Journal of the International Neuropsychological Society (2024), 1–13
doi:10.1017/S1355617724000547

Research Article

Heterogeneity in cognitive profiles of monolingual and bilingual Hispanic/Latino older adults in HABS-HD

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Abstract

Objective: The present study characterized heterogeneity in the cognitive profiles of monolingual and bilingual Latino older adults enrolled in the HABS-HD. **Methods:** A total of 859 cognitively unimpaired older adults completed neuropsychological testing. Raw scores for cognitive tests were converted to *z*-scores adjusted for age, education, sex, and language of testing. A latent profile analysis (LPA) was conducted for monolingual and bilingual speaker groups. A series of 2–5 class solutions were examined, and the optimal model was selected based on fit indices, posterior probabilities, proportion of sample sizes, and pattern of scores. Identified classes were compared on sociodemographic, psychosocial, and health characteristics. **Results:** For the monolingual group ($n = 365$), a 3-class solution was optimal; this consisted of a *Low Average Memory* group with low average verbal memory performances on the SEVLT Total Learning and Delayed Recall trials, as well as an *Average Cognition* group and a *High Average Cognition* group. For the bilingual group ($n = 494$), a 3-class solution was observed to be optimal; this consisted of a *Low Average Memory* group, with low average verbal memory performances on the learning and delayed recall trials of Logical Memory; a *Low Average Executive* group, where performance on Trails A and B and Digit Substitution were the lowest; and a *High Average Cognition* group, where performance was generally in the high average range across most cognitive measures. **Conclusions:** Cognitive class solutions differed across monolingual and bilingual groups and illustrate the need to better understand cognitive variability in linguistically diverse samples of Latino older adults.

Keywords: Bilingualism; cognitive heterogeneity; resiliency; Alzheimer's disease; health equity; latinos

(Received 14 May 2024; final revision 4 September 2024; accepted 11 September 2024)

Introduction

Hispanic/Latino (henceforth Latino) older adults are disproportionately impacted by Alzheimer's disease (AD) and are less likely to receive an early and accurate diagnosis when compared to non-Latino White adults (Rajan et al., 2021). These diagnostic delays decrease the efficacy of available treatments and have been linked to higher long-term healthcare costs associated with managing AD (Barnett et al., 2014; Dubois et al., 2015). Disparities in AD risk and diagnosis have been tied to a number of social and structural inequities that disproportionately impact Latino community members (Griffith et al., 2023). Decreased access to health-promoting resources (e.g., financial resources, health insurance coverage, and high-quality healthcare services) (Fitzpatrick et al., 2015; Jung et al., 2020; Mejia-Arango et al., 2020; Mullins et al., 2021) and greater exposure to health-depleting conditions (e.g., vascular health comorbidities, toxin exposure) have been identified as important risk factors of influence that are necessary points of intervention (Alemany et al., 2021; González et al., 2018; Yu et al., 2020). While these population-level inequities require attention and profound commitment by the scientific community and policy makers for effective mitigation, it is essential to recognize that there is incredible individual-level variability and resiliency within the Latino community that should be capitalized on in these endeavors. Additional scientific investigations centered on

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Data used in preparation of this article were obtained from the HABS-HD database (https://apps.unthsc.edu/itr/researchers). HABS-HD MPIs include: Sid E O'Bryant, Kristine Yaffe, Arthur Toga, Robert Rissman, & Leigh Johnson; and the HABS-HD Investigators: Meredith Braskie, Kevin King, James R Hall, Melissa Petersen, Raymond Parlmer, Robert Barber, Yonggang Shi, Fan Zhang, Rajesh Nandy, Roderick McColl, Monica Rivera Mindt, Amrita Cheema, Lisa Barnes, Mark Mapstone, Annie Cohen, Amy Kind, Ozioma Okonkwo, Raul Vintimilla, Zhengyang Zhou, Michael Donohue, Rema Raman, Matthew Borzage, Michelle Miekle, Beau Ances, Ganesh Babulal, Jorge Llibre-Guerra, Carl Hill, and Rocky Vig. The consent is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Cite this article: Clark A.L., Reyes A., Breton J., Petersen M., O'Bryant S., & Grasso S.M. for the HABS-HD Study Team. Heterogeneity in cognitive profiles of monolingual and bilingual Hispanic/Latino older adults in HABS-HD. *Journal of the International Neuropsychological Society*, 1–13, https://doi.org/10.1017/S1355617724000547

exploring the role of important sociocultural factors of influence that may ultimately buffer against risk factor exposure and protect against the development of AD in late life are needed.

Considering more than 75% of the Latino population residing in the United States are bilingual English-Spanish speakers, language is one important factor of influence that warrants additional attention (Lamar et al., 2019; Rosselli et al., 2019). Research has established that language may impact cognitive test performance and has further highlighted the need for important language considerations in the interpretation (e.g., proficiency, context of use, translations of test) and norming of cognitive tests (e.g., lack of robust norms for bilingual speakers) that are commonly utilized in diagnostic assessments of AD (Díaz-Santos et al., 2021; Marquine et al., 2021; Morlett Paredes et al., 2021). However, dual-language use (or bilingualism) has also been identified as an important factor that may enhance cognitive and neural reserve, and significant efforts have focused on characterizing the posited benefits of bilingualism on AD in recent years (Calvo et al., 2023; Gollan et al., 2011; Liu & Wu, 2021; Perani & Abutalebi, 2015; Raji et al., 2020). While the evidence largely suggests that bilingualism may not necessarily prevent the occurrence of AD, several studies have highlighted that bilingual speakers display a later age of dementia onset when compared to monolingual speakers (e.g., Berkes et al., 2020; Calabria et al., 2020). In contrast, other studies have failed to find such differences in age of dementia onset between monolingual and bilingual speakers (e.g., Gasquoine, 2016; Zahodne et al., 2014). It is posited that some of these null observations may be partially attributable to issues pertaining to the early and accurate diagnosis of cognitive impairment in bilingual speakers (Brini et al., 2020). There appear to be consistent and important differences between monolingual and bilingual speakers on cognitive tests noted in the literature, with bilingual speakers generally displaying better performance on measures of processing speed and executive functioning, but poorer performances on measures of phonemic fluency when compared to monolingual speakers (Grasso, 2023; Bialystok, 2009; Cox et al., 2016; Kousaie et al., 2014). Currently, it is unclear as to what extent these cognitive advantages may ultimately cause delays in the development of AD or whether these merely complicate the detection of AD due to varied threshold effects of impairment; with regard to the latter, it may be more difficult to detect impairment in those with higher levels of cognitive reserve and/or the clinical manifestation of AD may be distinct in bilingual speakers. Additionally, the heterogeneity of bilingualism itself across different sociocultural contexts as well as varied levels of language dominance, proficiency, and age of second-language acquisition may also contribute to these mixed findings (Brini et al., 2020).

