

Supplementary Materials for

A strong dependency between changes in fluid and crystallized abilities in human cognitive aging

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This PDF file includes:

Figs. S1 to S8
Tables S1 to S14

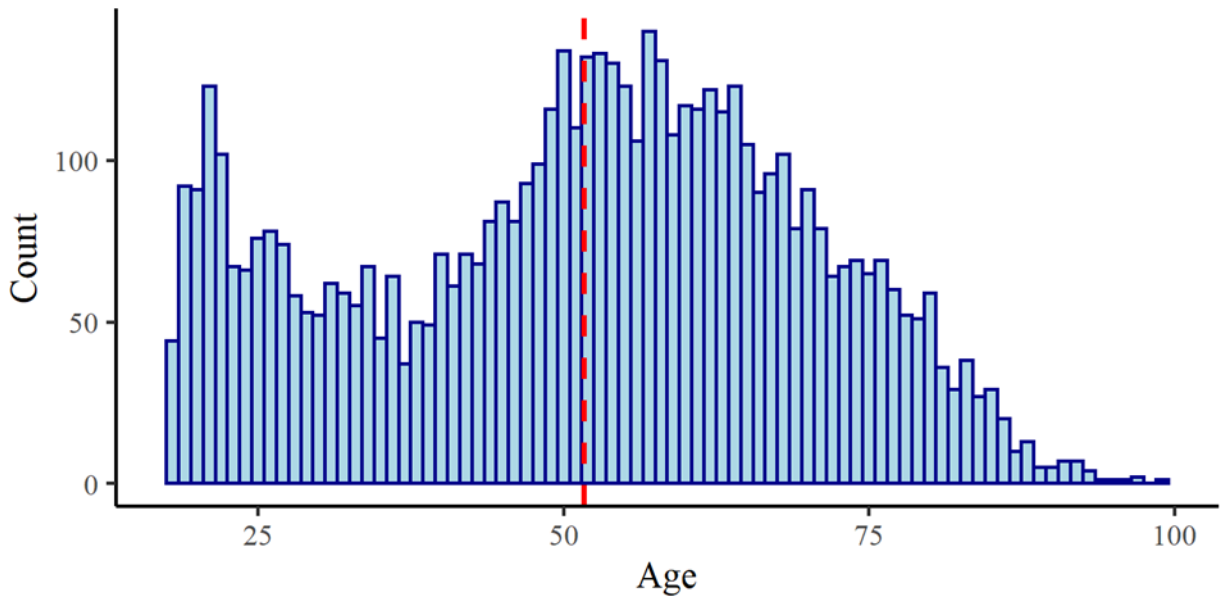


Fig. S1.

Age distribution at baseline ($N = 5566$, $M = 51.67$, $SD = 18.08$, range = 18–99 years) in VCAP.

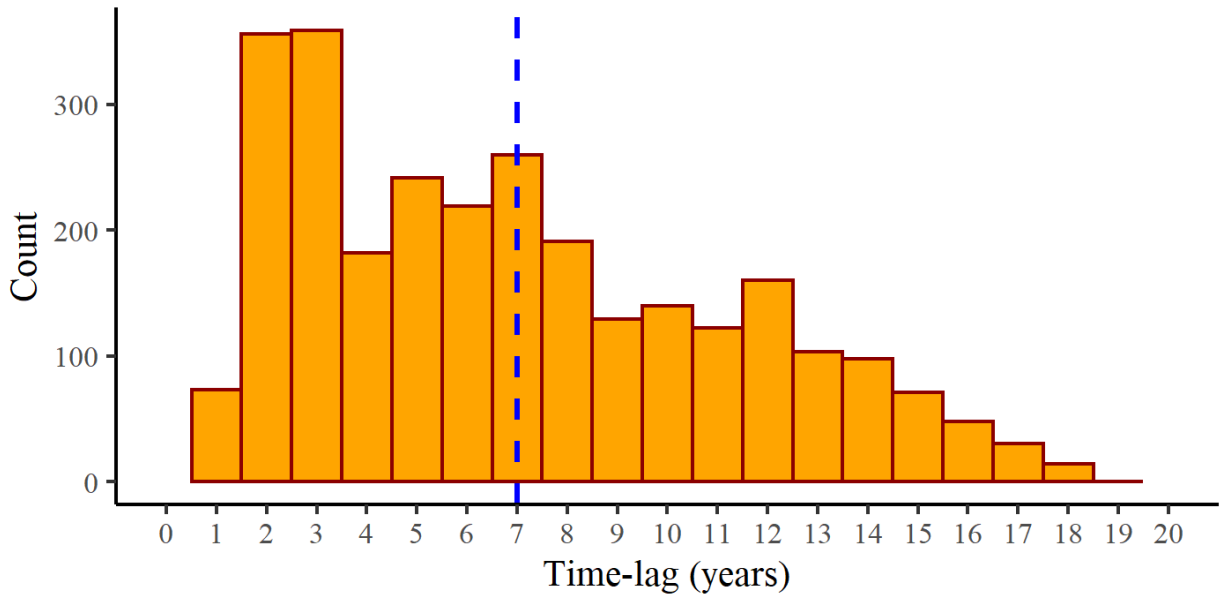


Fig. S2.

Time-lag distribution between baseline assessment and all subsequent assessments in VCAP (M = 7.00, SD = 4.21, range = 0.86–18.46 years).

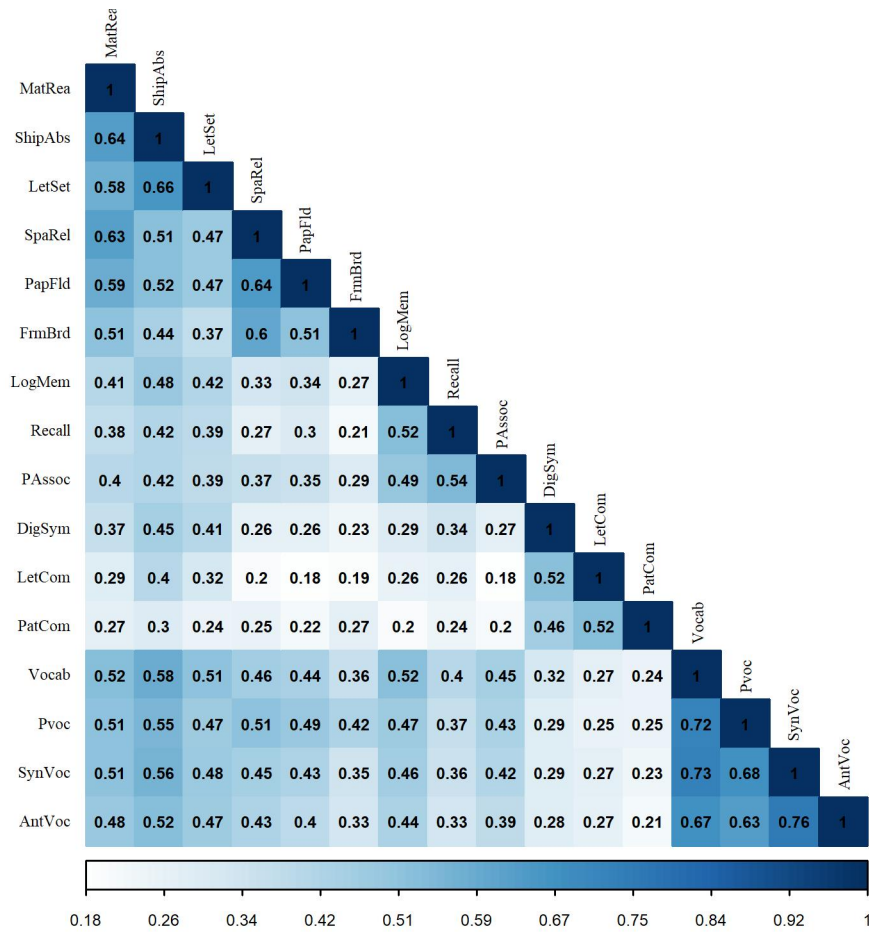


Fig. S3.

