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RESEARCH ARTICLE

Normative data for the Digit Symbol Substitution for diverse Hispanic/Latino adults: Results from the Study of Latinos-Investigation of Neurocognitive Aging (SOL-INCA)

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Abstract

INTRODUCTION: Executive functioning and processing speed are crucial elements of neuropsychological assessment. To meet the needs of the Hispanic/Latino population, we aimed to provide normative data for the Digit Symbol Substitution (DSS) test.

METHODS: The target population for the Study of Latinos-Investigation of Neurocognitive Aging included six heritage backgrounds ($n = 6177$). Average age was 63.4 ± 8.3 years, 54.5% were female, and mean education was 11.0 ± 4.7 years. Participants were administered the DSS as part of a larger battery. Heritage-adjusted DSS scores, and percentile cut-points were created using survey-adjusted regression and quantile regression models.

RESULTS: Age, education, sex, heritage, and language preference were associated with DSS scores.

DISCUSSION: Significant correlates of DSS performance should be considered when evaluating cognitive performance. Representative DSS norms for Hispanics/Latinos will advance assessment and accuracy of neurocognitive disorder diagnosis in clinical

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practice. To facilitate interpretation, we provide norms to reduce test biases and developed an online dashboard.

KEYWORDS
aging, Digit Symbol Substitution test, disparities, Hispanic, neuropsychology, normative data

Highlights

Normative data for the Digit Symbol Substitution (DSS) for diverse Hispanic/Latino adults: Results from the Study of Latinos-Investigation of Neurocognitive Aging (SOL-INCA)

- This study is the first to develop norms for the DSS test across four regions of the United States.
- Factors such as age, education, sex, and Hispanic/Latino heritage and language preference are associated with differences in executive functioning and information processing speed.
- We created norms and an online dashboard (https://solincalab.shinyapps.io/dsst_shiny/) providing an easily accessible tool to evaluate processing speed and executive functioning in Hispanic/Latino adults.

1 | INTRODUCTION

Hispanic/Latino adults are the largest ethnic minority group in the United States (19.1%) and the fastest-growing population among persons aged ≥ 65 years.[1] Because of advanced age and larger social and structural inequities within the United States, Hispanic/Latino adults are at increased risk of developing Alzheimer's disease and related dementias (ADRD)— 1.5 times more likely than non-Hispanic Whites.[2] With the continuing growth and overall aging of the population, Hispanics/Latinos living with ADRD are projected to increase from 379,000 in 2012 to 3.5 million by 2060.[3] Though Hispanics/Latinos are often considered a homogenous group, they differ by important cultural and demographic characteristics that are often overlooked.[4,5] There is a need for norms that account for important cultural and demographic characteristics applicable to an aging and diverse group. Notably, filling this gap in the literature continues to be a priority as endorsed at the 2016 to 2022 ADRD Summits.[6]

The Digit Symbol Substitution (DSS) test, a subtest of the Wechsler Adult Intelligence Scale–Revised (WAIS)[7] has been found to be reliable and clinically useful because of its sensitivity to cognitive deficits in a wide range of brain diseases and has been widely used in studies of cognitive aging and dementia.[8–13] The DSS is a measure of executive function (e.g., attention and processing speed) that has been used in large cohorts (e.g., Atherosclerosis in Communities study). However, norms are limited particularly on large and diverse groups of Hispanic/Latino adults.[14–17] Pontón et al. provided norms for the DSS based on 342 Hispanic/Latino adults ages 16 to 75 years (M = 38.4 ± 13.5), and education level 1 to 22 years (M = 10.7 ± 5.1) from the greater Los Angeles area. While these data provided norms, their applicability to Hispanic/Latino adults with different acculturative, regional, or linguistic backgrounds and heritage is unknown. More recently, Rivera Mindt et al. reported norms for the DSS on a sample of 203 native Spanish-speaking individuals ages 19 to 60 years.[17] However, this sample was limited to Hispanic/Latino adults from US border regions (n = 203), and the upper age limit of the sample was 60 years.

Non-verbal tests are frequently considered more culturally and educationally unbiased ("culturally free") than verbal tests. However, several studies have shown associations between education and culture on performance on common non-verbal neuropsychological tests. The performance on non-verbal tests (e.g., copying figures or symbols) can be significantly influenced by an individual's culture. The use of symbols may be unsuitable in cultures unfamiliar with symbolic drawings and shows differences in the perception of pictures by individuals of different cultures.[18–21] Moreover, non-verbal tests frequently require certain strategies and cognitive styles distinctive of middle-class Western cultures.[19,22,23] Regarding clinical assessment, however, it is unclear which version in Spanish[24–28] is most applicable for a more diverse Hispanic/Latino population in the United States. Research suggests avoiding the use of Spanish language versions of the WAIS (Mexico, Spain, and Puerto Rico) and the English language version (based on a non-Hispanic White population) among US Hispanics/Latinos to avoid the potential risk of under- or overestimating cognitive deficits.[17,27–29] This highlights the importance of selecting appropriate tools for use with diverse US Hispanics/Latinos.

Given these limitations, and the research priorities addressed during the ADRD Summit, there is a need for high-quality norms for specific Hispanic/Latino populations in the United States that consider cultural, ethnic, and genetic differences, and the effects of age, education, Hispanic/Latino heritage, and sex. The purpose of this study was to establish demographically adjusted norms for the DSS for a diverse sample of US Hispanic/Latino adults from the Study of Latinos-Investigation of Neurocognitive Aging (SOL-INCA).

