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Investigation of Potential Cognitive Tests for Use with Older Adults in Audiology Clinics

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Abstract

Background: Cognitive declines in working memory and processing speed are hallmarks of aging. Deficits in speech understanding also are seen in aging individuals. A clinical test to determine whether the cognitive aging changes contribute to aging speech understanding difficulties would be helpful for determining rehabilitation strategies in audiology clinics.

Purpose: To identify a clinical neurocognitive test or battery of tests that could be used in audiology clinics to help explain deficits in speech recognition in some older listeners.

Research Design: A correlational study examining the association between certain cognitive test scores and speech recognition performance. Speeded (time-compressed) speech was used to increase the cognitive processing load.

Study Sample: Two hundred twenty-five adults aged 50 through 75 years were participants in this study. Both batteries of tests were administered to all participants in two separate sessions.

Data Collection and Analysis: A selected battery of neurocognitive tests and a time-compressed speech recognition test battery using various rates of speech were administered. Principal component analysis was used to extract the important component factors from each set of tests, and regression models were constructed to examine the association between tests and to identify the neurocognitive test most strongly associated with speech recognition performance.

Results: A sequencing working memory test (Letter-Number Sequencing [LNS]) was most strongly associated with rapid speech understanding. The association between the LNS test results and the compressed sentence recognition scores (CSRS) was strong even when age and hearing loss were controlled.

Conclusions: The LNS is a sequencing test that provides information about temporal processing at the cognitive level and may prove useful in diagnosis of speech understanding problems, and in the development of aural rehabilitation and training strategies.

Key Words: Neurocognitive tests, principal components analysis, speech recognition

Abbreviations: BDI-II = Beck Depression Inventory-II; CSRS = compressed sentence recognition scores; CVLT-II = California Verbal Learning Test-II; IEEE = Institute of Electrical and Electronics Engineers, Inc.; IQ = intelligence quotient; LNS = Letter-Number Sequencing test; PCA = principal component analysis; RT = Reaction Time; WAIS = Wechsler Adult Intelligence Scale®; WASI = Wechsler Abbreviated Scale of Intelligence

Sumario

Antecedentes: El deterioro cognitivo en la memoria operacional y en la velocidad de procesamiento son distintivos del envejecimiento. Las deficiencias en la comprensión del lenguaje también se ven en individuos que envejecen. Una prueba clínica para determinar si los cambios en el envejecimiento

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cognitivo contribuyen con el envejecimiento en la compresión del lenguaje sería útil para establecer las estrategias de rehabilitación en las clínicas audiológicas.

Propósito: Identificar una prueba o una batería de pruebas neurocognitivas clínicas que pueda ser utilizada en las clínicas audiológicas para ayuda a explicar las deficiencias en reconocimiento del lenguaje en algunos sujetos mayores.

Diseño de Investigación: Es un estudio de correlación que examina la asociación entre ciertos puntajes de pruebas cognitivas y el desempeño en reconocimiento del lenguaje. Se utilizó lenguaje acelerado (comprimido en el tiempo) para aumentar la carga de procesamiento cognitivo.

Muestra del Estudio: Doscientos veinticinco adultos con edades entre 50 y 75 años participaron en el estudio. Ambas baterías de pruebas se les administraron a todos los participantes en dos sesiones separadas.

Recolección y Análisis de los datos: Un batería seleccionada de pruebas neurocognitivas y un batería de pruebas de reconocimiento de lenguaje comprimido en el tiempo se usó para extraer los factores componentes importantes de cada grupo de pruebas. Se construyeron modelos de regresión para examinar la asociación entre las pruebas y para identificar las pruebas neurocognitivas más fuertemente asociadas con el desempeño en el reconocimiento del lenguaje.

Resultados: Una prueba de memoria operacional secuencial (Secuenciación de letras y números – LNS) fue más fuertemente asociada con la comprensión del lenguaje rápido. La asociación entre los resultados de la prueba de LNS y los puntajes de reconocimiento de frases comprimidas (CSRS) fue fuerte aún cuando se controlaron la edad y la pérdida auditiva.

