

Online Supplement:
Cognitive diversity in a healthy aging cohort: Cross-domain cognition in the Cam-CAN project

Supplemental Table 1. *Cognitive tasks, variables, and measures across cognitive domains. Tasks are indicated whose measures are included in the Cross-Domain PCA and Typically Declining PCA.*

Domain	Task	N	Variables	Cognitive Measures	Cross-domain PCA	Typically Declining PCA
Attention/Executive	Fluid Intelligence	660	Total (out of 46)	Fluid Intelligence	yes	yes
	Multitasking	658	Time Deviation Tasks Completed (out of 5)	Multitasking	yes	
	Verbal Fluency	706	Letter Fluency Total Category Fluency Total	Verbal Fluency	yes	yes
	Choice Response Time	657	Mean RT Covariance	Choice RT	yes	yes

Language	Picture-picture Priming	648	Accuracy	Picture Naming	yes	
			Response Time			
			Phonological Priming			
			Semantic Priming			
	Tip of the Tongue (TOT)	644	TOT Rate	TOTs	yes	
	Sentence Comprehension	627	Syntactic Processing	Sentence	yes	
			Semantic Processing	Comprehension		
Emotion processing	Emotion Recognition	657	Anger Correct Total	Emotion Recognition	yes	
			Disgust Correct Total			
			Fear Correct Total			
			Happiness Correct Total			
			Sadness Correct Total			
			Surprise Correct Total			
	Emotion Reactivity and Regulation	289	Positive Reactivity	Emotion Reactivity		
			Negative Reactivity	Emotion Reappraisal		

			Positive Reappraisal Negative Reappraisal			
Memory	Visual Short Term Memory (VSTM)	656	Capacity Load 1 Capacity Load 2 Capacity Load 3 Capacity Load 4	VSTM Capacity	yes	yes
	Story Memory	707	Recall Immediate Recall Delayed Recognition	Story Memory	yes	yes
	Emotional Memory	325	Priming Positive Priming Neutral Priming Negative Recognition Positive Recognition Neutral Recognition Negative	Priming Recognition Recall		

			Recall Positive Recall Neutral Recall Negative			
Motor/Speed	Foot Stands	670	Seconds Balanced (out of 30)	Balance Test	yes	
	Chair Rises	688	Completion Time	Chair Rises	yes	
	Simple Reaction Time	658	Response Time	Simple RT	yes	yes
	Force Matching	322	Overcompensation Finger Overcompensation Slider	Force Matching		
	Motor Learning	318	Learning Rate Response Time Learning Rate Error	Motor Learning		
Face Processing	Face Recognition: Unfamiliar Faces	657	Correct Total	Unfamiliar Faces	yes	

	Face Recognition: Familiar Faces	659	Name Correct Occupation Correct Familiarity Correct	Familiar Faces	yes	
Crystallized Knowledge	Spot the Word	705	Correct Total (out of 60)	Spot the Word	yes	
	Proverbs	655	Correct Total (out of 12)	Proverbs	yes	

Supplemental Table 2. *Cross-domain and Typically Declining PCA results, with factor loadings for each cognitive measure on four Cross-Domain factors and one Typically Declining factor.*

	Cross-domain PCA				Typically Declining PCA
	Factor 1: Fluid Abilities	Factor 2: Naming	Factor 3: Crystallized Abilities	Factor 4: Sentence Comprehension	Factor 1
Eigenvalue	3.47	2.36	1.72	1.19	2.91
Percentage explained variance	20.41	13.87	10.13	7.02	48.43
Cum. Percentage explained variance	20.41	34.28	44.40	51.42	48.43

Loadings					
Fluid Intelligence	0.80	0.25	0.15	0.02	0.86
Choice RT	0.75	0.13	-0.04	-0.07	0.75
Balance Test	0.61	0.12	-0.07	-0.38	.
VSTM Capacity	0.58	0.26	< .01	0.42	0.70
Story Memory	0.56	0.14	0.33	0.11	0.65
Emotion Recognition	0.53	0.35	0.25	0.16	.
Simple RT	0.50	0.08	-0.02	-0.12	0.52
Verbal Fluency	0.50	0.28	0.38	0.14	0.65
Chair Rises	0.39	0.24	-0.23	-0.30	.
Familiar Faces	0.04	0.86	-0.12	0.13	.