2 | METHODS

2.1 | Study sample

The study used data from the SOL-INCA (2015–2018, ages 50–86), an ancillary study to the Hispanic Community Health Study/Study of Latinos (HCHS/SOL). As described previously[30] HCHS/SOL (2006–2008, ages 18–74) is a multisite, probability sampled, prospective cohort study that collected data from four major field centers in the United States with high Hispanic/Latino population densities. The sample included six Hispanic/Latino heritages (Table 1). Most participants were foreign born with 70.7% (n = 4533) reporting < 10 years in the United States, followed by 21.7% (n = 1129) reporting > = 10 years in the United States and 7.6% (n = 514) being US born. HCHS/SOL participants who underwent cognitive testing and were at least 50 years of age by their second visit were recruited for the SOL-INCA study (n = 6377). The current study focused on participants ages 50 to 86 years without any missing covariates (n = 6177). Participants' income is as follows: < $10,000 = 901 (16.8%), $10,001 to $20,000 = 1798 (30.2%), $20,001 to $40,000 = 1832 (28.6%), $40,001 to $75,000 = 675 (11.7%), > $75,000 = 206 (3.9%), and 452 (8.9%) reported no income. A subpopulation of cognitively normal (CN) participants was chosen based on no stroke or transient ischemic attack (TIA) at baseline (visit 1) and INCA (visit 2) and the six-item screener score (SIS) of < 5 or greater (n = 5017; visit 2). The average time between the visit 1 and 2 was approximately 7 years.

2.2 | Outcomes

2.2.1 | DSS test

The DSS test (WAIS-R) was administered during face-to-face interviews by bicultural and bilingual (English and Spanish) staff members as part of a larger neuropsychological battery (tests included: Brief-Spanish English Verbal Learning Test, Word Fluency, and the Trail Making Test). Staff members were trained and supervised by doctorate-level clinical psychologists. Participants were presented with a key that pairs a set of digits with a set of symbols and had 90 seconds to fill in as many blank boxes with the appropriate symbol for each digit shown at the top of the page. The instructions of the DSS test were translated to Spanish using back translation methods by HCHS/SOL bilingual staff at visit 1 (2008–2011). Translations from English to Spanish happened first, and the resulting Spanish version was independently translated back to English by a different translator. A group of researchers then compared the original English version to the back-translated English version and, where discrepancies occurred, a consensus about the most appropriate translation was made.[31] It should be noted that the actual DSS test, comprising digits and symbols, was identical in both languages.

RESEARCH IN CONTEXT

1. **Systemic review**: The authors of this study reviewed literature concerning normative data available for Spanish- and English-speaking Hispanics/Latinos using traditional sources (e.g., PubMed, Google Scholar).
2. **Interpretation**: Factors, such as age, education, sex, and Hispanic/Latino heritage and language preference were associated with differences in executive functioning and information processing speed.
3. **Future directions**: Normative data can help identify cognitive impairment and decline among Hispanic/Latino adults. The influence of sociocultural factors such as acculturation and bilingualism on Digit Symbol Substitution test performance should be investigated.

2.2.2 | The SIS

The SIS is a brief cognitive screener that consists of three orientation questions and a three-word list learning and memory trial.[32] It is not meant to provide a comprehensive assessment of cognitive function, but rather to quickly identify individuals who may need further evaluation. The sum of correct responses was the dependent measure, and a dichotomous SIS indicator was developed to examine low mental status functioning with a score of four or less out of a total possible score of six as the cut point. The SIS is a useful screening tool but should not be used a diagnostic tool.

2.3 | Covariates

We sought to determine how age, education, heritage, language of test administration (henceforth language preference), and sex were associated with the DSS. Age and education (in years) were represented continuously in the models and considered trichotomous indicators (50–59 years, 60–69 years, and 70+ years, and less than high school, high school or equivalent, more than high school education). Age and language preference were assessed at time of testing (visit 2), while all other covariates were assessed at baseline (visit 1).

To facilitate potential clinical interpretation, predictions based on the continuous measures can be found in a companion online dashboard (https://solincalab.shinyapps.io/DSST/) built based on regression models as specified below. A similar dashboard has been published using norms from other tests available through HCHS/SOL.[33] The dashboard allows users to generate raw score

TABLE 1 Population characteristics by language preference and Hispanic/Latino heritage.

		DSS		Female	Age (in years)		Education (in years)		SIS (range = 0–6)	
	Unweighted n	Mean	SD	%	Mean	SD	Mean	SD	Mean	SD
Overall	6177	31.6	13.5	54.5	63.4	8.3	11.0	4.7	5.2	0.9
Language										
Spanish	5411	30.4	13.2	55.4	63.7	8.3	10.8	4.8	5.2	0.9
English	766	40.2	12.3	48.4	61.4	7.5	12.6	3.2	5.3	0.8
P value language		<0.001		0.04	<0.001		<0.001		<0.01	
Hispanic/Latinoheritage										
Dominican	566	24.8	11.3	60.4	62.5	8.0	10.6	4.2	5.1	0.9
Central American	626	27.4	14.8	60.3	62.7	8.9	10.2	5.9	5.2	1.1
Cuban	1040	31.6	10.0	48.8	65.0	6.9	12.8	3.3	5.2	0.7
Mexican	2427	34.0	14.8	55.9	62.1	8.2	9.7	5.3	5.4	0.9
Puerto Rican	1060	31.9	14.2	53.6	64.4	8.4	11.2	3.9	5.1	1.0
South American	458	34.8	15.0	57.5	63.4	9.8	12.4	5.2	5.2	1.0
P value background		<0.001		<0.001	<0.001		<0.001		<0.001	