Conclusiones: El LNS es una prueba de secuenciación que provee información sobre el procesamiento temporal a nivel cognitivo y puede ser útil en el diagnóstico de problemas en la comprensión del lenguaje, y en el desarrollo de estrategias de rehabilitación aural y de entrenamiento.

Palabras Clave: Pruebas neurocognitivas, análisis de componentes principales, reconocimiento de lenguaje

Abreviaturas: BDI-II = Inventario Beck de Depresión-II; CSRS = puntaje de reconocimiento de frases comprimidas; CVLT-II = Prueba de Aprendizaje Verbal de California-II; IEEE = Instituto de Ingenieros Eléctricos y Electrónicos, Inc.; IQ = cocientes de inteligencia; LNS = Prueba de Secuenciación de letras-números; PCA = Análisis de Componentes Principales; RT = tiempo de reacción; WAIS = Escala Wechsler de Inteligencia del Adulto®; WASI = Escala Wechsler Abreviada de Inteligencia

Difficulties encountered by older listeners in everyday speech understanding may be related to a number of auditory and nonauditory issues that are interactive, which makes their clinical roles difficult to differentiate. The most obvious issues are changes in peripheral functions that include reduced hearing sensitivity and that result in distortions related to cochlear mechanics and other peripheral changes (Divenyi and Haupt, 1997). Age-related changes in "central auditory processing" may also impact speech understanding, particularly temporal auditory processing (Kricos et al, 1987). The term *central auditory processing* usually refers to brainstem pathways and nuclei which, when disordered, may delay or otherwise inhibit processing along the auditory pathways to the cortex. More recently, there is increasing evidence that cognitive changes known to accompany normal aging may impact the ability to perform the linguistic analyses needed for complex auditory stimuli such as speech (Pichora-Fuller, 2003; Vaughan et al, 2006). For example, changes in working memory and processing speed are hallmarks of cognitive aging that have been reported as being involved in speech understanding difficulties in some older listeners (Just and Carpenter, 1992; Waters and Caplan, 2001; Wingfield et al, 1988). As processing speed slows, the dual working memory processes of storing and processing rapidly incoming information such as ongoing speech is affected also.

The investigation of the role of cognitive deficits in speech understanding has been complicated by a lack of consensus in the selection of cognitive tests that are most sensitive to speech understanding difficulties. As a result there has been considerable inconsistency across studies. Cognitive measures in recent studies have included IQ (intelligence quotient) performance (Humes, 2005), semantic and lexical decision making (Hallgren et al, 2001), a battery of neuropsychological tests from the Wechsler Adult Intelligence Scale®—Revised (WAIS®-R) (Jerger et al, 1989), and use of contextual cues and memory demands on verbal recall tasks (Gordon-Salant and Fitzgibbons, 1997). Lunner (2003) used a text-based reading span test to examine the relationship of working memory to hearing aid benefit. A sequencing task was used in an investigation of the role of cognitive function in hearing aid benefit for older listeners (Lunner, 2003; Gatehouse et al, 2006), and Humes and Floyd (2005) also used a sequencing task to investigate the role of working memory in speech recognition in older listeners.

Vaughan et al (2006) recently demonstrated a significant association between a particular category of working memory tests and time-compressed speech recognition. In that study a number of neurocognitive tests, both clinical and experimental, were selected as putative measures of working memory and processing speed. The number of cognitive variables in that study was reduced by a principal component analysis (PCA) that produced three cognitive components, that is, sequential working memory, nonsequential working memory, and processing speed. Both working memory components were associated with time-compressed sentence recognition scores, but the nonsequential working memory component was strongly age related.

Cognitive deficits may also be involved in the failure of some older listeners to benefit adequately from hearing aids. Speech processed with modern, sophisticated hearing aid technology may be cognitively demanding. The ability to identify cognitive limitations in audiology patients could help to explain some of the complaints of speech understanding difficulties in older adults that are not adequately explained by degree of hearing loss. A practical and efficient cognitive test or battery of tests is needed for use in audiology clinics to augment the diagnosis and treatment of older patients. In our previous paper we identified, from a number of clinical and experimental tests, two working memory components that are associated with speech understanding. Our goal in this paper is to verify our original findings and to investigate which of the individual neurocognitive tests that comprise those PCA components are most sensitive to speech understanding difficulties in older adults.