TOT rate	0.12	0.63	0.29	-0.01	.
Picture Naming	0.40	0.62	< .01	-0.03	.
Unfamiliar Faces	0.28	0.57	-0.01	-0.11	.
Multitasking	0.25	0.27	0.13	-0.14	.
Spot the Word	-0.01	0.05	0.80	-0.12	.
Proverbs	0.07	< .01	0.75	0.02	.
Sentence Comprehension	-0.04	-0.01	-0.10	0.80	.

Follow-up to Cross-domain PCA: Multi-group CFA

Because the Cross-Domain PCA factors were based on a wide age range (18-88 years), we used confirmatory factor analysis (CFA) to provide evidence that the components derived from this PCA were representative across age groups. Specifically, we developed a model based on the results of the Cross-Domain PCA and tested the configural and measurement invariance across young, middle-aged and older age groups using multi-group CFA. Analyses were conducted in SPSS version 25 and AMOS version 26 (IBM, New York, USA). Data were included for all participants, and for CFA missing data was mean replaced. The model included three latent variables corresponding to the Fluid Abilities, Naming, and Crystallized Abilities factors with high loading measures as indicators (see Supplementary Table 2 for high loading measures). Because the Sentence Comprehension factor had only one high loading measure, in the place of a fourth latent variable we used the observed Sentence Comprehension measure. We tested configural invariance with a CFA including all 3 age groups, $\chi^2(342) = 658.34$, $p < .001$. Fit indices suggested that while CFI did not indicate good fit, (CFI = .78) GFI was adequate (GFI = .91) and RMSEA and RMR were in good ranges (RMSEA = .036 with a 90% CI [.032, .040], RMR = .056). As noted by Lai and Green (2016), it is not uncommon for fit indices to disagree, so model assessment benefits from using multiple indices. Additionally, although not all fit indices were in a good range, when the model was fit separately for each age group, fit indices were similar across groups for CFI (young = .76, middle-aged = .79, older = .78), GFI (young = .91, middle-aged = .90, older = .91), RMR (young = .05, middle-aged = .05, older = .07), and RMSEA (young = .065, middle-aged = .059, older = .064). Because the aim of the Cross-Domain PCA was to summarize the data rather than test the dimensionality and structure of the data set, the indices taken together suggest the model is a reasonable summary of the data for all age groups. In order

to test for invariance of the factor loadings across age groups, we used multi-group analysis to compare an unconstrained Model 1 to Model 2, which was constrained to make factor loadings equivalent across age groups. We first compared models across all three age groups, and using a chi-square test found evidence that the factor loadings were not invariant (See Supplementary Table 3; $\Delta\chi^2 (26) = 85.11, p < .001$). To understand the source of this variance we repeated the multi-group analysis for just young and middle-aged groups, and for just middle-aged and older groups. These comparisons provided evidence for measurement invariance between middle-aged and older groups ($\Delta\chi^2 (13) = 21.06, p = .07$) but a difference between young and middle-aged groups ($\Delta\chi^2 (13) = 31.02, p < .01$). In order to identify the specific sources of variance between young and middle-aged groups we compared the unconstrained Model 1 to a series of models with individual factor loadings held constant across age groups. These results indicated stronger loadings in the middle-aged compared to younger adults for four parameters: one indicator of the Fluid Abilities factor (Emotion Recognition), ($\Delta\chi^2 (1) = 5.68, p < .05$), and three indicators of the Naming factor (TOTs, $\Delta\chi^2 (1) = 4.89, p < .05$; Picture Naming, $\Delta\chi^2 (1) = 4.29, p < .05$; and Unfamiliar Faces, $\Delta\chi^2 (1) = 6.33, p < .05$).

Taken together, these analyses suggest that while a better fitting model could be possible, the components resulting from the Cross-Domain PCA provide a reasonable summary of a wide range of cognitive measures across age groups. The measurement invariance analysis suggests some differences in factor loadings across the age groups, which may provide focus for future research. In particular, the locus of variable factor loadings supports the importance of including a range of domain-specific cognitive measures and ages: the key age difference was between younger and middle-aged adults (rather than older adults) and involved stronger loadings for

parameters that were primarily relevant for the domain-specific Naming factor (rather than domain-general abilities).

