

Introduction

Traditional cognitive batteries quantify 10 to 15 scores per assessment session, limiting the breadth of factor analysis models of cognition. We analyzed 107 measures, including speech and language biomarkers (SLBs), from 22 subtests. In a sample of 1,916 healthy adults, factor analysis on this large measure set revealed cognitive domains that are difficult to detect using conventional batteries with fewer measures.

Methods

Overview. We analyzed 22 subtests of the California Cognitive Assessment Battery (CCAB, Woods et al., 2024) that included 107 measures of accuracy, response time, kinematics, and SLBs. Performance was assessed in a diverse sample of 1,916 native English-speaking participants (mean age 53.1 years, 37% White) who completed a 2-hour, telemedically proctored at-home CCAB assessment. Indicators were grouped into five theory-driven and correlation-driven cognitive domains—Executive Function (EF), Memory (EM), Lexical/Story processing (LS), Processing Speed (PS), and Speech Fluency (SF). Each domain was divided into two clusters to enable cross-validation of factor loadings (Figure 1).

Factor analysis of unregressed and residualized scores. Bifactor confirmatory factor analysis (CFA) results, obtained with the *lavaan* package in R, used (1) demographically unregressed z-scores, and (2) demographically residualized z-scores, computed after regression of individual scores on a comprehensive demographic model that included age, education, sex, vocabulary, race, and other covariates.

Model generalization. Model generalization was examined in two subsamples differing in mean age and date of enrollment.

Model robustness. Robustness analyses were conducted in a subsample (n=1,030) that underwent nine additional cognitive tests with 46 additional measures.