METHODS

Participants

Participants were 225 native speakers of American English, aged 50 to 75 years, with pure tone thresholds of 40 dB HL or better between 250 Hz and 1000 Hz, 60 dB HL or better at 2000 and 3000 Hz, and not greater than 70 dB HL at 4000 Hz. Normal hearing was defined as less than or equal to 25 dB HL at octave and interoctave frequencies from 250 through 4000 Hz. Candidates with conductive hearing loss (defined as air-bone gaps of >15 dB and abnormal tympanograms) (American Speech-Language-Hearing Association, 1990) were excluded. Other exclusion criteria were based on screening tests to rule out changes in cognitive function inconsistent with normal aging, that is, significantly below normal general intellectual ability (IQ), reduced memory, and the presence of significant clinical depression. Significant depression was defined by a Beck Depression Inventory-II (BDI-II) score of >19. Reduced intellectual ability was defined by a Wechsler Abbreviated Scale of Intelligence (WASI) IQ score <70. Reduced memory was defined by a California Verbal Learning Test-II (CVLT-II) uncued delayed recall z-score of ≤ -2. A limited battery of auditory processing tests was administered to be included in future analysis, but none was used to exclude participants.

Assessment Instruments

Neurocognitive Tests

As described above, the BDI-II, CVLT-II, and WASI IQ tests were used to exclude participants who were inappropriate for the study goals. The primary experimental neurocognitive battery listed below was composed of tests of working memory, speed of processing, and attention.

Visual Working Memory Tests

1. N-Back (Cohen et al, 1994; Cohen et al, 1997). This is a computerized test that has been frequently used to assess working memory in functional magnetic resonance imaging (fMRI) studies of brain function. The test requires the participant to identify, from a series of letters appearing one by one on the screen, each letter that has previously appeared either one or three letters before (i.e., one-back, three-back). Difficulty increases with increased number of intervening stimuli between repeated letters.

2. Self-Ordered Pointing Test (SOP) (Petrides and Milner, 1982; Petrides, 1994). This test requires the participant to point to one of eight or ten abstract black and white drawings that appear simultaneously in an array on the computer screen. The participant is presented with a series of trials with the designs rearranged at the beginning of each trial at different positions within the array. Trials are presented in three blocks each, of either eight trials for the eight-design array or ten trials for the ten-design array. For each trial, the participant must point to one of the designs without pointing to any design already selected in a previous trial in the same block.

Verbal Working Memory Tests

1. Wechsler Adult Intelligence Scale®—Third Edition (WAIS®-III) Digit Span subtest (Wechsler, 1997). Both the Digit Span Forward and Backward were used. Digit Span Forward requires the participant to repeat a series of numbers in exactly the same order. The Digit Span Backward increases demand on working memory by requiring the participant to repeat a series of numbers in reverse order.

2. WAIS-III Letter-Number Sequencing (LNS) subtest (Wechsler, 1997). This is a test of auditory working memory. A series of letters and numbers are presented in random order, and the participant must reorder the stimuli by first repeating the numbers in ascending order and then the letters in alphabetical order.

Speed of Processing Tests

1. WAIS-III Digit Symbol Coding test (Wechsler, 1997). This is a timed test presented visually. The participant is presented with a table matching numbers 1–9 with simple symbols and a longer array of numbers without symbols. The task is to copy the appropriate symbol for each number in a box below the number as quickly as possible without making mistakes. The task is made more efficient if the participant can learn to fill in the symbols without referring to the table. The task is terminated after 120 seconds. Number correct is scored.

2. Choice Reaction Time. This test has been associated with processing speed in speech recognition tests (Van Rooij and Plomp, 1990; Jerger et al, 1991). We used two simple tasks in each of the visual and auditory modalities. The participant must push either a right or a left button upon hearing or seeing the appropriate word (RIGHT, LEFT). Response latencies were recorded.