Supplemental Table 3. *Measurement invariance analysis using multi-group confirmatory factor analysis.*

Age groups	Model	χ^2	df	<i>p</i>	CFI	GFI	RMSEA	$\Delta\chi^2$	Δ df	<i>p</i>
3 groups: Young, Middle-aged, Older	Unconstrained	658.34	342	<.001	.78	.91	.04			
	Measurement weights	743.44	368	<.001	.73	.89	.04	85.11	26	<.001
2 groups: Young, Middle-aged	Unconstrained	443.13	228	<.001	.77	.91	.04			
	Measurement weights	474.15	241	<.001	.75	.90	.05	31.02	13	.003
2 groups: Middle-aged, Older	Unconstrained	412.36	228	<.001	.79	.90	.04			
	Measurement weights	433.43	241	<.001	.78	.90	.04	21.06	13	.07

χ^2 , Chi-square test; df, degree of freedom; *p*, *p*-value; CFI, comparative of fit index; GFI, goodness-of-fit index; RMSEA, root mean square error of approximation.

Supplemental Table 4. *Percentage variance explained by each factor in Cross-Domain PCAs and Typically Declining measure PCAs, conducted within each sampling decile. Cross-Domain PCAs were restricted to four factors for comparison with the Cross-Domain PCA for all participants.*

	Cross-Domain PCA				Typical-Declining PCA
Decile	Factor 1	Factor 2	Factor 3	Factor 4	Factor 1
18-27	16.99	13.47	12.22	12.01	36.74
28-37	15.85	10.22	9.82	9.81	39.18
38-47	14.60	13.55	12.93	10.08	36.66
48-57	14.24	12.67	12.26	10.35	35.89
58-67	17.89	10.83	9.87	9.73	31.89
68-77	16.09	11.56	10.83	8.78	37.67
78-87	14.29	14.11	12.93	10.32	34.48

Supplemental Table 5. *Intercorrelations of lifestyle variables.*

Variable	Age	Education	Social engagement	Enrichment activities
Age	.	.	.	.
Education	-.25**	.	.	.
Social engagement	.35**	-.09*	.	.
Enrichment activities	-.17**	.33**	.02	.

* $p < .05$; ** $p < .01$

Supplemental Table 6. Regression analyses examining significant age interactions from regressions including all participants (see Table 4).