Heatmap of age-residualized correlations among VCAP test scores at baseline assessment.

Scores at baseline were residualized for age and age-squared.

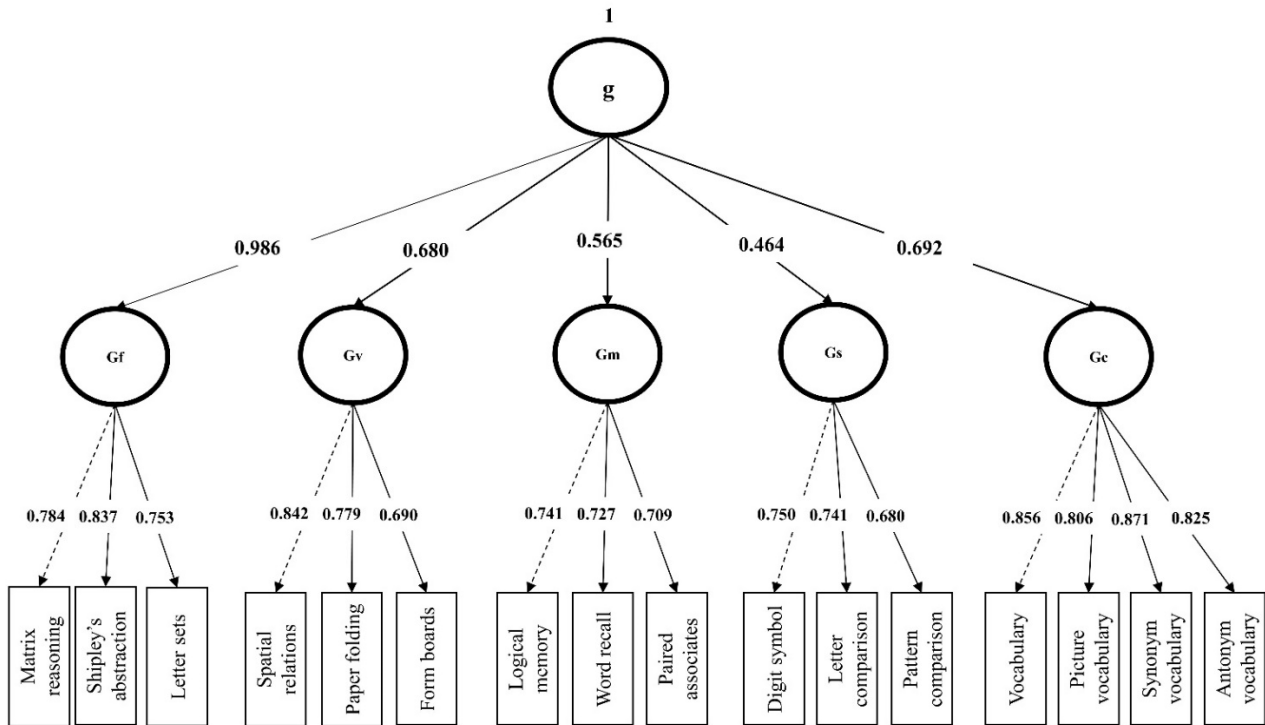


Fig. S4.

Fully standardized parameter estimates from age-residualized hierarchical common factor model of cognitive tests in VCAP at baseline. *Scores at baseline were residualized for age and age-squared.*

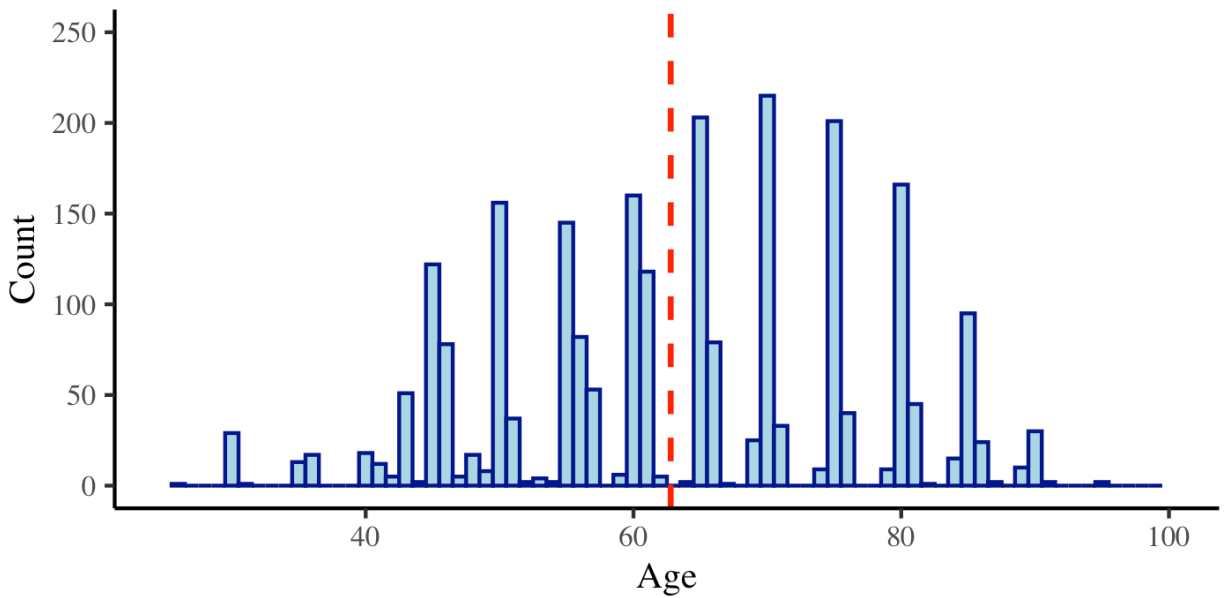
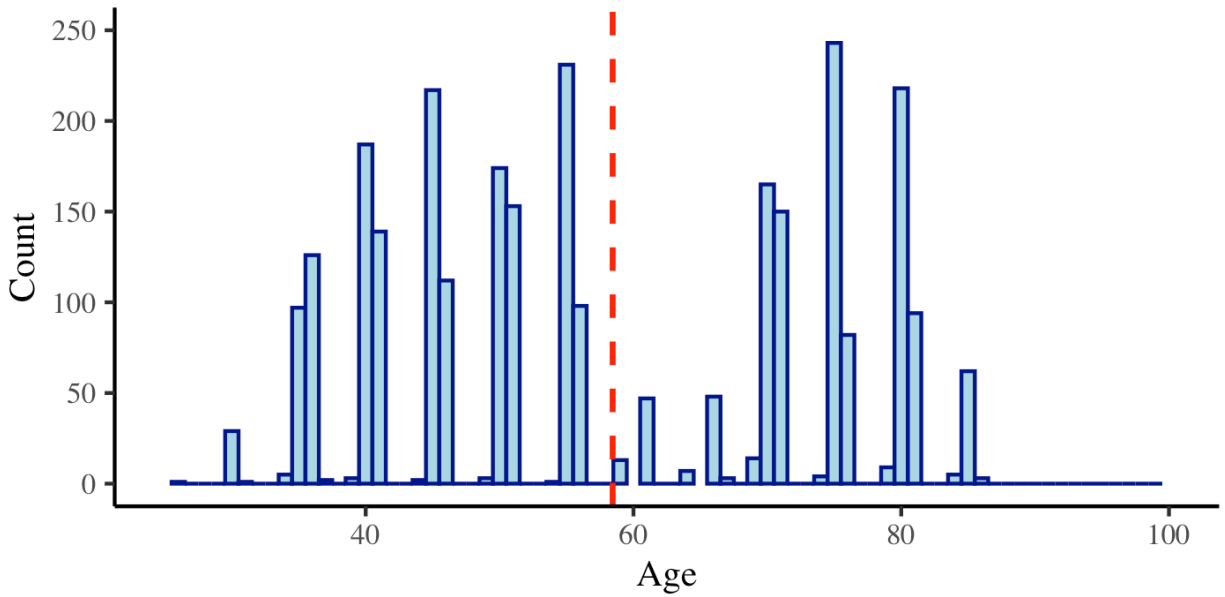