Studies examining the effects of bilingualism on cognitive performance have been further complicated by methodological shortcomings that include small size samples, as well as mixed language and ethnoracial group composition (Bialystok et al., 2014; Ossher et al., 2013). Most of the existing literature has primarily utilized monolingual non-Latino White comparison groups, whereas recent work from our group has established that this practice may convolute the identification of a bilingual Latino cognitive phenotype that displays unique strengths and weaknesses when compared to a monolingual Latino group (Grasso, 2023). This work is especially important as it provides some insight into impaired language performance as a potentially early sign of the AD process, as evidenced by the fact that (1) there were no differences between monolingual and bilingual speakers on language measures in the participants in the cognitively unimpaired (CU) phase, (2) differences on phonemic fluency between the speaker groups only emerged in mild cognitive impairment (MCI) phase, and (3) bilingual speakers with language impairment had higher levels of plasma amyloid-beta 42/40 when compared to those without language impairment (Grasso, 2023). Collectively, these findings have challenged key assumptions about differences on cognitive tests between monolingual non-Latino White and bilingual speakers and have provided insight into the complexities of language and bilingualism on AD risk in Latino adults.

As we continue to enhance our understanding of language in AD research studies, there is also a need to move beyond monolingual and bilingual comparisons frequently centered on single cognitive measures to better characterize important patterns of heterogeneity across cognitive testing batteries in Latino samples. Previous work in predominantly non-Latino White monolingual older adult samples has revealed that cluster and latent analytic strategies can be employed to identify groups of people with unique cross-battery cognitive performances into distinct cognitive classes that show varied risk for developing AD (Edmonds et al., 2020; Thomas et al., 2022; Zammit et al., 2021). For example, in a large sample of individuals enrolled in the ADNI study, these distinct classes included an (1) *amnestic MCI* class that displayed poor performance on memory measures but was intact on other cognitive domains, (2) *dysnomic/amnestic MCI* group with impaired naming and memory measures, (3) *mixed* MCI group with impaired memory and executive functioning, and (4) a *cognitively unimpaired* group (Edmonds et al., 2020). Importantly, these groups were observed to have unique patterns of cortical atrophy over time. Furthermore, in a sample composed largely of CU non-Latino White adults, five distinct cognitive classes were identified (Thomas et al., 2022). These groups included a *Low Domain-All* (low average across all cognitive tests) and a *Low Memory/Language* (low average memory and language performances) group, both of which demonstrated showing faster rates of progression to MCI/dementia than an *All-Average* cognitive testing group (Thomas et al., 2022). Importantly, there may be distinct biological mechanisms and/or life experiences that are responsible for initiating or maintaining these cognitive differences that have yet to be characterized, and studies centered on these efforts are essential as we continue to move toward precision-based models of AD diagnosis and treatment (Ganguli et al., 2018).

Characterizing cognitive heterogeneity may be essential for understanding important patterns of risk and resiliency to AD within monolingual and bilingual Latino older adults, and further aid in the development of more personalized detection and prevention methods for AD within the Latino community. To date, there has been limited application of latent analytic profiling methods to large samples of linguistically diverse Latinos and no known study has focused on characterizing cognitive classes in a well-characterized sample of monolingual and bilingual Latino older adults. Thus, the present study sought to (1) employ latent profile analysis to characterize cognitive profiles within each monolingual and bilingual speaker group and (2) determine whether the identified classes within each speaker group differ as a function of demographic, psychosocial, and health factors. We focus on characterizing cognitive heterogeneity in CU individuals in an effort to understand important patterns of variability prior to the influence of AD-related disease processes, as this is an essential first step to establishing an understanding of cognitive profiles in linguistically and culturally diverse individuals. Importantly, this work may ultimately help with early detection efforts and further

https://doi.org/10.1017/S1355617724000547 Published online by Cambridge University Press

clarify mixed findings pertaining to the effects of bilingualism on dementia onset. As such, we conduct these analyses in each language group (monolingual, bilingual) separately, given the previous literature showing that there are important differences in cognitive levels on specific tests between these language groups.

Methods

Data availability

Data from Health and Aging Brain Study—Health Disparities (HABS-HD) was used for the present study. HABS-HD is a single-site study centered on examining racial/ethnic disparities in AD and related dementias based at the Institute for Translational Research at the University of North Texas Health Science Center in Fort Worth, Texas (O'Bryant et al., 2021). HABS-HD participants complete physiological exams (blood draws, clinical labs, anthropomorphic assessments), sociocultural and psychiatric functioning questionnaires, and brain magnetic resonance imaging (MRI) scans. Each participant also completes comprehensive neuropsychological testing in their preferred language (English or Spanish). Written informed consent is obtained for all HABS-HD participants, and the larger study was approved by the Institutional Review Board of UNTHSC and UT Austin (STUDY00003075). Data was collected in accordance with university institutional guidelines and the Helsinki Declaration.

Inclusion criteria for HABS-HD consist of community-dwelling adults above the age of 50; self-reported race/ethnicity of Black/African American (henceforth Black), Latino, and non-Latino White; fluency in English or Spanish; willingness to provide blood samples; and eligibility to complete brain MRI scans. Exclusion criteria for the study include type 1 diabetes, current cancer diagnosis, severe mental illness or medical conditions that may impact cognitive functioning (e.g., renal disease), traumatic brain injury with a loss of consciousness within the past 12 months, current alcohol or substance abuse, and current diagnosis of dementia.

Study participants

Baseline data for 1,164 Latino participants were downloaded on 08/10/2023. The present study included a subset of 859 Latino participants (98% Mexican American) where365 were monolingual speakers and 494 were bilingual speakers. Participants included had completed the Short Acculturation Scale for Hispanics, cognitive testing, and were determined to be cognitively unimpaired per HABS-HD clinician confirmed consensus diagnosis (Clinical Dementia Rating Sum of Boxes = 0, no self-reported or informant-reported cognitive concerns, and largely unimpaired cognitive scores as indicated by z-scores > -1.5) at their baseline study visit (see O'Bryant et al., 2021).

Psychosocial and health characteristics

Participants completed background study questionnaires that captured information about the highest year of education completed, the number of years that have resided in the United States, and their socioeconomic status as measured by annual household income. The Geriatric Depression Scale (Yesavage, 1988) was used to assess current levels of depressive symptomatology, the Penn State Stress and Worry Scale (Meyer et al., 1990) was used to assess the trait of worry, and the Chronic Stress Scale was used to assess chronic stress (Bromberger & Matthews, 1996). We utilized the National Cholesterol Education Program Adult Treatment Panel III (ATP III) guidelines to develop dichotomous variables (yes/no) of metabolic syndrome (MetS) status and the five constituent cardiometabolic risk factors (Grundy et al., 2005). Participants were coded as having MetS if they had the presence of three or more of the following abnormal clinical readings: abdominal obesity ≥ 102 cm for men and ≥ 88 cm for women, triglyceride level ≥ 150 mg/dl, high-density lipoprotein < 40 mg/dL for men and < 50 mg/dL in women, blood pressure ≥ 130/85 mg Hg, and fasting glucose ≥ 100 mg/dL.

Bilingual and monolingual status

The Short Acculturation Scale for Hispanics was used to assess bilingualism status (Marin et al., 1987; SASH). Participants that responded "Yes" to the question "Do you speak a secondary language?" were categorized as bilingual; participants that responded "No" were categorized as monolingual. Data from the HABS-HD background questionnaire was used to clarify whether identified monolingual and bilingual speakers completed the study interview and testing session in English or Spanish. Within the bilingual group, 44% of participants were testing in Spanish. Within the monolingual group, 86% participants were testing in Spanish.