Tests of Attention

1. The Brief Test of Attention (BTA) (Schretlen, Bobholz, et al, 1996; Schretlen, Brandt, et al, 1996). For each trial of this test, participants are presented orally with sequences of letters and numbers of varying lengths. During the first condition, participants are required to count how many numbers are presented in each trial while ignoring the letters. During the second condition, participants are required to count how many letters are presented in each trial while ignoring the numbers. No recall of specific stimuli is involved in contrast to the LNS.

2. The Conners' Continuous Performance Test (Conners, 2000) is a computerized test of attention that requires sustained attention over a long time period (14 minutes). Participants are presented a series of single letters on the computer screen at varying interstimulus intervals and are instructed to press the space bar for every letter except *x*.

The orally presented neurocognitive tests were administered in a quiet room by live voice at or above conversational levels, depending on the individual patient's expressed comfort levels. This is the method routinely used in clinical neurocognitive testing.

Speech Recognition Tests

Two types of speech materials were chosen for this study based on differences in contextual cues to provide two levels of difficulty. The IEEE (Institute of Electrical and Electronics Engineers, Inc.) sentences (Rothauser et al, 1969) were selected because these sentences are both semantically and syntactically correct, but predictability is not high. Anomalous sentences, syntactically correct but devoid of contextual cues, were computer-generated from the vocabulary of the IEEE sentences to be of similar length and phonemic characteristics as the IEEE sentences and were designated Anomalous (ANOM) (e.g., "Hang the wheel in the stupid air"). The sentences were equated for difficulty under time-compression conditions in the NCRAR laboratory with young, normal-hearing listeners, aged 18 to 30 years. Sentence scores were averaged over time-compression rates, and based on the distribution of scores, sentences with scores outside 1.5 standard deviations were considered too easy or too difficult and were excluded from the final corpus. All experimental speech recognition materials were time-compressed by a custom software algorithm at four different rates (40%, 50%, 60%, and 65%). These time-compression rates were chosen based on sentence recognition performance-rate functions derived from previous research with normally hearing older listeners, aged 50 to 75 years (Vaughan and Letowski, 1997). Some lower rates of time compression were included in this study in anticipation of the effects of hearing loss on sentence recognition. Recorded sentences were presented via insert earphones at 90 dB SPL in a sound-treated booth. Sentences were delivered to the ear in which the pure tone average of 1000, 2000, and 4000 Hz was the lowest. If there was no difference, the right ear was used.

Statistical Analyses

Since Vaughan et al (2006), 49 additional participants have been tested, and the PCA was repeated to confirm the previous results with the additional participants. Then correlational analyses were conducted to identify which of the individual tests that constituted the three PCA components were most correlated with the sentence scores. Lastly, regression analyses were performed to determine which cognitive test or tests are the best candidates for practical use with older patients in audiology clinics.

RESULTS

All participants signed an informed consent form approved by the Portland Veterans Affairs (VA) Medical Center Institutional Review Board prior to their participation in the study. Of the 274 participants who were tested, 33 were excluded due to depression (BDI-II >19), and three were excluded for memory test evidence of dementia (CVLT-II delayed recall z-score ≤ -2). None were excluded because of a WASI IQ score

Table 1. Principal Component Analysis Results

	Nonsequential Working Memory (WM_NS)	Sequential Working Memory (WM_S)	Processing Speed (PS)
N-Back Total	**.660**	.080	−.161
SOP Overall	**−.747**	.023	.048
BTA Total	**.581**	.286	−.348
Digit Symbol	**.581**	.295	−.479
CPT	**.570**	.171	.112
Digits Forward	−.014	**.827**	−.051
Digits Backward	.165	**.783**	−.177
LNS	.416	**.696**	−.162
Auditory RT	−.095	−.150	**.824**
Visual RT	−.052	.081	**.871**