Fig. S5.

Age distributions at baseline in BETULA. Upper panel: Age distribution in tests for visuospatial reasoning, memory, and crystallized ability ($M = 58.45$, $SD = 14.73$, range = 25–86 years).

Lower panel: Age distribution in test for perceptual speed ($M = 62.78$, $SD = 14.05$, range = 25–95 years).

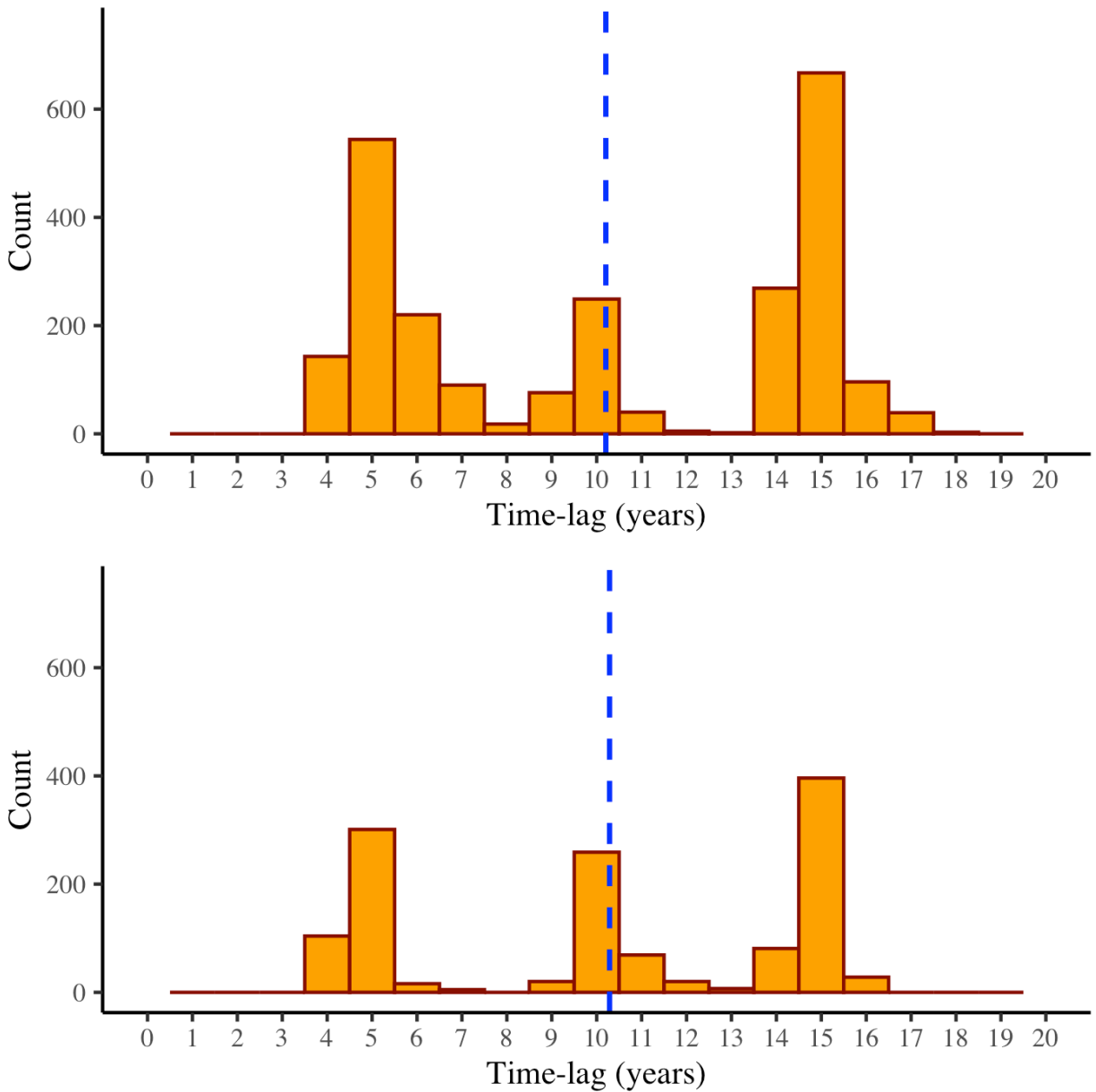


Fig. S6.

Time-lag distribution between baseline assessment and all subsequent assessments in BETULA.

Upper panel: Time-lag distribution in tests for visuospatial reasoning, memory, and crystallized ability ($M = 10.20$, $SD = 4.50$, range = 4–18 years). Lower panel: Time-lag distribution in test

for perceptual speed ($M = 10.29$, $SD = 4.28$, range = 4–16 years).