Based upon responses to questions on the SASH, bilingual speakers were also characterized based on language dominance and age of acquisition consistent with our previous work utilizing the HABS-HD dataset (Grasso, 2023). Language dominance was determined via responses to the question "In general, what language do you read and speak?" Respondents who indicated that they read and speak English and Spanish to an equal extent were categorized as "balanced," those that read and speak English better than Spanish were categorized as "English dominant," and speakers that indicated that they read and speak Spanish better than English were categorized as "Spanish dominant." Age of acquisition was determined via responses to the question "What was the language you used as a child?" Bilinguals were categorized as "early" learners if they indicated that they used English and Spanish as a child, and as "late" learners if they indicated only using Spanish or English as a child but reported that they spoke a secondary language at the time of interview.

Cognitive assessment

Participants were administered a comprehensive neuropsychological battery comprised of measures of general cognition (Mini-Mental Status Examination [MMSE; Folstein et al., 1975], Clinical Dementia Rating Scale [CDR; Morris, 1997]), attention/executive functioning (Trail Making Test [TMT] Parts A and B Total Time [Reitan, 1956], Digit Substitution Total [Wechsler, 1981], Digit Span Total [Wechsler, 1997]), verbal memory (Logical Memory I and II Total Scores from the Weschler Memory Scale-III [Weschler 1997]; Total Learning and Delayed Recall from the Spanish English Verbal Learning Test [SEVLT; González et al., 2002]), and language (Letter [FAS] and Animal Fluency Total Scores [Spreen & Straus, 1998]). The tests utilized to assess each of these cognitive domains were largely developed in English and have previously been utilized in other large studies of Hispanic/Latinos (González et al., 2019; Morlett Paredes et al., 2024). Furthermore, the SEVLT and TMT Part B have demonstrated to have measurement equivalency across Spanish and English language of testing (Cherner et al., 2008; González et al., 2002) although equivalency findings for some of the other cognitive tests have been somewhat mixed (Gavett et al., 2018; Goodman et al., 2021).

https://doi.org/10.1017/S1355617724000547 Published online by Cambridge University Press

Table 1. Participant demographics, psychosocial, and health characteristics across monolingual and bilingual language groups, mean (SD)

	Monolingual ($n = 365$)	Bilingual ($n = 494$)	t or X test statistics	p
Age, years	62.08 (7.42)	62.83 (7.85)	−1.42	0.15
Education, years	7.88 (4.26)	11.72 (3.95)	−13.48	<0.001
Gender, % female	72.88%	66.19%	4.38	0.04
% Tested in Spanish	86.03%	43.73%	158.96	< .001
SASH total score	1.55 (1.37)	3.01(1.48)	−14.75	< .001
Years lived in US	32.44 (17.30)	50.12 (17.63)	−14.60	< .001
Annual income, $	33,551.01 (69,470.99)	48,996.90 (54,072.18)	−3.44	0.001
MMSE total score	25.83 (3.00)	27.80 (1.95)	−10.90	< .001
GDS total score	7.17 (6.48)	5.32 (5.63)	4.38	< .001
Chronic stress total score	6.39 (6.32)	7.45 (6.70)	−2.37	0.02
PSWQ total	38.42 (14.89)	39.44 (14.43)	−1.00	0.32
MetS status, % yes	58.96%	55.14%	1.19	0.27
High waist circumference, % yes	76.44%	74.65%	0.36	0.55
Low high-density lipoprotein, % yes	40.40%	36.48%	1.33	0.25
High blood pressure, % yes	66.02%	69.63%	1.24	0.27
High glucose, % yes	54.86%	51.03%	1.20	0.27
High triglycerides, % yes	40.97%	35.66%	2.44	0.12

Note: SD = standard deviation, SASH = Short Acculturation Scale for Hispanics, MMSE = Mini-Mental Status Examination, GDS = Geriatric Depression Scale, PSWQ = Penn State Worry Questionnaire. Of the 365 participants from the monolingual group, 7 (1.92%) had missing SASH data, 4 (1.10%) had missing years lived in the US, 24 (6.58%) had missing annual income data, 19 (5.20%) had missing MetS status data, 16 (4.38%) had missing low high-density lipoprotein data, 3 (0.82 %) had missing blood pressure data, 15 (4.11%) had missing glucose data, and 16 (4.38%) had missing triglycerides data. Of the 494 participants from the bilingual group, 3 (0.61%) had missing SASH data, 7 (1.42%) had missing years lived in the US, 9 (1.82%) had missing annual income data, 17 (3.44%) had missing MetS status data, 1 (0.20%) had missing waist circumference data, 6 (1.21%) had missing low high-density lipoprotein data, 10 (2.02%) had missing blood pressure data, 6 (1.21%) had missing glucose data, and 6 (1.21%) had missing triglycerides data.

For the creation of demographically adjusted z-scores, participants were stratified into monolingual and bilingual speaker groups given previous literature has established notable differences in cognitive performance across these groups (Adesope et al., 2010; Bialystok & Craik, 2022; Grasso, 2023; Gollan et al., 2008). This involved taking raw scores for each cognitive test; adjusting each score for age, education, sex, and primary interview language using regression; and saving adjusted predicted values for each monolingual and bilingual group. Z-scores for each of cognitive measures were derived using the formula (observed value – predicted value)/standard error of the estimate for which the predicted value and standard error came from a demographically (age-, education-, sex-, and primary interview language-) adjusted regression formula. Decisions about demographic adjustments were made based on well-established relationships between many of these factors and cognitive performance in the existing literature (Heaton et al., 2003; Heaton, 2004; Norman et al., 2000), and confirmed through an initial set of analyses. These initial analyses revealed that age and education were significantly correlated with most of the cognitive outcomes of interest, and analysis of variance revealed there were significant differences across sex and language of testing; however, the strength of these associations was mitigated, and differences across sex and language were entirely eliminated with the demographic adjustments.

Statistical analyses

All analyses were performed using R version 3.5.0 (https://cran.r-project.org/) and MPlus Version 8 (Muthen et al., 2017). Data were screened to ensure basic assumptions were met. Analyses of variance were used to determine whether the language group (monolingual vs. bilingual) and within-language group class solutions differed on continuous demographic, psychosocial, and health characteristics. Chi-squared analyses examined language group and within-language class solutions differences on categorical demographic, psychosocial, and health characteristics.

A latent profile analysis (LPA) was performed for monolingual and bilingual groups separately. Demographically adjusted z-scores for each cognitive test were entered into each LPA, and the optimal number of classes was determined by evaluating Lo-Mendall-Ruben adjusted likelihood ratio test (LMRT), bootstrapped likelihood ratio test (BLRT), Akaike information criteria (AIC), Bayesian information criterion (BIC), sample size-adjusted BIC, and entropy. Importantly, LMRT provides a measurement of whether model fit is improved and a significant LMRT indicates that a more complex solution (e.g., four-class) provides a better fit relative to a less complex model (e.g., three-class). The BLRT provides a similar comparison between a less complex and more complex model using repeated sampling methods. AIC, BIC, and size-adjusted BIC are used to help determine model fit based on the log likelihood function, with lower values indicative of a better relative fit. Finally, entropy provides a metric of how well each class solution can be distinguished based on posterior probabilities. This involves assigning a posterior probability to each individual for each class solution, and entropy is the aggregation of these values, with higher values (> 0.80) indicating better class discernment. Class sample sizes were also evaluated. Discriminant function analyses (DFA) with individual test scores as independent predictors of group membership were conducted to further validate the distinctiveness of the latent classes.