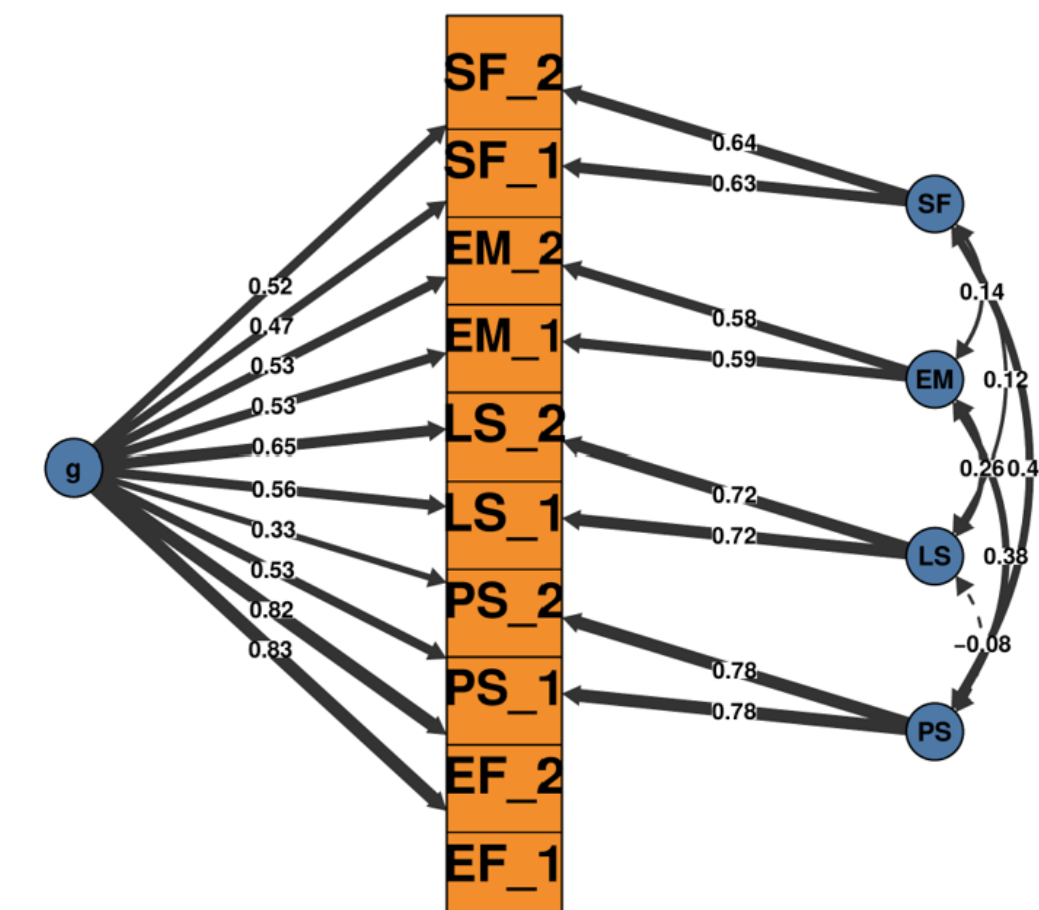
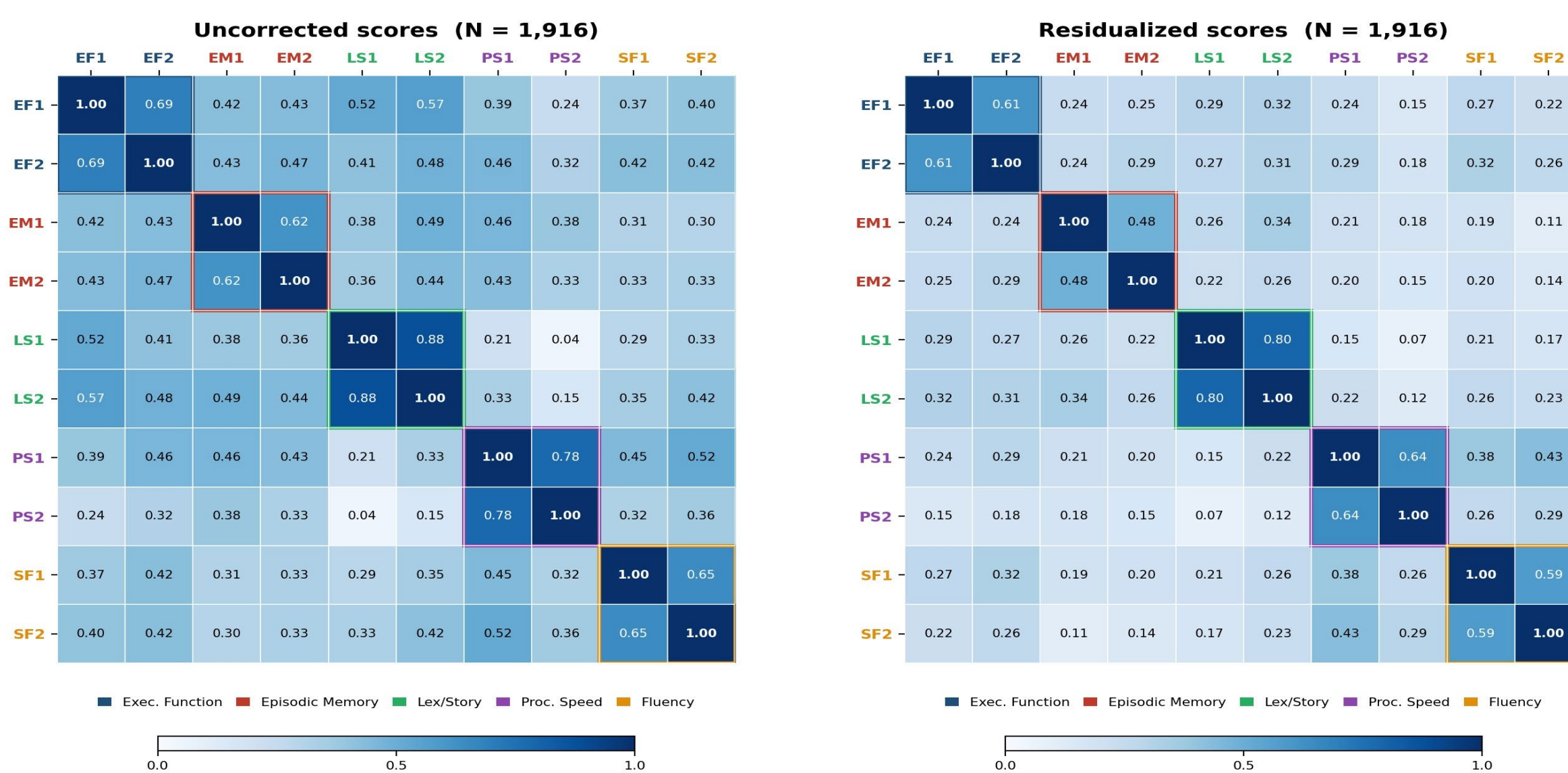