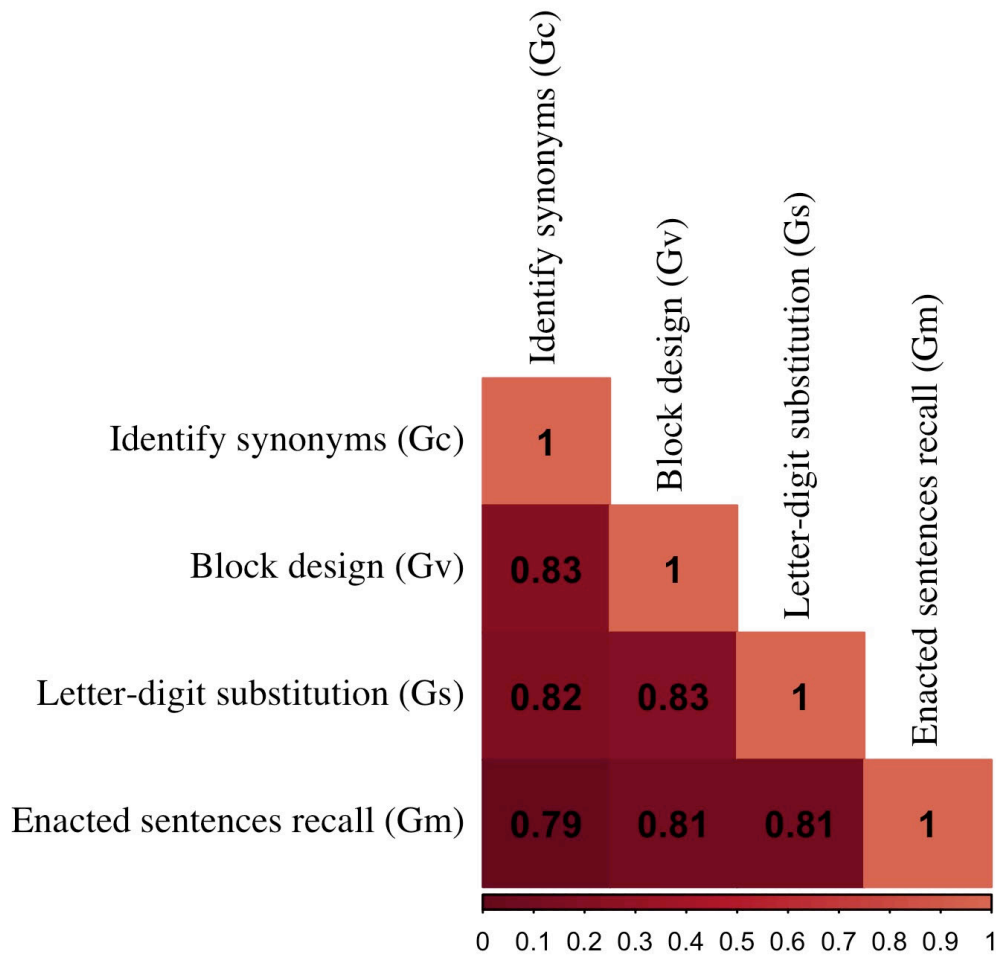


Fig. S7.

Heatmap of age-residualized correlations among standardized test scores at baseline assessment (T1) in BETULA. *Test scores at baseline were residualized by age and age-squared.*

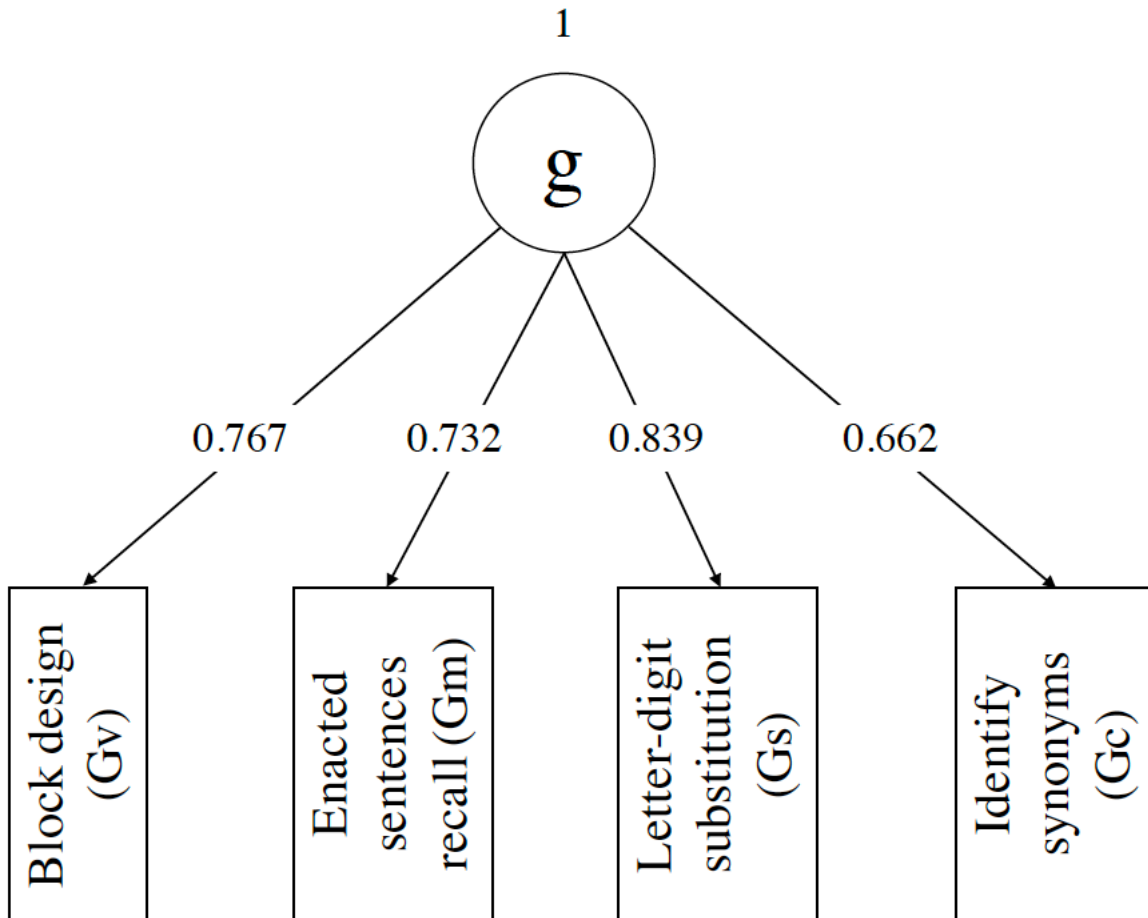


Fig. S8.

Fully standardized parameter estimates from age-residualized common factor model of cognitive tests at baseline (T1) in BETULA. *Test scores at baseline were residualized by age and age-squared.*

Table S1.

Sample size across assessments and cognitive tests in VCAP.

Domain	Cognitive test	Assessment							
		T1	T2	T3	T4	T5	T6	T7	T8
		N	N	N	N	N	N	N	N
Gf	Matrix reasoning	5435	2768	1639	1014	555	215	66	11
	Shipley's abstraction	4665	2733	1636	1003	538	212	64	11
	Letter sets	4894	2552	1447	887	477	181	56	9
Gv	Spatial relations	5432	2751	1621	996	537	204	64	11
	Paper folding	5451	2768	1632	997	542	205	64	11
	Form boards	5105	2666	1560	964	525	205	61	11
Gm	Logical memory	5488	2759	1646	1014	545	213	65	11
	Word recall	5548	2792	1673	1022	555	214	67	11
	Paired associates	5063	2781	1665	1021	555	215	67	11
Gs	Digit symbol	5546	2792	1672	1017	555	214	67	11
	Letter comparison	5494	2788	1671	1019	555	215	67	11
	Pattern comparison	5491	2789	1672	1018	555	215	67	11
Gc	Vocabulary	5553	2780	1661	1013	548	214	67	10
	Picture vocabulary	5556	2793	1672	1022	554	215	66	11
	Synonym vocabulary	5423	2762	1658	1006	547	213	67	11
	Antonym vocabulary	5398	2759	1657	1007	547	213	67	11

Table S2.