Results

Overall monolingual and bilingual sample characteristics

Participant demographic, psychosocial, and health characteristics are presented in Table 1. Results revealed that bilingual speakers had higher levels of education, acculturation, and income when compared to monolingual speakers ($ps < .001$). Bilingual speakers were also more likely to have lived in the U.S. for longer periods of time ($p < .001$) and displayed higher MMSE total scores when compared to monolinguals ($p < .001$). Monolingual speakers were more likely to be female ($p = .04$), be tested in Spanish ($p < .001$), and had slightly higher levels of depression ($p < .001$) when compared to bilingual speakers.

Monolingual LPA results

The LPA fit indices for the monolingual group and sample sizes for each different class solutions are presented in Table 2. Results revealed the best fitting and most substantively meaningful

Table 2. Monolingual speakers LPA fit indices for 2–5 class solutions

	AIC	BIC	sBIC	Entropy	Prob (min, max)	LMRT (*p*)	BLRT	Sample for each identified class
2- Classes	9804.44	9925.33	9826.99	0.787	0.50, 1.00	57.35 (.0003)	< .001	1 = 241 (66.10%); 2 = 124 (33.90%)
3- Classes	**9641.96**	**9805.75**	**9672.51**	**0.850**	**0.50, 1.00**	**60.69 (.0009)**	**< .001**	**1 = 142 (38.90%); 2 = 174 (47.70%); 3 = 49 (13.40%)**
4- Classes	9550.55	9757.24	9589.09	0.816	0.37, 1.00	82.92 (.264)	< .001	1 = 123 (33.70%); 2 = 141 (38.60%); 3 = 55 (15.10%); 4 = 46 (12.60%)
5- Classes	9499.78	9749.38	9546.33	0.786	0.44, 1.00	71.66 (.339)	< .001	1 = 93 (25.50%); 2 = 62 (16.90%); 3 = 92 (25.20%); 4 = 73 (20.00%); 5 = 45 (12.30%)

Note: AIC = Akaike's Information Criterion, BIC = Bayesian Information Criterion, sBIC = size-adjusted Bayesian Information Criterion, LMRT = Lo–Mendell–Ruben Adjusted Likelihood Ratio Test, BLRT = Bootstrapped Likelihood Ratio Test.

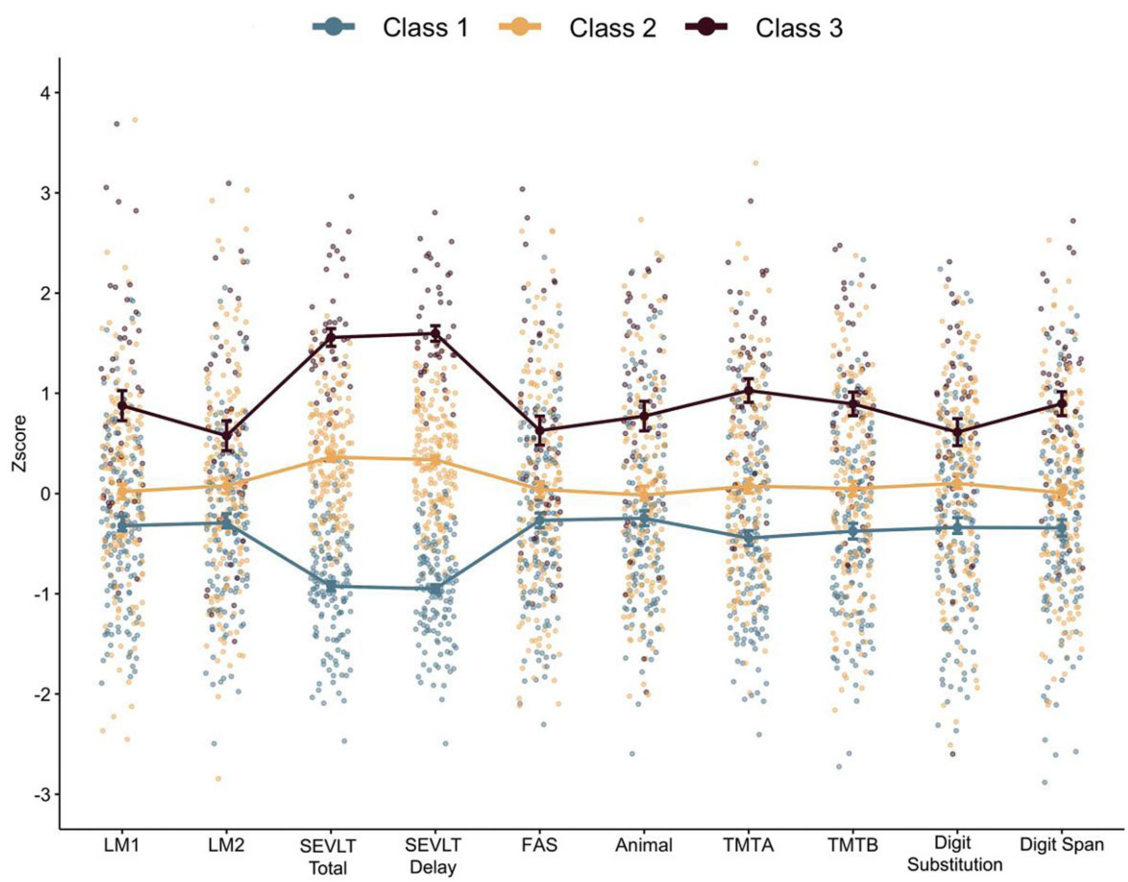

Figure 1. Distribution of scores across each cognitive test for the monolingual speakers 3-class solution. LM1 = Logical Memory I, LM2 = Logical Memory II, SEVLT = Spanish English Verbal Learning Test, FAS = Letter Fluency, Animal = Animal Fluency, TMTA = Trailing Making Test Part A, TMTB = Trailing Making Test Part B. Class 1 was identified as a *Low Average Memory* group with demonstrated low verbal memory (i.e., SEVLT Total and Delay) with average scores across other measures, Class 2 was identified as an *Average Cognition* group that demonstrated overall average cognitive performance across all measures, and Class 3 was identified as a *High Average Cognition* group that demonstrated high average cognition with relatively higher scores in SEVLT Total and Delay.

solution based on entropy, fit statistics, sample sizes, and pattern of scores was the 3-class solution. For the identified 3-class solution, entropy was .85 but dropped to .816 when increasing to a 4-class solution; LMRT went from significant with the 3-class solution ($p < .01$) to non-significant when moving to the 4-class solution ($p = .264$).