Figure 2. Unregressed score model. Bifactor confirmatory factor analysis path diagram using unregressed indicators. Path coefficients show standardized factor loadings and covariances (curved arrows). The general factor (g) loaded on all ten parcel indicators including both EF parcels, while four specific factors (PS, LS, EM, SF) orthogonal to g, loaded on their respective parcel pairs with loadings constrained to equality. EF parcels show strong g loadings (0.83, 0.82) with no residual specific-factor variance.

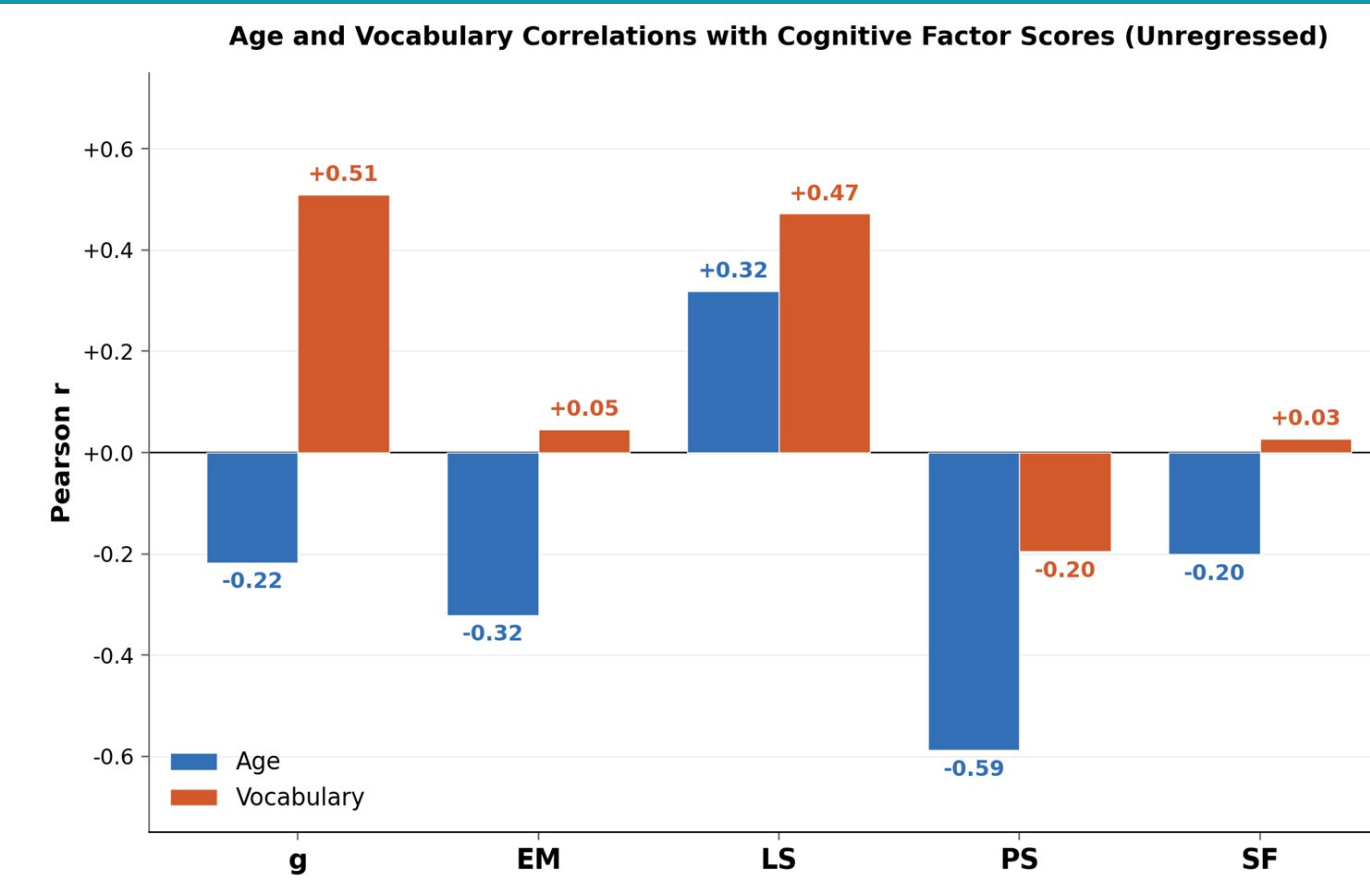


Figure 3. Demographic influences. Pearson correlations of age (blue) and vocabulary (orange) with bifactor specific-factor scores from the unregressed CFA solution. PS exhibits the classic fluid pattern with strong age decline and weak vocabulary association; LS exhibits the classic crystallized pattern with positive age and vocabulary effects; EM shows fluid-like age decline without vocabulary association; SF shows age decline without vocabulary effect. The general factor shows a mixed signature with strong vocabulary loading.