Abbreviations: DSS, Digit Symbol Substitution test; SIS, Six-Item Screener; SD, standard deviation.

predictions based on individual profiles of interest (e.g., predicted score for a 62-year-old, Dominican-origin male, with 6 years of education, and Spanish language preference) based on models fit to several groups: (1) the overall population, (2) no stroke or TIA at visit 1 and visit 2, (3) no stroke or TIA and CN (i.e., individuals free of stroke or TIA at visit 1 and visit 2 and a score of ≥ 5 in the SIS), (4) low mental status (SIS score of ≤ 4), and (5) typical mental status (SIS score of ≥ 5). Dashboard users can use observed raw individual scores of hypothetical individuals relative to the normative distribution (standardized *z* scores; SS) given their model expected value. Standardized scores (SS-scores) are generated using the following formula: SS = (Raw Score − Expected Value)/RMSE, whereby SS = calculated z-score(s), Raw Score = hypothetical value(s) on the DSS, Expected Value = model based estimate using the test specific regression equation ($\beta_{Intercept} + \beta_{Age} * Age + \beta_{Sex} * Sex + \beta_{Education} * Education + \beta_{Background} * Background + \beta_{Language} * Language$), and RMSE = root mean square error of estimated regression model.

2.4 | Analytical procedures

Modeling and visualization of the distributions were conducted using Stata v17, and R 3.5 software. First, we reported the demographic characteristics of the target population by heritage and language preference for testing (Table 1). Categorical measures are reported in percentages, and continuous measures as means (standard deviations). We also reported *P* values for differences in reported measures by heritage and language preference. Second, we reported overall normative scores for the DSS, as well as norms by age groups (50–59, 60–69, and 70+), sex, education levels, heritage, and language preference including means and standard deviations (SDs; Table 2). Score distributions are plotted in Figure 1. Third, we generated survey-adjusted correlation plots to visually characterize the strength and direction of crude associations between the DSS, age, language preference, education (in years), sex, and the SIS (Figure 2). Fourth, we fit survey linear regression models to estimate the adjusted associations between DSS and age, sex, education (in years), heritage, and language preference (Table 3). We fit these regression models for the overall target population and stratified by sex, age groups, and language preference. For stratified models, the stratification variable was excluded. Unstandardized beta coefficients (to interpret original metrics) and model covariates with respective *P* values are found in Table 3. We fit the survey linear regression models for two target populations: (1) all individuals 50 to 86 years of age, and (2) CN individuals 50 to 86 years with no self-reported stroke/TIA. We used post hoc techniques to compute normed average marginal estimates derived from the regression models and their 95% confidence intervals (CIs) for males and females within age and education groups (Table 4). These models were based on the target population of: (1) all individuals 50 to 86 years of age, and (2) CN individuals 50 to 86 years with no self-reported stroke/TIA (at visit 2). Finally, we refit the models described in step four for individuals 50 to 86 years stratified by heritage and language preference. As above, we used post hoc techniques to compute specific normed average marginal estimates derived from the regression models and their 95% CI for males and females within age and education groups (Tables S1 and S2 in supporting information).

3 | RESULTS

Average age was 63.4 years ± 8.3, with mean years of education of 11.0 ± 4.7, and an average SIS score of 5.2 ± 0.9 (17.6% had a SIS score of < = 4); 54.5% were female (38.6% had less than a high school education), 87.2% stated Spanish as their testing language of preference, and 5.4% reported history of stroke/TIA. Mexican-heritage

TABLE 2 Digit Symbol Substitution scores over descriptive statistics by sex, age, and language preference.