Class 1 represented 39% of the monolingual speaker sample and was identified as a *Low Average Memory group* with low average verbal memory performances on the SEVLT Total Learning and Delayed Recall trials, with mostly with average scores across other measures. Class 2 represented 48% of the sample and was identified as an *Average Cognition group* that demonstrated overall average levels of cognitive performance across all measures within the testing battery. Class 3 represented approximately 13% of the monolingual speaker sample and was identified as a *High Average Cognition* group that demonstrated cognitive performance largely in the high average range, with relatively higher scores on the SEVLT Total Learning and Delayed Recall trials. See Figure 1 for the pattern of score across each cognitive test for the 3-class solution. The LPA revealed approximately 14% of the sample had a

https://doi.org/10.1017/S1355617724000547 Published online by Cambridge University Press

Table 3. Demographics, psychosocial, and health characteristics across monolingual LPA class solutions, mean (SD)

Monolingual	Low Average Memory Class 1 (*n* = 142)	Average Cognition Class 2 (*n* = 174)	High Average Cognition Class 3 (*n* = 49)	*t* or *X*	*p*	Post hoc comparisons
Age, years	61.84 (7.61)	62.57 (7.64)	61.04 (5.90)	0.94	0.39	–
Education, years	7.89 (4.19)	7.78 (4.39)	8.20 (4.06)	0.19	0.83	–
Gender, % female	72.54%	71.84%	77.55%	0.64	0.72	–
% Tested in Spanish	87.32%	85.06%	85.71%	0.34	0.84	–
SASH total score	1.52 (1.34)	1.57 (1.40)	1.57 (1.40)	0.06	0.95	–
Years lived in US	31.14 (18.10)	32.55 (17.30)	35.82 (14.52)	1.32	0.27	–
Annual income, $	35,688.31 (90,166.82)	32,973.6 (58,942.69)	29,711.91 (25,175.45)	0.14	0.87	–
MMSE total score	24.87 (3.07)	26.02 (2.89)	27.96 (1.72)	22.32	< .001	2, 3 > 1; 3 > 2
GDS total score	8.87 (7.25)	6.37 (5.64)	5.08 (5.78)	9.19	< .001	1 > 2, 3
Chronic stress total score	6.72 (6.61)	6.03 (6.27)	6.67 (5.71)	0.51	0.60	–
PSWQ total	40.04 (14.55)	38.25 (14.75)	34.35 (15.80)	2.71	0.07	–
MetS status, % yes	55.80%	66.46%	42.55%	9.54	0.01	2 > 3
High waist circumference, % yes	78.87%	78.16%	63.27%	5.48	0.06	–
Low high-density lipoprotein, % yes	38.57%	45.34%	29.17%	4.34	0.11	–
High blood pressure, % yes	65.00%	70.12%	54.17%	4.37	0.11	–
High glucose, % yes	53.57%	61.11%	37.50%	8.49	0.01	2 > 3
High triglycerides, % yes	45.00%	37.27%	41.67%	1.86	0.39	–

Note: SD = standard deviation, SASH = Short Acculturation Scale for Hispanics, MMSE = Mini-Mental Status Examination, GDS = Geriatric Depression Scale, PSWQ = Penn State Worry Questionnaire. Of the 142 participants from the *Low Average Memory* group, 2 (0.70%) had missing SASH data, 2 (1.41%) had missing years lived in the US, 13 (9.15%) had missing annual income data, 4 (2.82%) had missing MetS status data, 2 (1.41%) had missing low high-density lipoprotein data, 2 (1.41%) had missing blood pressure data, 2 (1.41%) had missing glucose data, and 2 (1.41%) had missing triglycerides data. Of the 174 participants from the *Average Cognition* group, 5 (2.87%) had missing SASH data, 1 (0.57%) had missing years lived in the US, 9 (5.17%) had missing annual income data, 13 (7.47%) had missing MetS status data, 13 (7.47%) had missing low high-density lipoprotein data, 12 (6.90%) had missing glucose data, and 13 (7.47%) had missing triglycerides data. Of the 49 participants from the *High Average Cognition* group, 1 (2.04%) had missing years lived in the US, 2 (4.08%) had missing annual income data, 2 (4.08%) had missing MetS status data, 1 (2.04%) had missing low high-density lipoprotein data, 1 (2.04%) had missing blood pressure data, 1 (2.04%) had missing glucose data, and 1 (2.04%) had missing triglycerides data.

Table 4. Bilingual speakers LPA fit indices for 2–5 class solutions

	AIC	BIC	sBIC	Entropy	Prob (min, max)	LMRT (*p*)	BLRT	Sample per class
2- Classes	13,365.77	13,496.05	13,397.66	0.755	0.50, 1.00	108.41 (0.0063)	< .001	1 = 286 (57.90%); 2 = 208 (42.10%)
3- Classes	**13,211.94**	**13,388.45**	**13,255.14**	**0.735**	**0.34, 1.00**	**227.75 (0.298)**	**< .001**	**1 = 173 (35.00%); 2 = 157 (31.80%); 3 = 164 (33.20%)**
4- Classes	**13,053.17**	**13,275.90**	**13,107.68**	**0.773**	**0.34, 1.00**	**757.63 (0.49)**	**< .001**	**1 = 167 (33.80%); 2 = 83 (16.80%); 3 = 123 (24.90%); 4 = 121 (24.50%)**
5- Classes	12,964.27	13,233.24	13,030.102	0.778	0.33, 1.00	1009.61 (0.439)	< .001	1 = 58 (11.70%); 2 = 117 (23.60%); 3 = 135 (27.30%); 4 = 81 (16.40%); 5 = 103 (20.80%)

Note: AIC = Akaike's Information Criterion, BIC = Bayesian Information Criterion, sBIC = size-adjusted Bayesian Information Criterion, LMRT = Lo–Mendell–Ruben Adjusted Likelihood Ratio Test, BLRT = Bootstrapped Likelihood Ratio Test.

probability of group membership less than 80% (Class 1 = 20, Class 2 = 22, Class = 8), with no participants having a probability of group membership less than 50%. A DFA further confirmed 96.4% of the sample was correctly classified, with 99.2% Class 1, 93.3% Class 2, and 100% Class 3 classification accuracy.

Monolingual speakers: class comparisons of demographic, psychosocial, and health characteristics

Results revealed that the 3-classes significantly differed on the MMSE total score, depression severity, MetS status, and elevated glucose levels; the *Low Average Memory* group performed more poorly on the MMSE and had more severe depressive symptomatology when compared to the other two groups, and the *High Average* group performed better than the *Average Cognition* group on the MMSE total score. The *Average Cognition* group had higher levels of MetS and elevated glucose levels relative to the *High Average Cognition* group, but did not significantly differ from the *Low Average Memory* group. No other differences on sociodemographic, psychosocial, or health variables were observed between the classes ($ps > .05$). See Table 3.

Bilingual LPA results

The LPA fit indices for the bilingual group and sample sizes for each different class solutions are presented in Table 4. Based on AIC, BIC, sBIC, and entropy, the 4-class solution was the most meaningful; however, the LMRT was not significant ($p = .49$) suggesting that a less complex solution (i.e., 3-classes) provided a better fit. Data for the 3-class solution is presented below given this is the "ideal" model, but the 4-class solution fit statistics and patterns of scores are available for review (see supplemental material).