Time-lag (years) since baseline assessment (T1) across follow-up assessments (T2–T8) in

VCAP.

	Follow-up assessment													
	T2		T3		T4		T5		T6		T7		T8	
Years since	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Baseline (T1)	3.13	1.89	6.04	2.09	8.55	2.16	11.35	2.38	13.35	2.04	14.82	2.31	15.43	1.18
Previous assessment	3.13	1.89	3.23	1.62	2.80	1.18	3.09	1.34	3.11	1.13	2.06	0.53	3.00	1.65

Table S3.

Description of tasks in VCAP used in this study

Domain	Variable	Description
Gf	Matrix reasoning	Select the pattern that best completes the missing cell in a 3×3 matrix
	Shipley's abstraction	Determine the letters, words, or numbers that best complete a progressive sequence
	Letter sets	Identify which of five groups of letters follows a different pattern from the others
Gv	Spatial relations	Determine which three-dimensional object could be constructed by folding the two-dimensional object
	Paper folding	Determine the location of holes that would result from a punch through a sequence of folds of a piece of paper
	Form boards	Determine which shapes are needed to fill in a target space
Gm	Logical memory	Remember as many idea units as possible from three stories
	Word recall	Recall as many words as possible across four-word list trials
Gs	Paired associates	Recall the second words from word pairs
	Digit symbol	Use a code table to write the corresponding symbol below each digit
	Letter comparison	Compare pairs of letter strings and judge whether they are the same or different
Gc	Pattern comparison	Compare pairs of line patterns and judge whether they are the same or different
	Vocabulary	Define words out loud
	Picture vocabulary	Name the objects pictured
	Synonym vocabulary	Choose the word most similar in meaning to the target
	Antonym vocabulary	Choose the word most opposite in meaning to the target

Note: This table was adapted from (50).

Table S4.

Description of tasks in BETULA used in this study

Domain	Variable	Description
Gv	Block design	Place red and white blocks to form a target pattern
Gm	Enacted sentences recall	Recall two-word sentences from a list of 16 that have been enacted just before (e.g., "roll the ball")
Gs	Letter-digit substitution	Use a code table to write down letter corresponding to each digit
Gc	Identify synonyms	Underline the synonym to a target word in a row of five words written next to the target word

Table S5.

Sample size across assessments and cognitive tests in BETULA.

Domain	Cognitive Test	Assessment			
		T1 N	T2 N	T3 N	T4 N
Gv	Block design	3317	2259	1214	891
Gm	Enacted sentences recall	3319	2270	1218	900
Gs	Letter-digit substitution	2387	1140	740	459
Gc	Identify synonyms	3319	2322	1272	969

Table S6.

Time-lag (years) since baseline assessment (T1) across follow-up assessments (T2–T4) in
BETULA.

Years since	T2		T3		T4	
	M	SD	M	SD	M	SD
Baseline (T1) in Gv, Gm, Gc	5.11	0.67	9.92	0.58	14.92	0.71
Previous assessment in Gv, Gm, Gc	5.11	0.67	4.95	0.47	4.98	0.54
Baseline (T1) in Gs	4.87	0.50	10.17	0.56	14.89	0.46
Previous assessment in Gs	4.87	0.50	5.26	0.50	4.81	0.41

Table S7. Parameter estimates from time-based factor of curves models in VCAP with constant retest specification.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_f^a	0.082 (0.015)	-0.016 (0.013)	-0.092 (0.051)	-0.038 (0.034)	0.905 (0.010)	0.542 (0.040)	0.317 (0.036)	0.980 (0.005)	0.830 (0.035)	0.894 (0.027)	0.109 (0.004)	0.033 (0.008)	0.132 (0.030)	0.025 (0.004)	-0.048 (0.018)	0.019 (0.013)	-0.056 (0.012)
G_v^a	0.061 (0.015)	-0.006 (0.013)	0.088 (0.049)	-0.095 (0.033)	0.755 (0.009)	0.529 (0.044)	0.326 (0.036)	0.841 (0.006)	0.954 (0.048)	0.962 (0.010)	0.103 (0.004)	0.236 (0.008)	0.027 (0.031)	0.009 (0.002)	-0.035 (0.018)	0.022 (0.012)	-0.013 (0.012)
G_m^a	0.038 (0.017)	0.001 (0.012)	-0.004 (0.058)	-0.063 (0.039)	0.645 (0.011)	0.811 (0.045)	0.490 (0.042)	0.761 (0.008)	0.893 (0.029)	0.972 (0.005)	0.122 (0.005)	0.303 (0.010)	0.167 (0.049)	0.014 (0.001)	-0.071 (0.023)	0.014 (0.017)	-0.048 (0.017)
G_s^a	0.038 (0.018)	0.001 (0.014)	-0.176 (0.057)	-0.087 (0.038)	0.694 (0.013)	0.655 (0.048)	0.399 (0.040)	0.712 (0.009)	0.974 (0.044)	0.975 (0.015)	0.131 (0.006)	0.469 (0.014)	0.023 (0.041)	0.008 (0.005)	0.050 (0.031)	-0.035 (0.024)	-0.001 (0.015)
G_c^b	0.006 (0.011)	-0.003 (0.011)	0.083 (0.032)	-0.062 (0.021)	0.446 (0.011)	0.330 (0.022)	0.194 (0.018)	0.502 (0.010)	0.940 (0.058)	0.946 (0.009)	0.050 (0.003)	0.590 (0.011)	0.014 (0.015)	0.004 (0.000)	-0.071 (0.016)	0.026 (0.013)	-0.007 (0.005)

$\rho_{F_i,F_s}^a=0.239$ ($p<0.001$), $\rho_{F_i,F_q}^a=-0.137$ ($p=0.011$), $\rho_{F_s,F_q}^a=-0.897$ ($p<0.001$).

1. The variance of F_i , F_s and F_q were fixed to 1.0 to define the metrics of the latent growth factors.

2. We specified time-based growth curve modelling, such that the basis coefficients for each of the five slopes were set to the time in decades from baseline to each assessment on variable w .