	Overall	Female	Male	50–59 years	60–69 years	70+ years	Spanish	English
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Overall target population	31.6 (13.5)	32.1 (15.2)	31.1 (11.3)	37.3 (13.3)	31.2 (10.6)	23.5 (9.8)	30.4 (13.2)	40.2 (12.3)
Age								
50–59 years	37.3 (13.3)	38.6 (15.4)	35.9 (10.8)	n/a	n/a	n/a	36.3 (13.1)	42.5 (12.9)
60–69 years	31.3 (12.8)	31.3 (14.6)	31.2 (10.6)	n/a	n/a	n/a	30.1 (12.4)	19.7 (12.1)
70+ years	23.5 (9.8)	24.1 (10.4)	22.5 (8.8)	n/a	n/a	n/a	22.4 (9.4)	34.7 (8.9)
Sex								
Female	32.1 (15.2)	n/a	n/a	38.6 (15.4)	31.3 (14.6)	24.1 (10.4)	30.8 (14.8)	42.1 (14.1)
Male	31.1 (11.3)	n/a	n/a	35.9 (10.8)	31.2 (10.6)	22.5 (8.8)	29.9 (11.1)	38.5 (10.3)
Education								
Less than high school	24.2 (12.1)	24.5 (13.3)	23.9 (10.4)	30.2 (12.1)	25.1 (11.3)	17.0 (8.5)	23.3 (11.8)	33.3 (10.4)
High school	32.5 (11.2)	33.5 (13.0)	31.6 (9.3)	35.8 (11.0)	32.2 (11.0)	25.5 (8.3)	31.7 (11.0)	38.4 (11.0)
More than high school	38.3 (12.1)	38.2 (12.1)	37.3 (10.1)	43.5 (12.1)	37.2 (11.6)	30.5 (8.1)	37.0 (11.7)	37.0 (11.7)
Hispanic/Latino heritage								
Dominican	24.8 (11.3)	25.5 (12.8)	23.6 (8.8)	29.7 (10.4)	24.2 (11.1)	15.2 (7.0)	24.4 (11.1)	36.2 (9.9)
Central American	27.4 (14.8)	27.4 (14.8)	27.0 (12.3)	32.9 (12.3)	27.0 (12.4)	17.5 (8.7)	27.3 (15.0)	31.8 (7.4)
Cuban	31.6 (10.0)	32.2 (11.0)	30.9 (9.0)	37.1 (9.9)	32.4 (10.4)	25.6 (7.0)	31.1 (9.9)	42.6 (8.1)
Mexican	34.0 (14.8)	34.3 (16.8)	33.5 (12.1)	39.3 (13.7)	32.3 (13.4)	24.6 (13.0)	32.7 (14.6)	44.4 (11.2)
Puerto Rican	31.9 (14.2)	33.2 (16.2)	30.4 (11.7)	39.1 (14.4)	32.7 (13.2)	23.0 (9.6)	26.6 (12.8)	38.2 (13.0)
South American	34.8 (15.0)	33.5 (16.0)	36.6 (13.3)	41.2 (13.2)	35.2 (13.9)	23.7 (8.7)	34.6 (15.0)	39.7 (11.4)
Language preference								
Spanish	30.4 (13.2)	30.8 (14.8)	29.9 (11.1)	36.3 (13.1)	30.1 (12.4)	22.4 (9.4)	n/a	n/a
English	40.2 (12.3)	42.1 (14.1)	38.5 (10.3)	42.5 (12.9)	39.7 (12.1)	34.7 (8.9)	n/a	n/a

Abbreviation: SD, standard deviation.

individuals composed 32.9% of the target population, followed by Cubans (25.8%), Puerto Ricans (15.4%), Dominicans (9.4%), South Americans (9.0%), and Central Americans (7.3%). We found significant differences in age, education, sex, and SIS distributions by heritage and language preference.

Cubans were slightly older (mean age 65.0 years, SD = 6.9) than other background groups. Cubans (12.8 years, SD = 3.3) and South Americans (12.4 years; SD = 5.2) had higher education relative to other heritages. Higher education was noted among individuals with English as their preferred language for testing compared to Spanish speakers (12.6 years; SD = 3.2 vs. 10.8 years; SD = 4.8). Population characteristics by heritage and language preference for testing are presented in Table 1.

The average DSS scores for the overall target population are reported in Table 2. Means and SDs of observed raw scores by age, education, language preference, heritage, and sex are included in Table 2. Females scored significantly higher than males on average. Higher educational attainment was associated with higher scores. Older age (70+) was associated with lower DSS scores. In terms of Hispanic/Latino heritage, Mexicans scored significantly higher than other heritages. Figure 1 shows the graph distribution of DSS scores by age, education, language preference, and sex. Figure 2 represents survey-adjusted correlation plots between DSS, sex, age, education, and language preference.

Regression estimates derived from the regression models are presented in Table 3. Each year increase in age was associated with ß = −0.54 ($P < 0.001$) units decrease in DSS scores, and females had consistently higher DSS scores than males. Education was positively associated to performance; each additional year of educational attainment was associated with ß = 1.41 ($P < 0.001$) units increase in DSS scores. Language preference for testing was associated with DSS performance: English-speaking participants performed higher compared to Spanish speakers (ß = 6.36; $P < 0.001$). Mexican participants had consistently higher DSS performance scores than other heritages. All estimates remained consistent in the CN subpopulation that was free of stroke or TIA and a SIS score ≥ 5 (Table 3, Panel B). Average marginal estimates derived from the regression models for the overall population (Panel A) and the CN subpopulation (Panel B) in Table 4 show decrements in DSS scores by older age in both females and males and by age in groups that differ in educational attainment. Raw score predictions based on individual profiles as well as *z* scores can be calculated using the companion dashboard. Equivalent estimates derived

