.

Given such complexities any estimate of the relative influence of factors must be considered tentative. Nevertheless, in parallel with our assumptions concerning the relative influence of factors across stages of ontogenetic development we predict that the relative impact of factors that drive the FEs may shift with socio-cultural/societal development (effects of schooling may be dominant in settings where nutritional intake is well beyond deficiency limits). The implementation of sequential designs in cross-cultural settings would enable a test of these predictions. Given that similar approaches are taken in the context of child development and that longitudinal data on markers of relevant constructs are collected, the causal influence among factors that contribute to Flynn effects may be disentangled further.

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