3. Each of the five cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .

Table S8. Parameter estimates from age-based factor of curves models in VCAP with logarithmic retest specification.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_f^a	0.188 (0.009)	0.188 (0.015)	-0.229 (0.006)	-0.046 (0.003)	0.879 (0.016)	0.213 (0.020)	0.057 (0.006)	1.014 (0.007)	1 (0.092)	0.959 (0.014)	0.114 (0.003)	-0.021 (0.011)	0.000 (0.008)	0.000 (0.000)	0.008 (0.003)	-0.002 (0.004)	0.000 (0.000)
G_v^a	0.245 (0.008)	0.110 (0.015)	-0.233 (0.006)	-0.021 (0.003)	0.700 (0.014)	0.133 (0.017)	0.045 (0.007)	.816 (0.009)	0.898 (0.191)	0.972 (0.012)	0.106 (0.004)	0.247 (0.011)	0.004 (0.009)	0.000 (0.000)	-0.017 (0.003)	-0.003 (0.005)	0.000 (0.000)
G_m^a	0.200 (0.011)	0.197 (0.015)	-0.210 (0.006)	-0.047 (0.003)	0.581 (0.017)	0.153 (0.014)	0.056 (0.005)	0.727 (0.014)	0.773 (0.119)	0.866 (0.037)	0.135 (0.004)	0.302 (0.013)	0.016 (0.012)	0.001 (0.000)	0.002 (0.004)	-0.014 (0.006)	-0.001 (0.001)
G_s^a	0.160 (0.010)	0.212 (0.014)	-0.344 (0.006)	-0.045 (0.003)	0.453 (0.017)	0.145 (0.012)	0.043 (0.005)	0.584 (0.017)	0.833 (0.181)	0.872 (0.061)	0.133 (0.005)	0.397 (0.014)	0.009 (0.013)	0.001 (0.000)	-0.029 (0.005)	-0.009 (0.006)	0.001 (0.001)
G_c^b	-0.009 (0.006)	0.121 (0.010)	0.120 (0.004)	-0.039 (0.002)	0.725 (0.012)	0.130 (0.006)	0.045 (0.003)	0.782 (0.008)	0.957 (0.129)	0.931 (0.033)	0.049 (0.002)	0.333 (0.012)	0.002 (0.005)	0.000 (0.000)	-0.007 (0.003)	-0.006 (0.003)	0.000 (0.000)
	Retest Basis coefficients								Implied retest means								
	T1	T2	T3	T4	T5	T6	T7	T8	T1	T2	T3	T4	T5	T6	T7	T8	
G_f^a	0	0.693	1.099	1.386	1.609	1.792	1.946	2.079	0	0.130	0.207	0.261	0.302	0.337	0.366	0.391	
G_v^a	0	0.693	1.099	1.386	1.609	1.792	1.946	2.079	0	0.170	0.269	0.340	0.394	0.439	0.477	0.509	
G_m^a	0	0.693	1.099	1.386	1.609	1.792	1.946	2.079	0	0.139	0.220	0.277	0.322	0.358	0.389	0.416	
G_s^a	0	0.693	1.099	1.386	1.609	1.792	1.946	2.079	0	0.111	0.176	0.222	0.257	0.287	0.311	0.333	
G_c^b	0	0.693	1.099	1.386	1.609	1.792	1.946	2.079	0	-0.006	-0.010	-0.012	-0.014	-0.016	-0.018	-0.019	

$\rho_{F_i,F_s}^a = -0.098$ ($p=0.031$), $\rho_{F_i,F_q}^a = -0.913$ ($p<0.001$), $\rho_{F_s,F_q}^a = 0.116$ ($p=0.240$).

1. The variance of F_i , F_s and F_q were fixed to 1.0 to define the metrics of the latent growth factors.
2. We specified age-based growth curve modelling, such that the basis coefficients for each of the five slopes were set to the age in decades of individual n at each assessment on variable w , centered at 50 years.
3. Each of the five cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .

Table S9. Parameter estimates from age-based factor of curves models in VCAP with latent basis retest specification.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_f^a	0.125 (0.009)	0.194 (0.015)	-0.235 (0.007)	-0.048 (0.003)	0.881 (0.016)	0.212 (0.021)	0.057 (0.007)	1.013 (0.007)	1.001 (0.099)	0.959 (0.014)	0.113 (0.003)	-0.020 (0.011)	0.000 (0.009)	0.000 (0.000)	0.008 (0.003)	-0.002 (0.004)	0.000 (0.000)
G_v^a	0.148 (0.009)	0.118 (0.015)	-0.238 (0.006)	-0.023 (0.003)	0.703 (0.013)	0.133 (0.017)	0.045 (0.007)	0.816 (0.009)	0.897 (0.215)	0.973 (0.012)	0.105 (0.003)	0.247 (0.011)	0.004 (0.010)	0.000 (0.000)	-0.018 (0.003)	-0.003 (0.005)	0.000 (0.000)
G_m^a	0.101 (0.010)	0.214 (0.015)	-0.217 (0.006)	-0.050 (0.003)	0.588 (0.017)	0.151 (0.015)	0.056 (0.005)	0.730 (0.013)	0.766 (0.133)	0.870 (0.036)	0.136 (0.004)	0.303 (0.013)	0.016 (0.013)	0.001 (0.000)	0.002 (0.004)	-0.015 (0.006)	-0.001 (0.001)
G_s^a	0.090 (0.010)	0.220 (0.014)	-0.349 (0.006)	-0.047 (0.003)	0.455 (0.017)	0.145 (0.012)	0.043 (0.005)	0.585 (0.017)	0.834 (0.195)	0.876 (0.061)	0.134 (0.005)	0.398 (0.015)	0.009 (0.014)	0.001 (0.000)	-0.028 (0.005)	-0.009 (0.007)	0.001 (0.001)
G_c^b	-0.001 (0.001)	0.121 (0.010)	0.116 (0.004)	-0.040 (0.002)	0.725 (0.012)	0.131 (0.006)	0.044 (0.003)	0.782 (0.008)	0.960 (0.145)	0.929 (0.036)	0.046 (0.003)	0.334 (0.012)	0.001 (0.006)	0.000 (0.000)	-0.007 (0.005)	-0.005 (0.005)	0.000 (0.040)
Basis coefficients								Implied retest means									
	T1	T2	T3	T4	T5	T6	T7	T8		T1	T2	T3	T4	T5	T6	T7	T8
G_f^a	0	1.000	1.710 (0.084)	2.062 (0.102)	2.631 (0.136)	3.169 (0.216)	3.950 (0.382)	4.391 (0.713)		0	0.125	0.214	0.258	0.329	0.396	0.494	0.549
G_v^a	0	1.000	1.904 (0.070)	2.396 (0.080)	2.764 (0.104)	3.239 (0.182)	4.191 (0.851)	3.623 (0.512)		0	0.148	0.282	0.355	0.409	0.479	0.620	0.536
G_m^a	0	1.000	2.129 (0.106)	3.114 (0.125)	3.958 (0.160)	4.651 (0.261)	5.468 (0.410)	4.758 (0.864)		0	0.101	0.215	0.315	0.400	0.470	0.552	0.481
G_s^a	0	1.000	1.995 (0.122)	2.749 (0.145)	3.086 (0.172)	3.780 (0.328)	3.779 (0.410)	2.494 (1.867)		0	0.090	0.180	0.247	0.278	0.340	0.340	0.224
G_c^b	0	1.000	9.524 (7.854)	-5.470 (4.347)	3.594 (2.326)	5.019 (6.854)	-1.853 (5.057)	-4.687 (5.617)		0	-0.001	-0.010	0.005	-0.004	-0.005	0.002	0.005

$\rho_{F_i, F_s}^a = -0.096$ ($p=0.034$), $\rho_{F_i, F_q}^a = -0.922$ ($p<0.001$), $\rho_{F_s, F_q}^a = 0.106$ ($p=0.277$).

1. The variance of F_i , F_s and F_q were fixed to 1.0 to define the metrics of the latent growth factors.

2. We specified age-based growth curve modelling, such that the slope basis coefficients for each of the five slopes were set to the age in decades of individual n at each assessment on variable w , centered at 50 years.