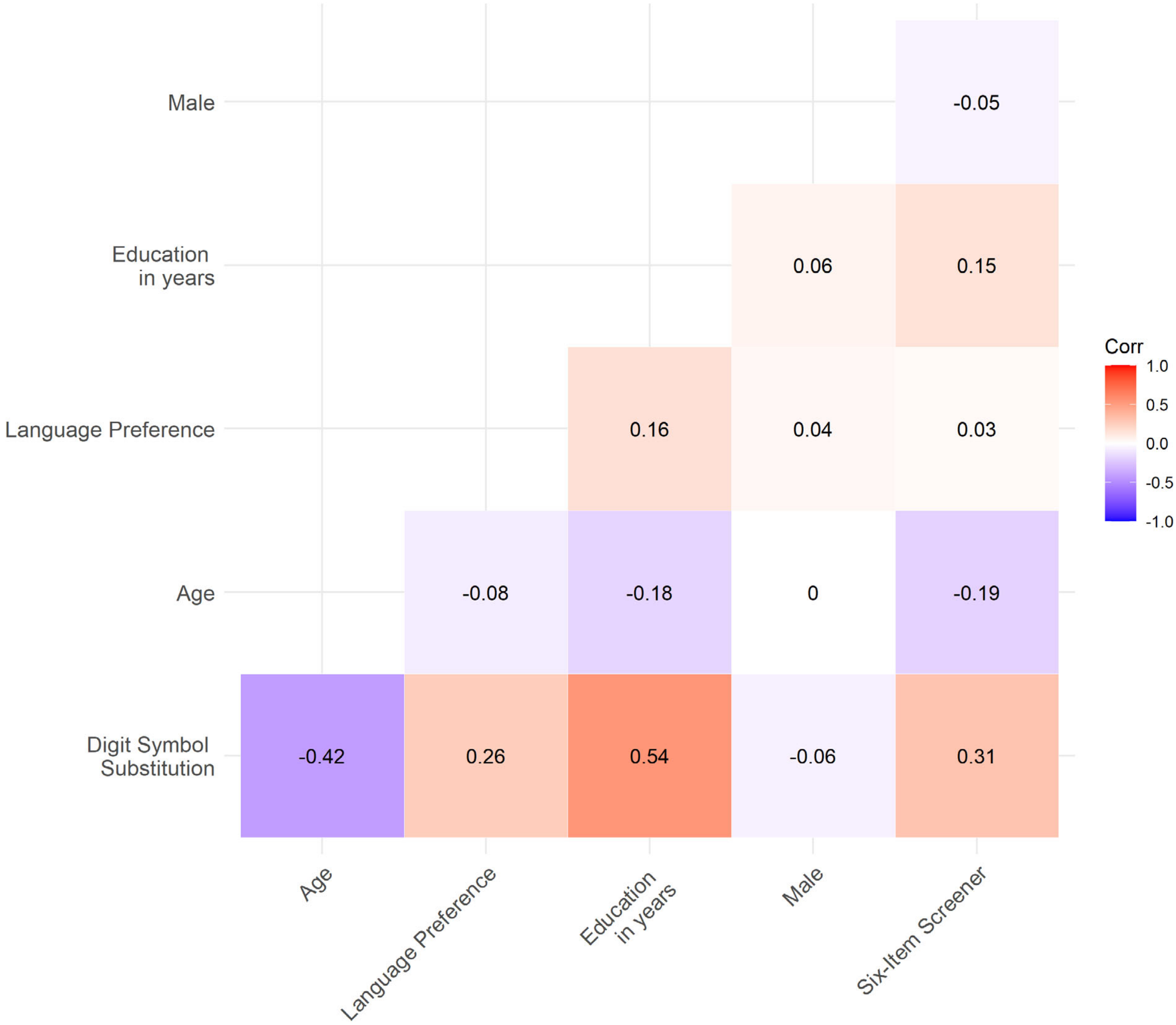

FIGURE 1 Distribution (unweighted) of Digit Symbol Substitution scores by age, education, language preference, and sex. Notes: LTHS = less than high school (anything from primary school to high school (not including high school diploma); HSEQ = high school or equivalent (someone with a high school diploma or GED); MTHS = more than high school (someone reporting an education beyond high school). The distributions for heritage groups are not included in these plots as superimposing the six plots would make the interpretation visually overwhelming.

from heritage stratified models are presented by age, education, and sex in Table S1.

4 | DISCUSSION

This study establishes demographically adjusted normative values for the DSS test among older Hispanic/Latino adults from SOL-INCA. Results represent the largest and most diverse norms for Hispanic/Latino adults in the United States. Additionally, middle-aged and older adults were oversampled in HCHS/SOL, allowing us to capture an increasing important age range for understanding life course cognitive aging, specifically those ≥ 50 years of age. Thus, our study fills scientific gaps for appropriate norms for Hispanic/Latino cognitive aging and represents an important step forward to more accurate and appropriate cognitive assessment tools for clinicians and researchers working with Hispanic/Latino adults, as prioritized by the 2016 to 2022 ADRD Summits.[6] Additionally, to facilitate the application of these norms, we provide a free and easy-to-use dashboard (https://solincalab.shinyapps.io/DSST/).

Consistent with previous findings, older age was significantly associated with a decline in DSS performance.[16,17] DSS measures several processes known to decline with age including attention and processing speed.[24–29] The neural substrates of cognitive decline include cardiometabolic changes and vascular disease that influence brain structure (e.g., white matter pathology). This can be particularly important for a timed test like the DSS test. In addition, age-related illnesses, including but limited to ADRDs, even in a preclinical phase, can lead to reductions in cognitive performance in domains assessed by the DSS.