Notes: Only tests loading .5 or greater were used in each component (highlighted in **bold**). SOP = Self-Ordered Pointing; BTA = Brief Test of Attention; CPT = Continuous Performance Test; LNS = Letter-Number Sequencing; RT = Reaction Time.

of less than 70. Seven participants did not return for visit two to complete the cognitive testing, and two returned for visit two, but were unable to complete the cognitive testing due to effects of prescriptive medications. Four additional participants were excluded as outliers on the sentence recognition data, leaving a total of 225 participants whose data were available for analysis. The average age of those participants was 61.6 years (SD = 6.9), and less than one-third were female (n = 70), leaving 155 males. Test results were discussed with excluded participants, and they were encouraged to discuss their concerns with their primary care physicians.

Principal Component Analysis

In order to replicate and confirm the previous results obtained with the additional 49 participants tested, the PCA procedure used in Vaughan et al (2006) was repeated. As before, raw scores were used without age adjustment so that age could be accounted for separately in the analyses. The same three principal components emerged from the ten cognitive overall test scores (including two Digit Span and two Reaction Time) as in the previously published data (Vaughan et al, 2006): nonsequential working memory (WM_NS), sequential working memory (WM_S), and processing speed (PS) (see Table 1). These three components once again accounted for approximately 61% of the cognitive variance.

In the current analyses, we also subjected the Anomalous and IEEE sentence recognition scores (SRS) at 50% and 60% time-compression rates to a separate PCA to identify compressed sentence recognition score (CSRS) components. This sentence PCA resulted in a single component with 80% of the sentence score variance accounted for, suggesting that the two types of sentences at these two time-compression rates share enough variance that they may be considered to be largely measures of the same construct. Context had very little effect in these tests, probably because, while the IEEE does offer contextual cues, predictability in these sentences, in contrast to the R-SPIN High Predictability sentences, is quite low (Rothauser et al, 1969). The 50% and 60% time-compression rates were chosen for the analysis because lower (0% and 40%) and higher (65%) rates result in fewer scores due to the adaptive nature of the testing. This adaptive testing procedure is described in detail in a previous publication (Vaughan et al, 2006).

Analysis of Covariance

Based on the distribution of the compressed sentence recognition scores (CSRS) from the principal component analysis, the participants were divided into Low, Mid, and High CSRS subgroups. The Low and High subgroups consisted of the top and bottom quartiles of the distribution and the interquartile scores comprised the Mid subgroup. Three analyses of covariance (ANCOVAs) were conducted to compare performance of the CSRS subgroup within each of the three cognitive PCA components. First, ANCOVAs were done with hearing loss as a covariate and then repeated with both hearing loss and age as covariates to isolate the effects of age (Table 2). All analysis of these data were conducted with the PTA (1000, 2000, 4000 Hz) used to define hearing loss. These analyses were consistent with our previous findings showing a robust association between the performance on the two working memory components from the current PCA and the single time-compressed sentence recognition component, or CSRS (see Figure 1). The significant differences between subgroups did not hold for the PS component when age was

Table 2. Results of Two ANCOVAs Comparing Performance on Cognitive Components Among SRS Subgroups

	WM_NS		WM_S		PS	
Covariates	F	p-value	F	p-value	F	p-value
1) Hearing Loss Only	6.227	.002[1,3]	7.637	.001[1,2]	3.655	.027[1,2]
2) Hearing Loss and Age	3.116	.046[1,3]	8.869	.000[1,2,3]	2.740	.067

Notes: SRS subgroups: (1) with hearing loss only as a covariate and (2) with both hearing loss and age as covariates. Hearing loss was defined as the pure tone average of three frequencies (1k, 2k, and 4k Hz) in the test ear. Significant post hoc group comparisons are shown as superscripts: [1]Low vs. high, [2]Low vs. mid, [3]High vs. mid.