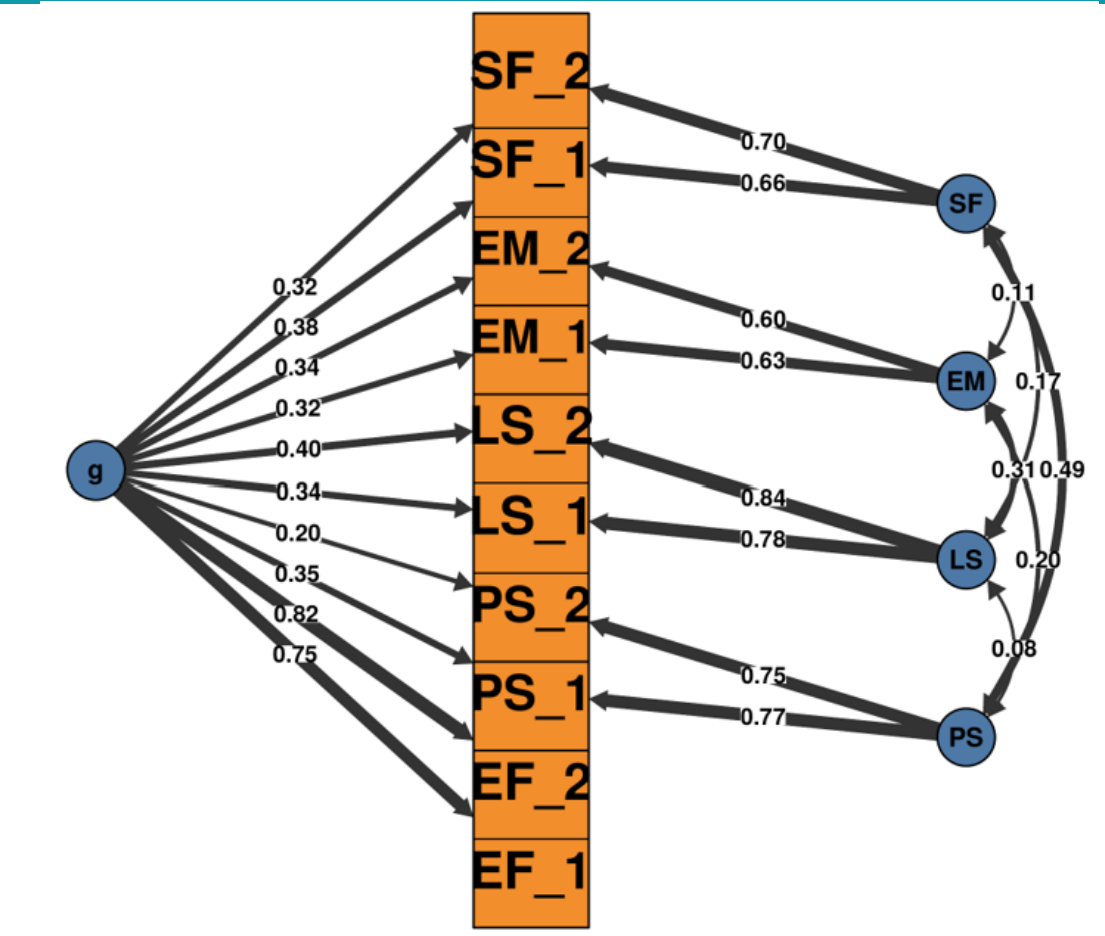


Figure 4. Residualized score model. Bifactor confirmatory factor analysis path diagram with demographically residualized measures recovering the same bifactor architecture. EF subclusters retained strong g loadings (0.75, 0.82). With residualization general-factor loadings on non-EF subclusters declined by 30–50%, indicating that a portion of g-saturation reflected shared demographic variance. Specific factor loadings strengthened slightly relative to the unregressed model.

Summary

- Confirmatory factor analysis revealed five distinct cognitive domains: a general ability factor plus four distinct specific domains — processing speed, memory, language content, and speech fluency.
- Executive-function indicators loaded almost exclusively on the general factor, suggesting that executive control represents a central component of general cognitive ability rather than a separable domain.
- Model fit was acceptable for the unregressed model (CFI=0.976, RMSEA=0.076, SRMR=0.027) and good for the residualized model (CFI=0.986, RMSEA= 0.043, SRMR = 0.022) indicating that demographic correction improved model fit and sharpened domain distinctions.
- Omega hierarchical statistics showed that the unregressed model was dominated by a strong general factor ($\omega_H = 0.77$), with specific-factor ω_{HS} values ranging from 0.42 to 0.68. Demographic residualization reduced general-factor saturation ($\omega_H = 0.60$) while increasing the strength of the specific factors ($\omega_{HS} = 0.51$ –0.73) increasing the separation among cognitive domain latent factors.
- Two domains, language content and speech fluency, reflected SLB analysis of word choice and richness (LS) and how fluently they said it (SF).
- Metric invariance, but not scalar invariance, was observed for both unregressed and residualized models across sub-cohorts.
- Comparable model fits were obtained in 1,030 participants assessed with nine additional tests and 46 additional measures.
- Because all tests were delivered and scored by computer, the model was free of the examiner-to-examiner variation that muddies factor analyses of hand-administered batteries.

Discussion