Similar to previous cross-sectional findings among Hispanic/Latino adults, our results also revealed significant demographic effects of

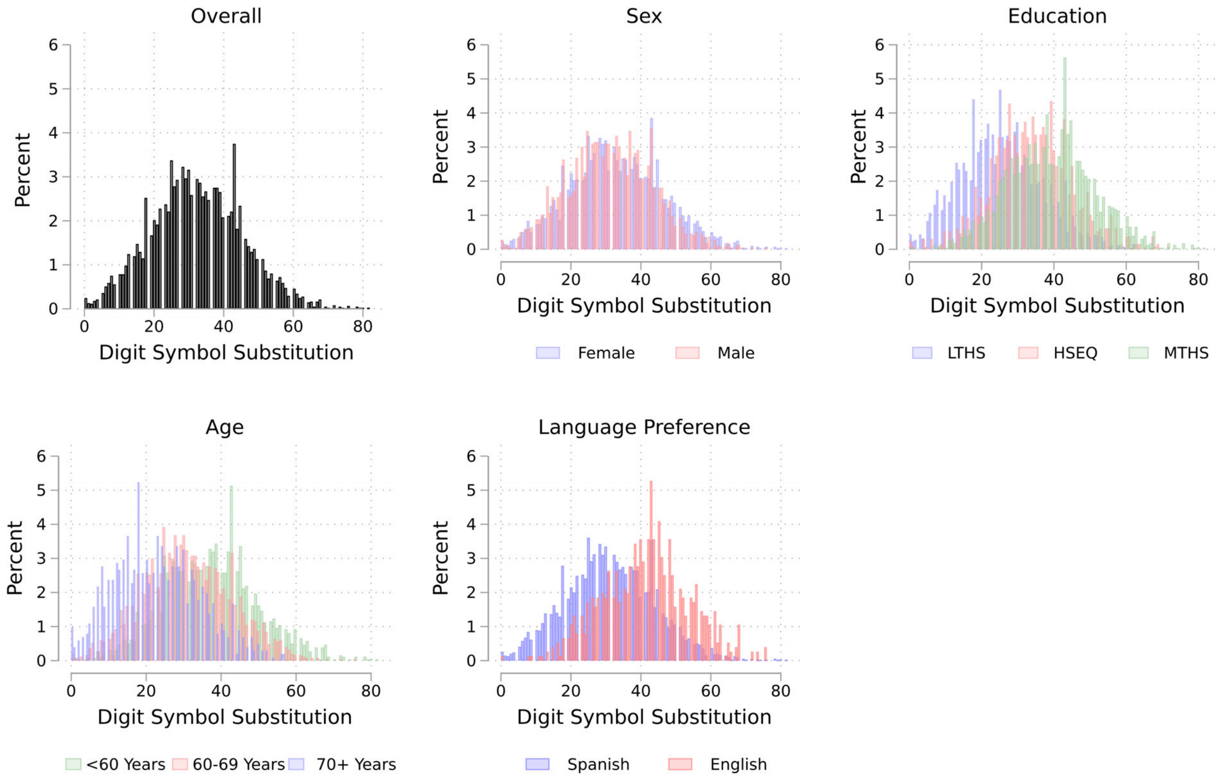

FIGURE 2 Survey-adjusted correlation plots between Digit Symbol Substitution, age, education, language preference, and sex.

higher educational attainment with higher DSS performance.[16,17] Our large sample provides a wider educational range that may prove useful when studying cognitive aging among Hispanic/Latino adults. In previous normative studies, average educational level was typically 10 years.[16,17] The educational attainment of Hispanic/Latino adults in the United States has reached its highest level in at least three decades.[34] Therefore, it is fundamental to develop norms from samples that have a wide range of educational attainment. Importantly, due to the potentially major differences in quality of education across countries of origin, it is very important to use the education-adjusted norms generated for a single country when administering the DSS to individuals from that country because many of the participants were educated outside the United States. Thus, research should further investigate whether quality of education measured by educational experience (e.g., country of educational attainment, resources given to the schooling system, classroom size, type of school attended, parental education) impact performance.

Our results showed that females scored higher than men on the DSS consistent with previous studies that have also shown a female advantage on processing speed tests.[35–38] However, findings have not always been consistent, with some studies reporting that men outperform women[39,40] and others reporting no significant differences.[16,17,41,42] Our results showed that sex differences in those for whom English was the preferred language was more pronounced than in those for whom Spanish was their preferred language. Although there have been inconsistencies, results from the present study suggest that sex should considered when using the DSS.

Although the DSS is often considered "culture free" due to its non-verbal nature,[43–45] the present study suggests that this is not the case. That is, preference for Spanish was associated with lower DSS scores. There are various studies that have examined language preference in cognitive abilities such as processing speed,[46] working memory,[47,48] and attention.[49] It is important to note that language differences in non-verbal tasks can be influenced by factors such as cultural background, education, and socio-economic status. There may be cultural differences in how attention and cognitive functions are valued and developed that could impact performance. For example, research has suggested that Spanish-speaking cultures may place less emphasis on speed and efficiency in completing tasks, which are important components of the DSS.[39] The Spanish-speaking participants in the present study had lower educational attainment compared to the English-speaking participants. This factor may have contributed to differences in DSS performance, as greater educational attainment is commonly associated with better performance.

Other research suggests that bilingual individuals, especially those who learned both languages early in life, may have better working memory compared to monolinguals due to the cognitive benefits of bilingualism. A recent study with 170 native Spanish speakers reported that degree of Spanish–English bilingualism was associated with better performance on several neuropsychological tests, including the DSS test.[50] Though HCHS/SOL and SOL-INCA did not assess for bilingualism, findings from these studies revealed higher second-language (English) proficiency/use (vs. lower second-language use) was associated with higher global cognition, fluency, and DSS

TABLE 3 Regression estimates of the associations between covariates and Digit Symbol Substitution by age, language preference and sex.