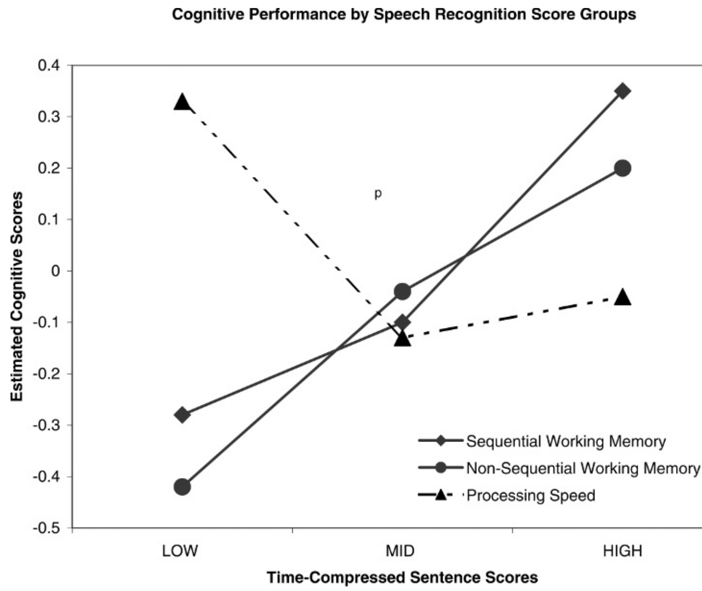

Figure 1. Cognitive performance divided by the results of the three principal component factors as a function of the three levels of speech recognition performance.

accounted for as a covariate in the analysis. The two trend lines on the graph in Figure 1 show that CSRS groups consistently score in similar ranges on sequential and nonsequential working memory components. The PS component shows that the longest latencies are indeed found in the Low CSRS subgroup; however, as Figure 1 illustrates, the PS latency scores do not distinguish between the Mid and High CSRS subgroups. Overall, these analyses show that the previous cognitive components and their association with speech recognition scores are stable with an augmented sample.

Correlational Analysis

To identify individual neurocognitive tests that were more strongly associated with the understanding of time-compressed speech, partial correlations with the CSRS component were calculated, controlling for age and hearing loss. These were performed for the ten individual tests in the experimental neurocognitive test battery (Table 3), along with the three neurocognitive tests that were administered for purposes of exclusion criteria (BDI, CVLT-II, and WASI–III IQ scale). This resulted in 15 separate partial correlations including the three sections of the IQ test (full-scale, verbal and performance). Of the ten neurocognitive tests from the study battery, all three tests from the WM_S component were significantly correlated with the CSRS at the .01 level, while only the SOP ($r = -.176$) and the Digit Symbol test ($r = .179$) from the WM_NS were significantly correlated with the CSRS at the .05 level. Only the Auditory RT (Reaction Time) from the PS component was correlated with the CSRS ($r = -.243$; $p < .05$). The CPT (Continuous Performance Test), BTA, and N-Back from the WM_NS component, and Visual RT from the PS component were not significantly correlated with the CSRS. This left six of the original ten individual neurocognitive tests that made up the PCA components that had significant correlations with the CSRS. One of the exclusion criteria tests (CVLT-II) was significantly correlated with the CSRS ($r = .223$), and all three of the WASI IQ subtest scores were significantly correlated at the .01 level. Overall, the highest partial correlations with the CSRS were for the LNS ($r = .329$), WASI Full Scale IQ ($r = .313$), and WASI Verbal IQ (VIQ) ($r = .311$).

Regression Analyses

A series of three step-wise multiple regression analyses were conducted to determine (1) the amount of variance of the CSRS accounted for by age, hearing loss, and the three PCA components; (2) variance accounted for by individual neurocognitive tests with the highest partial correlations, and (3) the contribution of IQ scores. Age and hearing loss accounted for approximately 28% of the variance consistently across all three analyses. Age was accounted for separately in these analyses rather than using the age-adjusted cognitive test scores that were available for some but not all of the neurocognitive tests.