3. Each of the five cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .

Table S10. Parameter estimates from age-based factor of curves models in VCAP with constant retest specification for observations made at ages less than or equal to age 65 years.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_f^a	0.126 (0.010)	0.200 (0.018)	-0.134 (0.009)	-0.006 (0.006)	0.864 (0.018)	0.239 (0.019)	0.063 (0.017)	1.006 (0.009)	0.999 (0.101)	0.902 (0.060)	0.108 (0.004)	-0.009 (0.014)	0.000 (0.012)	0.001 (0.000)	0.006 (0.004)	-0.003 (0.006)	0.001 (0.001)
G_v^a	0.200 (0.011)	0.148 (0.019)	-0.166 (0.010)	0.010 (0.006)	0.709 (0.015)	0.203 (0.021)	0.044 (0.022)	0.813 (0.011)	0.848 (0.093)	0.773 (0.186)	0.108 (0.006)	0.259 (0.014)	0.016 (0.011)	0.001 (0.001)	-0.017 (0.005)	-0.012 (0.006)	0.002 (0.001)
G_m^a	0.150 (0.012)	0.189 (0.018)	-0.126 (0.009)	-0.001 (0.006)	0.589 (0.019)	0.205 (0.039)	0.078 (0.015)	0.728 (0.016)	0.781 (0.118)	0.829 (0.059)	0.132 (0.005)	0.308 (0.016)	0.027 (0.014)	0.003 (0.001)	0.003 (0.006)	-0.027 (0.007)	-0.001 (0.002)
G_s^a	0.121 (0.012)	0.353 (0.018)	-0.277 (0.009)	-0.032 (0.006)	0.453 (0.024)	0.187 (0.036)	0.061 (0.016)	0.564 (0.022)	0.842 (0.147)	0.826 (0.088)	0.142 (0.007)	0.439 (0.019)	0.014 (0.015)	0.002 (0.001)	-0.025 (0.008)	-0.022 (0.008)	0.001 (0.002)
G_c^b	-0.014 (0.007)	-0.004 (0.013)	0.167 (0.006)	-0.030 (0.004)	0.719 (0.014)	0.128 (0.010)	0.044 (0.005)	0.764 (0.010)	0.895 (0.114)	0.803 (0.063)	0.044 (0.002)	0.368 (0.014)	0.004 (0.005)	0.001 (0.000)	0.000 (0.004)	-0.015 (0.003)	0.000 (0.001)

$\rho_{F_i,F_s}^a=0.014$ ($p=0.757$), $\rho_{F_i,F_q}^a=-0.867$ ($p<0.001$), $\rho_{F_s,F_q}^a=0.077$ ($p=0.524$).

1. The variance of F_i , F_s and F_q were fixed to 1.0 to define the metrics of the latent growth factors.
2. We specified age-based growth curve modelling, such that the basis coefficients for each of the five slopes were set to the age in decades of individual n at each assessment on variable w , centered at 44.53 years (mean age at baseline for the subsample of observations made at ages less than or equal to years old).
3. Each of the five cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .

Table S11. Parameter estimates from time-based factor of curves models in BETULA with constant retest specification.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_v^a	-0.078 (0.015)	-0.001 (0.022)	-0.43 (0.344)	-0.791 (0.442)	0.95 (0.018)	0.823 (0.042)	0.098 (0.021)	0.812 (0.01)	0.479 (0.021)	0.047 (0.01)	0.253 (0.007)	0.464 (0.022)	2.273 (0.102)	4.432 (0.198)	-0.238 (0.073)	0.279 (0.102)	-3.165 (0.142)
G_m^a	-0.109 (0.084)	0.000 (0.022)	0.222 (0.496)	-1.558 (0.637)	0.887 (0.02)	0.824 (0.059)	0.1 (0.042)	0.864 (0.011)	0.814 (0.024)	0.145 (0.025)	0.52 (0.012)	0.268 (0.019)	0.345 (0.034)	0.470 (0.06)	-0.034 (0.02)	0.059 (0.025)	-0.369 (0.045)
G_s^a	0.175 (0.067)	-0.178 (0.029)	-2.12 (0.421)	-0.038 (0.548)	1.332 (0.025)	1.301 (0.072)	0.423 (0.056)	0.928 (0.008)	0.933 (0.009)	-0.344 (0.03)	0.212 (0.018)	0.284 (0.013)	0.252 (0.033)	1.331 (0.179)	-0.059 (0.05)	0.325 (0.112)	-0.519 (0.072)
G_c^b	-0.016 (0.049)	0.004 (0.015)	0.124 (0.296)	-0.672 (0.381)	0.679 (0.018)	0.648 (0.053)	-0.085 (0.028)	0.687 (0.012)	0.705 (0.04)	-0.094 (0.03)	0.178 (0.007)	0.516 (0.02)	0.425 (0.1)	0.803 (0.126)	-0.095 (0.048)	0.193 (0.077)	-0.425 (0.102)

$\rho_{F_i,F_s}^a = 0.9$ ($p < 0.001$), $\rho_{F_i,F_q}^a = -2.013$ ($p = 0.011$), $\rho_{F_s,F_q}^a = -0.869$ ($p < 0.001$).

1. The variance of F_i , F_s and F_q were fixed to 1.0 to define the metrics of the latent growth factors.
2. We specified time-based growth curve modelling, such that the basis coefficients for each of the five slopes were set to the time in 25-years steps from baseline to each assessment on variable w.
3. Each of the four cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .

Table S12. Parameter estimates from age-based factor of curves models in BETULA with logarithmic retest specification.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_v^a	0.232 (0.017)	0.571 (0.021)	-1.007 (0.04)	-0.525 (0.031)	0.603 (0.031)	0.163 (0.091)	0.262 (0.066)	0.646 (0.029)	0.75 (0.197)	0.826 (0.148)	0.267 (0.007)	0.509 (0.036)	0.021 (0.01)	0.032 (0.031)	-0.020 (0.025)	-0.105 (0.037)	-0.001 (0.033)
G_m^a	0.281 (0.02)	0.594 (0.02)	-0.823 (0.039)	-0.694 (0.034)	0.478 (0.03)	0.163 (0.082)	0.255 (0.07)	0.708 (0.037)	0.578 (0.182)	0.891 (0.054)	0.515 (0.012)	0.227 (0.028)	0.074 (0.027)	0.017 (0.004)	0.057 (0.023)	-0.036 (0.042)	-0.032 (0.031)
G_s^a	0.27 (0.021)	0.998 (0.027)	-1.043 (0.055)	-0.871 (0.041)	0.653 (0.035)	0.421 (0.121)	0.311 (0.16)	0.76 (0.032)	0.697 (0.12)	0.657 (0.215)	0.211 (0.019)	0.311 (0.04)	0.188 (0.06)	0.128 (0.034)	0.017 (0.036)	-0.083 (0.056)	-0.154 (0.038)
G_c^b	0.236 (0.015)	0.350 (0.016)	-0.175 (0.031)	-0.608 (0.027)	0.617 (0.025)	0.308 (0.031)	0.225 (0.049)	0.757 (0.021)	0.773 (0.041)	0.403 (0.095)	0.163 (0.006)	0.283 (0.025)	0.064 (0.012)	0.261 (0.07)	0.110 (0.029)	-0.075 (0.034)	-0.080 (0.057)
	Retest Basis coefficients								Implied retest means								
		T1	T2	T3	T4						T1	T2	T3	T4			
G_v^a		0	0.693	1.099	1.386						0	0.161	0.255	0.322			
G_m^a		0	0.693	1.099	1.386						0	0.187	0.297	0.374			
G_s^a		0	0.693	1.099	1.386						0	0.195	0.309	0.390			
G_c^b		0	0.693	1.099	1.386						0	0.164	0.259	0.327			

$\rho_{F_i,F_s}^a = 0.302$ ($p=0.142$), $\rho_{F_i,F_q}^a = -0.596$ ($p<0.001$), $\rho_{F_s,F_q}^a = 0.193$ ($p=0.784$).