Panel A	Overall	Female	Male	50–59 years	60–69 years	70+ years	Spanish	English
Age (in years)	−0.54*** (0.03)	−0.57*** (0.04)	−0.50*** (0.04)	n/a	n/a	n/a	−0.55*** (0.03)	−0.39*** (0.08)
Sex								
Female	ref	n/a	n/a	ref	ref	ref	ref	ref
Male	−2.47*** (0.37)	n/a	n/a	−3.88*** (0.53)	−0.94 (0.51)	−2.43** (0.90)	−2.14*** (0.38)	−4.60*** (1.02)
Education (in years)	1.41*** (0.04)	1.46*** (0.06)	1.34*** (0.06)	1.64*** (0.07)	1.37*** (0.06)	1.28*** (0.09)	1.40*** (0.04)	1.53*** (0.20)
Hispanic/Latino background								
Dominican	−9.79*** (0.61)	−9.97*** (0.71)	−9.58*** (0.95)	−11.51*** (0.79)	−9.26*** (1.08)	−7.44*** (1.16)	−9.79*** (0.63)	−10.55*** (2.29)
Central American	−6.39*** (0.65)	−6.30*** (0.73)	−6.46*** (1.05)	−7.51*** (0.96)	−6.05*** (0.97)	−5.34*** (1.28)	−6.32*** (0.67)	−9.66*** (2.16)
Cuban	−4.47*** (0.52)	−4.70*** (0.77)	−4.24*** (0.76)	−6.27*** (0.71)	−4.44*** (0.81)	−2.13 (1.22)	−4.59*** (0.54)	−0.83 (2.38)
Mexican	ref	ref	ref	ref	ref	ref	ref	ref
Puerto Rican	−4.98*** (0.60)	−4.71*** (0.75)	−5.38*** (0.88)	−4.22*** (1.09)	−4.73*** (0.80)	−5.12*** (1.10)	−5.28*** (0.62)	−3.56** (1.36)
South American	−1.76*** (0.68)	−2.55** (0.88)	−0.52 (1.05)	−2.23*** (1.02)	−1.48 (1.05)	−1.97 (1.57)	-1-.67*** (0.71)	−3.26 (3.51)
Language								
Spanish	ref	ref	ref	ref	ref	ref	n/a	n/a
English	6.36*** (0.67)	7.26*** (0.85)	5.62*** (1.00)	4.26*** (1.09)	6.73*** (0.89)	9.93*** (1.38)	n/a	n/a
Intercept	53.94*** (1.90)	55.09*** (2.51)	50.02*** (2.74)	23.08*** (0.93)	19.28*** (0.82)	13.41*** (1.01)	54.94*** (2.04)	49.89*** (5.22)
Panel B	**Overall**	**Female**	**Male**	**50-59 years**	**60-69 years**	**70+ years**	**Spanish**	**English**
Age (in years)	−0.52*** (0.03)	−0.57*** (0.04)	−0.46*** (0.04)	n/a	n/a	n/a	−0.54*** (0.03)	−0.37*** (0.09)
Sex								
Female	ref	n/a	n/a	ref	ref	ref	ref	ref
Male	-2.57*** (0.38)	n/a	n/a	−4.09*** (0.49)	−1.15*** (0.58)	−2.13*** (1.00)	−2.32*** (0.39)	−4.17*** (1.14)
Education (in years)	1.40*** (0.04)	1.43*** (0.06)	1.36*** (0.06)	1.57*** (0.07)	1.34*** (0.06)	1.32*** (0.09)	1.40*** (0.04)	1.42*** (0.22)
Hispanic/Latino heritage								
Dominican	−10.02*** (0.70)	−10.16*** (0.75)	−9.89*** (1.20)	−11.75*** (0.83)	−8.84*** (1.29)	−7.43*** (1.28)	−10.02*** (0.71)	−10.69*** (2.47)
Central American	−6.30*** (0.61)	−6.46*** (0.80)	−6.08*** (0.91)	−7.33*** (0.96)	−5.90*** (0.88)	−4.39*** (1.20)	−6.15*** (0.63)	−11.78*** (2.30)
Cuban	−4.04*** (0.52)	−4.50*** (0.76)	−3.58*** (0.81)	−5.64*** (0.69)	−3.74*** (0.79)	−1.54 (1.32)	−4.19*** (0.53)	−1.01 (2.37)
Mexican	ref	ref	ref	ref	ref	ref	ref	ref
Puerto Rican	−4.42*** (0.66)	−4.38*** (0.80)	−4.47*** (0.99)	−3.42** (1.13)	−4.58*** (0.88)	−4.04*** (1.20)	−4.75*** (0.70)	−3.15* (1.39)
South American	−2.35*** (0.68)	−3.73*** (0.82)	−0.31 (1.16)	−2.37*** (1.05)	−2.01*** (1.01)	−2.69 (1.65)	−2.41*** (0.71)	−0.65 (3.10)
Language								
Spanish	ref	ref	ref	ref	ref	ref	n/a	n/a
English	6.86*** (0.75)	7.53*** (0.95)	6.31*** (1.11)	4.93*** (1.11)	7.45*** (1.00)	10.10*** (1.49)	n/a	n/a
Intercept	53.84*** (1.81)	56.41*** (2.43)	47.73*** (2.52)	24.54*** (0.89)	20.08*** (0.87)	13.90*** (1.06)	54.92*** (1.90)	50.99*** (5.70)

Abbreviation: ref, reference group.
$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

TABLE 4 Digit Symbol Substitution score average marginal estimates [95% confidence intervals] by age, education, and sex.