For the 3-class solution, Class 1 represented 35% of the bilingual speaker sample and was a *Low Average Memory* group with low average verbal memory performances on the learning and delayed recall trials of Logical Memory, with mostly with average scores across other measure. Class 2 represented 32% of the bilingual

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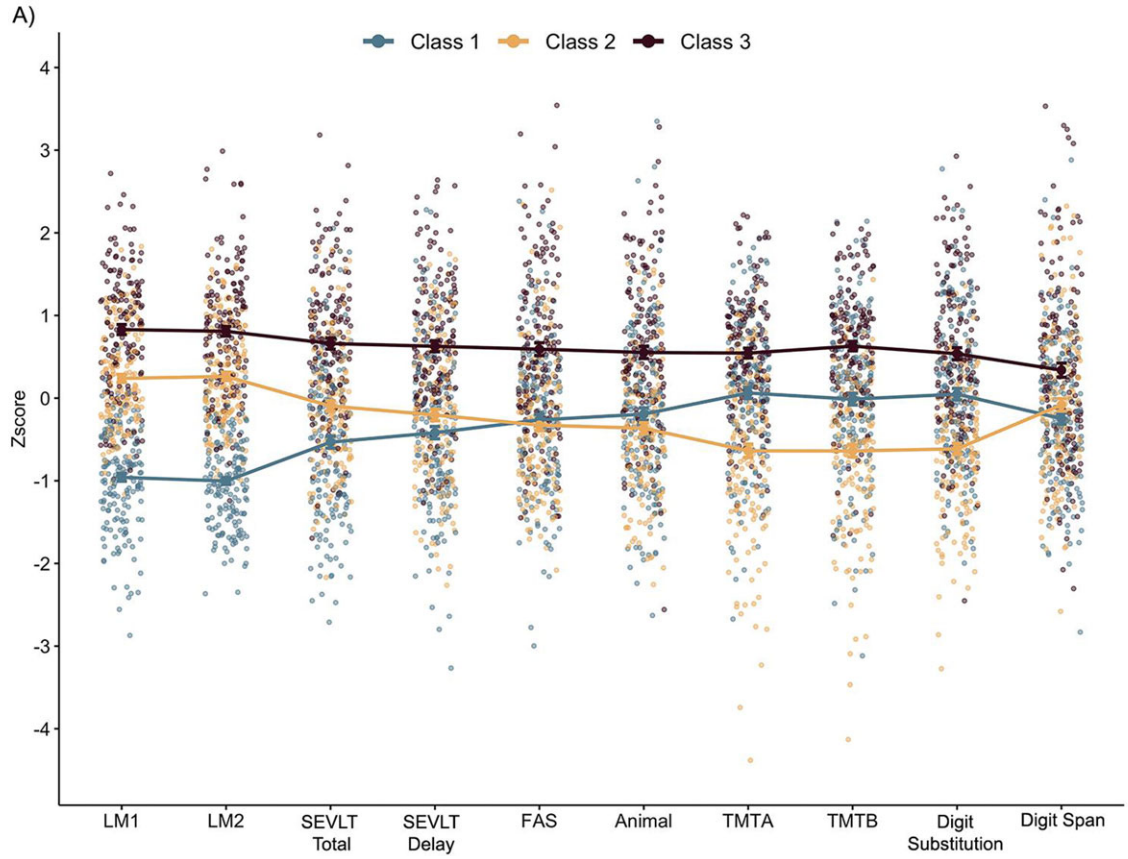

Figure 2. Distribution of scores across each cognitive test for the bilingual 3-class solutions. LM1 = Logical Memory I, LM2 = LogicaL Memory II, SEVLT = Spanish English Verbal Learning Test, FAS = Letter Fluency, Animal = Animal Fluency, TMTA = Trailing Making Test Part A, TMTB = Trailing Making Test Part B. Distribution of scores across groups for the 3-class solution. For the 3-class solution, Class 1 was a *Low Average Memory* with demonstrated low verbal memory (i.e., LM 1 and LM 2) with average scores across other measures, Class 2 was characterized by *Low Average Executive* group with demonstrated low executive scores (TMTA, TMTB, Digit Substitution) with average scores across other measures, and Class 3 was characterized by a *High Average Cognition* group with higher average scores across most cognitive tests.

speaker sample and was characterized by *Low Average Executive* group where performances on Trails A and B and Digit Substitution were the lowest. Class 3 represented 33% of the bilingual speaker sample and was characterized by a *High Average Cognition* group, where performance was generally in the high average range across most cognitive measures. For the 3-class solution, the DFA correctly classified 95.7% of the sample (97% Class 1, 94.6% Class 2, 95.3% Class 3). One hundred and twenty four of the participants in the 3-class solution had a probability of group membership less than 80%, with 9 participants having a probability of group membership less than 50%. Figure 2 includes the pattern of scores for 3-class solution.

Bilingual speakers: class comparisons of demographic, psychosocial, and health

The 3-class solution was compared on demographic, psychosocial, and health characteristics. Results revealed the classes significantly differed on the MMSE total score, with higher scores in the *High Average Cognition* group when compared to the other two groups ($p < .001$). There were also significant group differences in the proportion of individuals with elevated waist circumference ($p = .02$); the *Low Average Memory* group had a significantly higher proportion of individuals with elevated waist circumference relative to the *High Average Cognition* group ($p = .01$). No other significant group differences between the classes on any other variables of interest. See Table 5.

Discussion

The present study employed latent profile analysis to characterize cognitive classes in a large sample of monolingual and bilingual CU Latino older adults. Results revealed that there is cross-battery heterogeneity in cognitive performance that can be characterized within each monolingual and bilingual speaker group. Within the monolingual group, a 3-class solution emerged and consisted of *Low Average Memory*, *Average Cognition*, or *High Average Cognition* groups. Within the bilingual group, a 3-class solution emerged, and cross-cognitive battery performances consisted of *Low Average Memory*, *Low Average Executive*, and *High Average Cognition* groups. When the identified classes within each language group were compared on sociodemographic, psychosocial, and health factors, there were few observed differences. Collectively, this work illustrates there is incredible cross-battery cognitive variability within monolingual and bilingual speaker groups that needs to be further explored. We suspect the identified classes represent unique groups of CU adults with varying levels of cognitive reserve, as well as risk and resiliency to the future development of AD. For example, while speculative, monolingual and bilingual speakers with low average memory or executive

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Table 5. Demographics psychosocial, and health characteristics across bilingual LPA class solutions, mean (SD)

Bilingual	Low Average Memory Class 1 (*n* = 173)	Low Average Executive Class 2 (*n* = 157)	High Average Cognition Class 3 (*n* = 164)	*t* or *X*	*p*	Post hoc comparisons
						–
Age, years	63.41 (7.92)	62.22 (8.18)	62.80 (7.45)	0.94	0.39	–
Education, years	11.64 (4.07)	11.80 (4.07)	11.74 (3.72)	0.08	0.93	–
Gender, % female	65.32%	64.97%	68.29%	0.49	0.78	–
% Tested in Spanish	43.93%	45.22%	42.07%	0.33	0.85	–
Language dominance, % unbalanced	84.34%	84.97%	87.82%	0.89	0.64	–
Age of acquisition, % late	86.75%	89.54%	84.62%	1.66	0.44	–
SASH total score	3.04 (1.46)	2.92 (1.47)	3.06 (1.52)	0.41	0.66	–
Years lived in US	51.73 (17.21)	48.76 (17.79)	49.73 (17.89)	1.21	0.30	–
Annual income, $	46, 691.53 (39, 799.09)	47, 606.20 (44, 388.81)	52, 793.60 (72, 705.27)	0.60	0.55	–
MMSE total score	27.46 (2.02)	27.57 (2.21)	28.37 (1.42)	11.34	< .001	3 > 1, 2
GDS total score	5.57 (5.678)	5.71 (5.91)	4.66 (5.28)	1.67	0.19	–
Chronic stress total score	7.23 (6.96)	7.13 (5.85)	7.98 (7.16)	0.78	0.46	–
PSWQ total	39.25 (14.59)	40.34 (14.99)	38.79 (13.74)	0.49	0.62	–
MetS status, % yes	44.00 %	45.37 %	42.74 %	0.16	0.92	–
High waist circumference, % yes	81.40%	73.89 %	68.29 %	7.69	0.02	1 > 3
Low high-density lipoprotein, % yes	16.54 %	13.27 %	15.20 %	0.50	0.78	–
High blood pressure, % yes	75.15 %	63.82 %	69.33 %	4.87	0.09	–
High glucose, % yes	46.15 %	52.26 %	54.89 %	2.67	0.26	–
High triglycerides, % yes	35.50 %	37.42 %	34.15 %	0.37	0.83	–