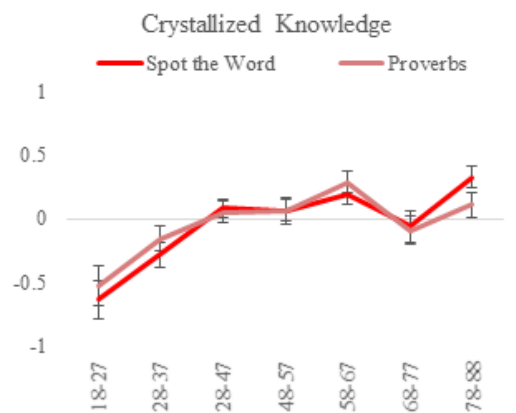
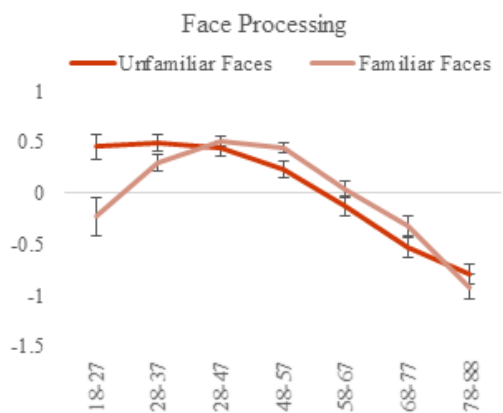
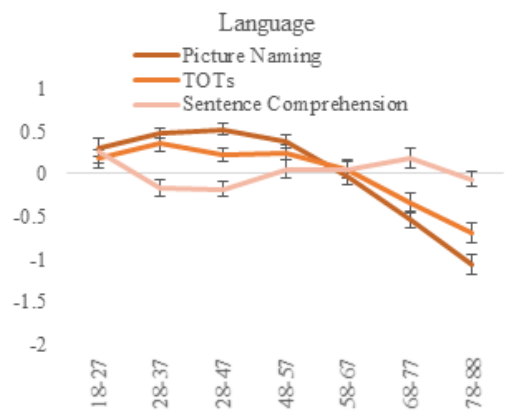
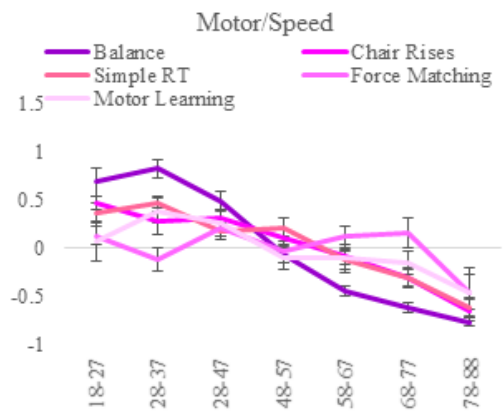
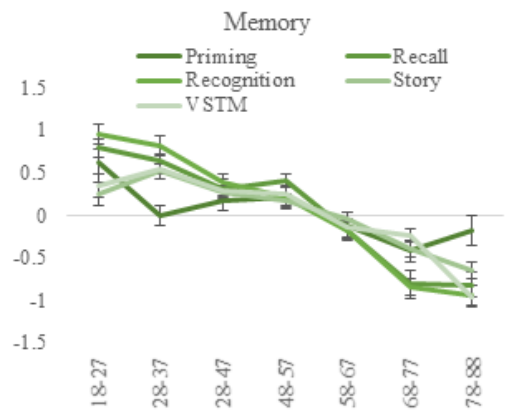
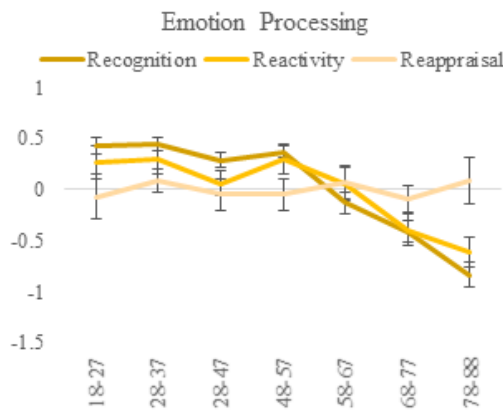
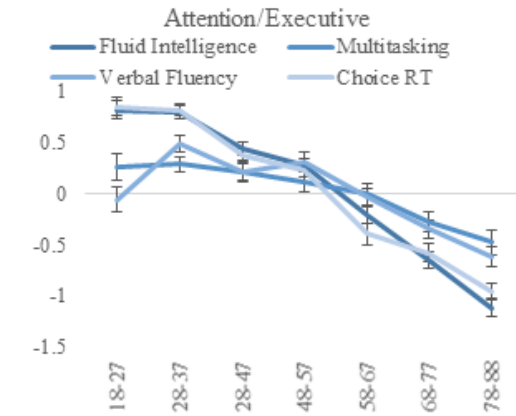
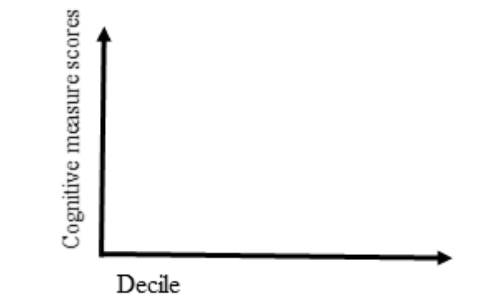
Regressions were conducted within age groups with Cross-Domain and Typically Declining factor scores regressed on lifestyle measures with age and gender covariates. Standardized β values are reported, as well as explained variance (R^2) and F values for each model.

	Gender	Age	Education	Social engagement	Enrichment activities	R^2	F
Factor 1: Fluid abilities							
Young	.01	-.31**	.18*	-.24**	.21**	.33	12.77**
Middle-aged	.05	-.43**	.16	.01	.15	.25	6.82**
Older	-.04	-.38**	.25*	.09	.12	.23	4.98**
Factor 2: Naming							
Young	.03	.22*	.04	.14	-.09	.10	2.84*
Middle-aged	.09	-.18	.18	.11	-.04	.09	1.95
Older	.08	-.24*	-.07	-.07	.05	.09	1.58

Factor 3: Crystallized Abilities							
Young	-.13	.21*	.31**	-.13	.17*	.20	6.68**
Middle-aged	.03	.15	.47**	-.06	.14	.30	8.45**
Older	.18*	.22**	.75**	-.12	-.09	.59	23.80**

* $p < .05$; ** $p < .01$

Supplemental Figure 1. *Cognitive measures in each sampling decile grouped by cognitive domains. The values of measures plotted were aligned so that higher values represent better performance.*



Supplemental References

- Lai, K., & Green, S. B. (2016). The Problem with Having Two Watches: Assessment of Fit When RMSEA and CFI Disagree. *Multivariate Behavioral Research*, 51(2–3), 220–239.
<https://doi.org/10.1080/00273171.2015.1134306>