1. The variance of F_i , F_s and F_q were fixed to 1.0 to define the metrics of the latent growth factors.

2. We specified age-based growth curve modelling, such that the basis coefficients for each of the five slopes were set to the age in decades of individual n at each assessment on variable w , centered at 50 years.

3. Each of the five cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .

Table S13. Parameter estimates from age-based factor of curves models in BETULA with latent basis retest specification.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_v^a	0.103 (0.016)	0.592 (0.022)	-1.029 (0.04)	-0.524 (0.031)	0.608 (0.031)	0.142 (0.089)	0.266 (0.064)	0.648 (0.029)	0.732 (0.224)	0.827 (0.155)	0.265 (0.007)	0.509 (0.036)	0.018 (0.009)	0.033 (0.034)	-0.017 (0.026)	-0.107 (0.037)	-0.001 (0.034)
G_m^a	0.148 (0.021)	0.607 (0.02)	-0.842 (0.039)	-0.696 (0.034)	0.479 (0.03)	0.180 (0.079)	0.253 (0.069)	0.708 (0.037)	0.555 (0.186)	0.887 (0.056)	0.514 (0.012)	0.228 (0.028)	0.072 (0.027)	0.017 (0.004)	0.056 (0.023)	-0.036 (0.042)	-0.032 (0.031)
G_s^a	0.215 (0.019)	1.000 (0.027)	-1.055 (0.056)	-0.873 (0.041)	0.652 (0.035)	0.408 (0.127)	0.308 (0.164)	0.758 (0.032)	0.680 (0.132)	0.650 (0.223)	0.211 (0.019)	0.314 (0.04)	0.194 (0.064)	0.13 (0.036)	0.016 (0.036)	-0.084 (0.057)	-0.157 (0.039)
G_c^b	0.148 (0.013)	0.371 (0.016)	-0.251 (0.03)	-0.628 (0.027)	0.609 (0.025)	0.375 (0.034)	0.201 (0.051)	0.749 (0.021)	1.467 (0.15)	1.085 (0.124)	0.162 (0.006)	0.289 (0.025)	0.032 (0.006)	0.275 (0.07)	0.113 (0.029)	-0.084 (0.034)	-0.088 (0.058)
				Retest Basis coefficients								Implied retest means					
				T1	T2	T3	T4					T1	T2	T3	T4		
G_v^a					0	1	2.34 (0.324)	3.811 (0.539)					0	0.071	0.113	0.143	
G_m^a					0	1	2.236 (0.304)	2.8 (0.362)					0	0.103	0.163	0.205	
G_s^a					0	1	1.363 (0.135)	1.863 (0.189)					0	0.149	0.236	0.298	
G_c^b					0	1	1.984 (0.157)	3.022 (0.234)					0	0.103	0.163	0.205	

$\rho_{F_i,F_s}^a = 0.324$ ($p=0.151$), $\rho_{F_i,F_q}^a = -0.594$ ($p<0.001$), $\rho_{F_s,F_q}^a = 0.230$ ($p=0.755$).

1. The variance of F_i , F_s and F_q were fixed to 1.0 to define the metrics of the latent growth factors.

2. We specified age-based growth curve modelling, such that the basis coefficients for each of the five slopes were set to the age in decades of individual n at each assessment on variable w , centered at 50 years.

3. Each of the five cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .

Table S14. Parameter estimates from age-based factor of curves models in BETULA with constant retest specification for observations made at ages less than or equal to age 65 years.

Cognitive domain	Latent variable means (SE)				Unstandardized loadings (SE)			Standardized loadings			Residual variances and covariances (SE)						
	μ_r	μ_i	μ_s	μ_q	F_i	F_s	F_q	F_i	F_s	F_q	$\sigma^2_{e[t]}$	σ^2_{ui}	σ^2_{us}	σ^2_{uq}	$\sigma_{ui,us}$	$\sigma_{ui,uq}$	$\sigma_{us,uq}$
G_v^a	0.182 (0.021)	0.526 (0.026)	-0.873 (0.053)	-0.366 (0.081)	0.590 (0.033)	0.153 (0.301)	0.135 (0.55)	0.635 (0.030)	0.574 (0.958)	0.592 (1.726)	0.240 (0.009)	0.515 (0.037)	0.048 (0.097)	0.034 (0.202)	-0.01 (0.035)	-0.061 (0.088)	0.003 (0.084)
G_m^a	0.231 (0.026)	0.534 (0.025)	-0.738 (0.046)	-0.386 (0.088)	0.462 (0.038)	0.211 (0.083)	0.196 (0.206)	0.707 (0.048)	0.718 (0.152)	1.000	0.508 (0.016)	0.213 (0.032)	0.042 (0.019)	0.000 (0.000)	0.031 (0.051)	0.015 (0.071)	0.002 (0.125)
G_s^a	0.188 (0.026)	0.903 (0.031)	-0.956 (0.063)	-0.463 (0.106)	0.627 (0.039)	0.293 (0.375)	0.11 (0.225)	0.737 (0.039)	0.597 (0.561)	0.248 (0.468)	0.209 (0.035)	0.337 (0.048)	0.155 (0.099)	0.184 (0.097)	-0.008 (0.065)	-0.126 (0.091)	-0.145 (0.15)
G_c^b	0.100 (0.016)	0.316 (0.018)	0.039 (0.035)	-0.276 (0.053)	0.572 (0.024)	0.305 (0.054)	0.012 (0.112)	0.741 (0.023)	0.866 (0.090)	0.039 (0.362)	0.117 (0.005)	0.268 (0.025)	0.031 (0.022)	0.095 (0.05)	0.053 (0.024)	0.062 (0.049)	0.01 (0.058)

$\rho_{F_i,F_s}^a = 0.4$ ($p=0.508$), $\rho_{F_i,F_q}^a = -0.211$ ($p=0.668$), $\rho_{F_s,F_q}^a = -0.211$ ($p=0.752$).

1. The variance of F_i , F_s , and F_q were fixed to 1.0 to define the metrics of the latent growth factors.
2. We specified age-based growth curve modelling, such that the basis coefficients for each of the five slopes were set to the age in 25-year steps of individual n at each assessment on variable w , centered at 50 years.
3. Each of the four cognitive outcomes was standardized by subtracting the mean of all datapoints at the baseline occasion and dividing by the standard deviation of the age and age² residuals of all the datapoints at baseline.

^a 1st step: unconstrained factor of curves model excluding G_c .

^b 2nd step: constrained factor of curves model including G_c .