- The model recovered a five-construct cognitive architecture: a general factor (g) that absorbed almost all Executive Function (EF) variance, plus four separable specific factors representing Processing Speed (PS), Memory (EM), Lexical/Story processing (LS), and Speech Fluency (SF).
- The differential demographic signatures of factor scores—PS as fluid, LS as crystallized, EM as fluid-and-vocabulary-independent, SF as fluid and age-sensitive, provided construct-level validation that the recovered factors index theoretically distinct cognitive dimensions rather than differential age-related decline.
- The bifactor model isolated SLB-based measures, LS and SF, as distinct latent factors, reflecting the distinction between lexical content and articulatory-phonological timing proposed in models of spoken language production (Levelt, 1989).
- To our knowledge, the CCAB is among the first cognitive assessment batteries to (a) include bifactor CFA model fits to domain-level indicators rather than single test scores, (b) report bifactor specific-factor scores alongside raw and demographically corrected domain and individual test scores; and (c) provide a domain profile with potentially clinically meaningful dissociations (LS versus SF; selective EM impairment against preserved g) that conventional scores cannot provide.

References

- Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. MIT Press.
- Woods, D., Pebler, P., Johnson, D. K., Herron, T., Hall, K., Blank, M., Geraci, K., Williams, G., Chok, J., Lwi, S., Curran, B., Schendel, K., Spinelli, M., & Baldo, J. (2024). The California Cognitive Assessment Battery (CCAB). *Frontiers in Human Neuroscience, 18*, 1305529. <https://doi.org/10.3389/fnhum.2023.1305529>

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Figure 1. Subcluster correlation matrices for uncorrected (left) and residualized (right) CCAB scores. Each cognitive domain is represented by two subclusters. Within-domain correlations were uniformly the strongest cells in their rows and columns, supporting the parcel structure. EF parcels showed the strongest off-diagonal correlations across both matrices, consistent with executive control reflecting a domain-general process. Demographic residualization compressed off-diagonal correlations by 30–50% while preserving the relative pattern of within- versus between-domain correlations.