Note: SD = standard deviation, SASH = Short Acculturation Scale for Hispanics, MMSE = Mini-Mental Status Examination, GDS = Geriatric Depression Scale, PSWQ = Penn State Worry Questionnaire. Of the 173 participants from the *Low Average Memory* group, 7 (4.05%) had missing language dominance and age of acquisition data, 2 (1.16%) had missing SASH data, 2 (1.16%) had missing years lived in the US, 3 (1.73%) had missing annual income data, 48 (27.75%) had missing MetS status data, 1 (0.58%) had missing waist circumference data, 49 (28.32%) had missing low high-density lipoprotein data, 5 (2.89%) had missing blood pressure data, 4 (2.31%) had missing glucose data, and 4 (2.31%) had missing triglycerides data. Of the 157 participants from the *Low Average Executive* group, 4 (2.55%) had missing language dominance and age of acquisition data, 1 (0.64%) had missing SASH data, 1 (0.64%) had missing years lived in the US, 2 (1.27%) had missing annual income data, 49 (31.2%) had missing MetS status data, 44 (28.02%) had missing low high-density lipoprotein data, 5 (3.18%) had missing blood pressure data, 2 (1.28%) had missing glucose data, and 2 (1.28%) had missing triglycerides data. Of the 164 participants from the *High Average Cognition* group, 8 (4.88) had missing language dominance and age of acquisition data, 4 (2.44%) had missing years lived in the US, 4 (2.44%) had missing annual income data, 40 (24.3%) had missing MetS status data, 39 (23.78%) had missing low high-density lipoprotein data, and 1 (0.61%) had missing blood pressure data.

performances may be at risk for the future development of AD given these domains are commonly affected by AD pathologic change, whereas individuals with high average cognitive performance may have a lower risk due to more room to fall before reaching cognitive impairment. Nevertheless, future works examining potential differences in the rates of progression to MCI/AD, AD biomarker outcomes, and neuroimaging trajectories across each of these classes are ultimately needed to better understand how clinical outcomes may differ across identified classes within each speaker group.

Although LPA has been applied to a variety of different neurologic samples to understand important variability in disease outcomes across different cognitive classes, this has largely taken place in non-Latino White samples, and therefore, assumptions have limited generalizability to more ethnoracially diverse samples (Bialystok et al., 2014; Ossher et al., 2013). However, researchers from the Study of Latino-Investigation of Neurocognitive Aging (SOL-INCA) study recently conducted an LPA in a large sample of CU Latinos ($N \sim 6{,}000$) of diverse heritages (Graves et al., 2024). This study revealed a 5-class solution of *High Global* (10%), *High Memory* (25%), *Low Memory* (33%), *Low Executive* (17%), and *Low Global* (12%) groups. Notably, participants in this study were tested in either English or Spanish and we assume a sizable proportion of the sample may have also been bilingual, although this is not directly reported in the publication. Although the number of optimal class solutions in this study differed from our own observations, it is important to note that some of these identified classes map onto groups identified in our stratified monolingual (e.g., *High Global* in the SOL-INCA sample *versus High Average Cognition in the present study*) and bilingual analyses (*Low Memory* in the SOL-INCA sample vs. *Low Memory in the present study*). Thus, some of the classes identified in the SOL-INCA study may be related to monolingual or bilingual group status. The Graves et al. study also found key differences in heritage status across the 5-class solution, and it is also possible that key differences in the class solutions across the studies may also be related to heritage composition, as our sample consisted predominantly of Mexican Americans.

The cognitive classes identified across the monolingual and bilingual speaker groups were qualitatively different, and there were some nuanced differences between the DFA statistics and optimal class solutions across each language group in our study that should be acknowledged. The 3-class solution of *Low Average Memory, Average Cognition, or High Average Cognition* from the monolingual group did not directly map onto the 3-class solutions identified in the bilingual sample. For example, a *Low Average Executive* group emerged in the bilingual group that was not present in the monolingual group. One plausible explanation for the identified *Low Average Executive* bilingual group is that they differ in their bilingual characteristics (beyond those capturable by the SASH) and therein may have less reserve. Our findings also identified a *Low Average Memory* monolingual group that had lower performance on unstructured memory tests (SEVLT), whereas the *Low Average Memory* bilingual group had lower performance on structured memory tests (Logical Memory). Considering there have been noteworthy differences on cognitive test performance between CU monolingual and bilingual samples (e.g., Grasso, 2023; Lamar et al., 2022), we suspect that this would subsequently impact classifications across language groups. Indeed, the literature has revealed that bilingual speakers have generally been observed to perform better on tests of attention/ executive functioning when compared to monolingual speakers

(Bialystok, 2014; Grasso, 2023). Although this was not formally tested, our bilingual *Low Average Memory* group did seemingly have slightly better average executive *z*-scores than the monolingual *Low Average Memory* group, which could potentially be evidence of a bilingual cognitive advantage on tests of executive/attention measures. Nevertheless, it is important to recognize that there is an ongoing debate about the consistency and size of this bilingual executive advantage effect in the existing literature, as there is some evidence that these effects are entirely mitigated when monolingual and bilingual speakers are matched on potential confounding variables (Dick et al., 2019; Nichols et al., 2020; Paap et al., 2015). Importantly, our particular set of analyses were not conducted to evaluate the potential presence or absence of enhanced executive functions in bilinguals, but rather to capture the heterogeneity present across cognitive assessment within monolingual and bilingual groups, respectively. Ultimately, more work on bilingualism is needed to better understand differences in cognitive test performance that may emerge in other homogenous samples of Mexican Americans, and under what circumstances we see these effects.

Within each of the language groups, identified classes were compared on demographic, psychosocial, and health factors of interest. The *Low Average Memory* group within the monolingual sample had significantly higher levels of depression and displayed a lower MMSE total score relative to the *Average* and *High Average Cognition* groups. It is possible that these depressive symptoms and generally lower levels of global neurocognitive functioning as measured by the MMSE may be playing a contributory role in their cognitive group classification. Indeed, it has been established that anxiety, stress, and depressive symptoms can negatively impact cognitive test performance (Marquine et al., 2022; Muñoz et al., 2021) and lower levels of global cognitive performance may be slightly indicative of lower levels of cognitive reserve (Kang et al., 2018). As such, we postulate that his group could be vulnerable to faster rates of progression to MCI and/or AD, and future studies are needed to clarify whether they represent an "at risk" group. Interestingly, analysis of the health data revealed *Average Cognition* group had higher levels of MetS and elevated glucose levels relative to the *High Average Cognition* group, although no differences with the *Low Average Memory* group were observed in the monolingual group analyses. Similarly, the *Low Average Memory* group had a significantly higher proportion of individuals with elevated waist circumference relative to the *High Average* group in the bilingual group analyses. Considering these cardiometabolic health outcomes are also associated with poorer cognition (Awad et al., 2004; González et al., 2018; Rodriguez-Fernandez et al., 2017), this may be one potential mechanism by which cognitive levels are slightly lower in these *Low Average Memory* groups and may also place them at risk for future decline. In contrast, there was some evidence of a slightly higher MMSE total score in the *High Average Cognition* group that emerged in both the bilingual and monolingual 3-class solutions. We postulate that the *High Average Cognition* may represent a "resilient" group with higher levels of cognitive reserve and global functioning that could therefore have "more to lose" before reaching cognitive impairment. They also did not display poor performances in domains commonly implicated in AD when compared to the *Low Memory* and *Low Executive* groups. Nevertheless, these interpretations are purely speculative, and additional longitudinal studies are needed to clarify whether longitudinal outcomes differ across the identified class solutions.