	Sex					
	Female			Male		
	Education					
Panel A	LTHS	HSEQ	MTHS	LTHS	HSEQ	MTHS
DSS						
50–59 years	30.8 [29.9; 31.6]	37.7 [36.8; 38.5]	43.5 [42.7; 44.3]	28.7 [27.8; 29.6]	35.6 [34.7; 36.5]	41.5 [40.7; 42.2]
60–69 years	25.9 [25.0; 26.7]	32.7 [31.8; 33.6]	38.6 [37.8; 39.5]	23.8 [22.9; 24.7]	30.7 [29.7; 31.7]	36.5 [35.7; 37.4]
70+ years	18.9 [17.9; 19.9]	25.7 [24.6; 26.9]	31.6 [30.5; 32.8]	16.8 [15.7; 17.9]	23.7 [22.4; 25.0]	29.5 [28.3; 30.8]
	Sex					
	Female			Male		
	Education					
Panel B	LTHS	HSEQ	MTHS	LTHS	HSEQ	MTHS
DSS						
50–59 years	31.9 [31.0; 32.8]	38.8 [37.9; 39.7]	44.6 [43.8; 45.4]	29.7 [28.8; 30.7]	36.6 [35.6; 37.5]	42.4 [41.6; 43.2]
60–69 years	26.8 [26.0; 27.7]	33.7 [32.8; 34.6]	39.5 [38.7; 40.4]	24.7 [23.6; 25.7]	31.5 [30.5; 32.6]	37.3 [36.4; 38.3]
70+ years	20.4 [19.3; 21.5]	27.3 [26.1; 28.5]	33.1 [32.0; 34.2]	18.2 [17.0; 19.5]	25.1 [23.7; 26.4]	30.9 [29.7; 32.1]

Note: Numbers in brackets "[]" represent confidence intervals.
Abbreviations: HSEQ, high school or equivalent; LTHS, less than high school; MTHS, more than high school.

scores at follow-up.[51] Additionally, higher language proficiency was associated with higher performance on all cognitive indices while higher patterns of use were associated with higher fluency and DSS scores.[52] Thus, future research should investigate whether degree of bilingualism has an effect on DSS performance.

In the present study, DSS performance varied significantly by heritage. These results remained consistent after covariable adjustments. While we found differences in performance by groups, we should avoid generalizing about groups of people based on their heritage. A previous study found that Mexican–Americans performed better on the DSS than Puerto Ricans and Dominicans. The researchers suggested that these differences may be due to variations in acculturation, language use, or educational and occupational opportunities.[31] Another study found that Puerto Ricans and Dominicans performed lower on the DSS compared to Mexican–Americans. Researchers similarly suggested that these differences are due to acculturation, language use, and educational and occupational opportunities. It is possible that these factors could have influenced cognitive development and contributed to differences in cognitive function among different subgroups. For example, individuals who have had less access to education or who may have experienced language barriers could have fewer opportunities to develop cognitive skills measured by tests like the DSS. Another study found that Mexican–Americans performed better on the DSS than Cubans and Puerto Ricans, even after accounting for age, education, and acculturation.[53] Those researchers suggested that the differences may be due to a combination of genetic and environmental factors. It is likely that these differences may be related to variability in cardiovascular and other disease risk factors that may explain cognitive differences between Latino/Hispanic groups. Crucially, further research is needed to better understand the complex factors contributing to cognitive function across heritages.

4.1 | Limitations and future directions

This study has several limitations. First, although we identified a significant association of language preference with DSS scores, effects of bilingualism were not assessed in the current study, for which future studies should account. Second, the data were collected from four US regions and therefore are not necessarily nationally representative. However, most existing norms among Hispanics/Latinos are limited to small convenience samples from specific regions of the country while the present study evaluated the largest and most diverse population of Hispanics/Latinos in the United States to date. Third, stroke/TIA history was based on self-report. To determine more accurate CN and stroke/TIA diagnoses, future studies should collect neuroimaging data and consider other diagnoses such as serious psychiatric, developmental, or neurological conditions and substance use histories, which may affect normative scores. Separate and specialized norms may be more appropriate for assessing and evaluating cognition in these populations. These norms apply to the WAIS-R DSS and not to the newer Digit Symbol Coding in the WAIS-III or Coding in WAIS-4. Having these norms is an advantage in studying Hispanics/Latinos but investigators initiating studies in Hispanic/Latino communities will need to weigh this advantage against advantages of the newer versions of the test.

Despite the limitations, and although studies have developed norms for the DSS in the United States,[17] this study was the first to develop DSS norms across four regions of the United States. Consistent with the 2016 to 2022 ADRD Summits' priority to reduce health disparities, we created norms and an online dashboard (https://solincalab.shinyapps.io/dsst_shiny/) providing an easily accessible tool to evaluate processing speed and executive functioning in Hispanic/Latino adults. The norms in this study have the potential to positively impact the future of neuropsychological assessment among Hispanics/Latinos.

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CONFLICT OF INTEREST STATEMENT

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CONSENT STATEMENT

All human subjects provided informed consent.

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SUPPORTING INFORMATION

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