Interestingly, our results revealed that the three identified classes within the bilingual group did not differ on bilingualism factors including age of acquisition or language dominance. This pattern of results suggests that cognitive classifications in these groups are not merely a byproduct of how early in life one began learning a second language or which language is most dominant. However, given we controlled for language of testing, we may have also reduced our ability to detect the influence of bilingual factors that are associated with language of testing. Relatedly, while there are several ways to approach analyzing this data, our analyses were conducted on cognitive *z*-scores that were adjusted for age, sex, education, and language of testing. This adjustment of cognitive *z*-scores for language of testing was necessary so that we could have increased confidence that the identified classes were not merely the consequence of differences in language of testing. While adjusting cognitive scores for potential confounds is a common approach in neuropsychological research, it is important to recognize that these adjustments may not entirely mitigate the effects of confounding variables (Kamalyan et al., 2021). Thus, to further evaluate any potential influence of language of testing on the present findings, we also conducted a series of exploratory analyses where we calculated cognitive *z*-scores that were adjusted for age, sex, and education only (wherein we did not include language of testing) and conducted the LPA in monolingual Spanish speaker, bilingual English speaker, and bilingual Spanish speaker groups (monolingual English speakers were excluded due to their small sample size). These analyses revealed similar 3-class solutions across monolingual and bilingual speaker groups indicating the classes we observed are not merely a byproduct of language of testing differences, but attributable to monolingual and bilingual group status.

The current data available to characterize bilinguals in this cohort is somewhat limited, and we largely relied upon one subjective measure to characterize bilinguals in this cohort. Therefore, we cannot reject the possibility that use of other *objective* measures of bilingualism (e.g., performance on a specific task/test in each language) to characterize our groups could result in a different set of class solutions. Self-report measures of bilingualism have advantages including the ability to efficiently query a number of factors related to the bilingual experience and have been shown to correlate with objective measures (Gollan et al., 2012; Macbeth et al., 2022; Marian et al., 2007; Marian & Hayakawa, 2021; Ross, 1998). At the same time, these measures have several limitations including differences in the interpretation of scales (Tomoschuk et al., 2019), issues with validity surrounding specific linguistic skills (Ross, 1998), and evidence of language dominance reversal in subsets of older adults (Gollan et al., 2012). As such, when possible, a combination of self-report and objective measures should be utilized in future research.

The pattern of results reported herein leaves one to postulate about factors that may ultimately be responsible for the observed cognitive heterogeneity and cognitive classes we identified in this sample. Although we conducted analyses in CU older adults, it is possible that *preclinical* AD processes that have not yet resulted in cognitive impairment may be one factor underlying the variability. Alternatively, there are an array of life course experiences as detailed by the NIA Health Disparities Research Framework that may have played a role in ultimately shaping patterns and overall cognitive and neural reserve (Hill et al., 2015). It is important to recognize that there were important background and psychosocial characteristics that differed across the bilingual and monolingual groups. The bilingual group had

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higher levels of acculturation, years of education, and income and had resided in the U.S. for longer periods of time relative to the monolingual group. Although we adjusted for the potential influence of some of these variables in our analyses by using demographically adjusted *z*-scores, it is essential to realize that group differences on these factors are not nullified with this approach (Kamalyan et al., 2021). Importantly, the larger cultural context and differences between these groups may have ultimately shaped levels of cognition and some of the cognitive profiles that emerged in our results, as there have been several studies showing that higher levels of cognition in those with higher levels of education and better quality education (Dotson et al., 2009; Farias et al., 2011; Mungas et al., 2018), and factors related to acculturation (e.g., nativity, language) and the contextual environmental (e.g., discrimination, social networks) independently and differentially contribute to cognitive performance (Estrella et al., 2021; Lamar et al., 2021a, b). In reality, the cognitive profiles within each of these groups are likely intimately related to the constellation of many social and psychosocial factors that characterize the lived experiences of these groups, and it is important to recognize that classes identified may differ in samples with varied experiences in these domains as well.

There are a number of strengths and weaknesses to the present study that are worthwhile to note. This study was conducted in a well-characterized sample of Latino older adults predominantly of Mexican American descent, and the consideration of cognitive variability across these language groups is novel and important for the reasons highlighted above. The testing of multiple-class solutions and adjustment for sample-specific demographics across each language group for each cognitive test prior to conducting the LPA were also strengths. Furthermore, our emphasis on CU individuals is a strength given language effects on cognition have been well established and it is important to understand cognitive variability in these language groups before introducing variability associated with genuine impairment and other disease processes. However, there are also several important weaknesses to acknowledge. Ultimately, more work is needed investigating the associations between self-report and objective measures of bilingualism in older adults with and without cognitive impairment and across distinct sociocultural contexts to better understand the most useful methods for capturing this important construct of interest. While we controlled for language of testing, it is important to note the monolingual group consisted predominantly of Latinos that were Spanish speaking, and different patterns may emerge in a sample that had higher levels of English only Latino monolinguals. Relatedly, there were important differences in the lived experiences of the monolingual and bilingual groups as reflected by key differences in income, acculturation, education, and years of residency, which may have impacted which cognitive classes emerged. Replication of these findings in other samples is also key to ensure observed effects in the monolingual group were not simply due to the “salsa effect” and that each identified class is a true pattern characteristic of the groups. Finally, measurement equivalency of cognitive measures in ethnoracially and linguistically diverse individuals needs to be further established, and some of the cognitive tests utilized here may more reliably estimate the constructs of interest when testing is completed in English when compared to Spanish.

Taken together, our study revealed that there are distinct cognitive classes that can be identified in monolingual and bilingual speakers, and that these cognitive classes are qualitatively different across each language group. Future studies examining rates of progression and nuanced neuroimaging patterns across the groups are underway and will help clarify to what extent the identified cognitive classes represent groups that are at risk or resiliency to the development of AD.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/S1355617724000547.

Acknowledgements. The authors thank all the HABS-HD participants and study staff for their commitment to advancing representative aging research and for publicly sharing these data with other researchers.

Funding statement. This work was supported by the National Institute on Aging (NIA) of the National Institutes of Health (NIH) under Awards R01AG05407 to R01AG058533 (HAB-HD Study Team) and R03 AG085241 (Dr Clark). Additional grant support to Dr Clark included a HABS-HD Faculty Fellowship (U19AG078109) and Alzheimer’s Association (AARG-22-723000) award, as well as from the Center on Aging and Population Sciences (P30AG066614). Coauthors were also supported by NSF Graduate Research Fellowships (J.B., DGE 2137420). The consent is the sole responsibility of the authors and does not necessarily represent the official views of the NIH.

Competing interests. None.

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https://doi.org/10.1017/S1355617724000547 Published online by Cambridge University Press

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