The other predictor variables in each regression analysis competed stepwise. Table 4 displays the amount of variance accounted for in each analysis. In Regression #1 with only the three PCA components as the predictor variables, the WM_S component is responsible for about half of the variance (5.7%) accounted for by all three PCA components. When the neurocognitive tests from the correlational analysis were used as the predictor variables in regression #2 (Table 4), only three of the original seven predictor

Table 3. List of Tests Used to Determine Association with Time-Compressed Speech Performance

Test	Abbreviation	Type of Test
N-Back	N-Back	Computer/Visual
Self-Ordered Pointing	SOP	Computer/Visual
Brief Test of Attention	BTA	Verbal/Live Voice
Digit Symbol Coding	DS	Paper and Pencil
Connors' Continuous Performance Test	CPT	Computer/Visual
Digits Forward	DF	Verbal/Live Voice
Digits Backward	DB	Verbal/Live Voice
Letter-Number Sequencing	LNS	Verbal/Live Voice
Auditory Reaction Time	Auditory RT	Computer/ Recorded Voice
Visual Reaction Time	Visual RT	Computer/Visual

variables were maintained in the stepwise analysis. Of those, LNS accounted for 8% of the total variance accounted for by cognitive variables (11.8%). In the third and final regression analysis (#3, Table 4), the #2 regression model was extended to include the WASI IQ tests as predictor variables. This regression model accounted for 41.6% of the CSRS variance, and after the 28.2% that accounted for age and hearing loss, LNS was still the most robust cognitive variable, accounting for 7.8% of the CSRS variance. The WASI VIQ accounted for an additional 2.5% while Digit Span Forward accounted for 1.7% and Auditory RT for 1.4%. Approximately 13% percent of the total variance was attributable to cognitive variables of which more than half was due to the LNS test alone.

DISCUSSION

The purpose of this report was to expand our previous findings by exploring the effects of individual neurocognitive tests on time-compressed speech recognition. The PCA of neurocognitive variables reported here produced the same three cognitive components as in the original analysis (Vaughan et al, 2006), lending support to our earlier findings. An additional PCA of sentence test scores yielded a single CSRS component in the current analysis, which was found to be associated with the working memory components of the neurocognitive PCA, most robustly with the WM_S. A series of analyses to determine the individual neurocognitive test or tests most associated with CSRS variability identified the LNS test, which was responsible for more than half of the total variance accounted for by the entire battery of neurocognitive tests. The association between the LNS test results and the compressed sentence recognition scores (CSRSs) was strong even when age and hearing loss were controlled.

Our results are in agreement with other studies that show the importance of accounting for hearing loss and age in any effort to identify other important influences on speech understanding difficulties in older listeners. Hearing loss and age together were consistently responsible for the majority of the variance (28%) of time-compressed sentence scores in all three of the regression models in this study. The correlation between age and hearing loss ($r = .389$) was highly significant ($p = .01$) although age accounted for slightly more of the sentence score variability than hearing loss. This may be taken as further support for the existence of other age-related changes in addition to hearing sensitivity that are involved in deficits in speech understanding. Altogether the total variance accounted for by the neurocognitive tests employed in the current study together with hearing loss and age amounted to 41.6%, which is less than half of the sentence score variance. Clearly, more research is needed to identify other factors that affect speech understanding in older listeners.

Table 4. Results of Three Regression Analyses with CSRS as the Independent Variable, and Age and Hearing Loss Accounted for in Each Analysis

Variables	# 1 PCA Components	#2 Individual Tests	# 3 Include IQ Tests
Age	15.7%	15.6%	15.3%
Hearing Loss	12.4%	12.6%	12.9%
WM_S	5.7%	–	–
WM_NS	1.9%	–	–
PS	2.3%	–	–
LNS	–	8%	7.8%
Digit Forward	–	2.1%	1.7%
Auditory RT	–	1.7%	1.4%
WASI VIQ	–	–	2.5%

Notes: Neurocognitive variables in all three regression analyses competed stepwise. Regression #1 shows the amount of variance accounted for by each of the three cognitive components from the PCA. Regression #2 shows the amount of variance accounted for by individual neurocognitive tests that entered into the stepwise regression model, and Regression # 3 shows the variance accounted for by the WASI VIQ in addition to the individual neurocognitive tests. WM_S = sequential working memory; WM-NS = nonsequential working memory; PS = processing speed; LNS = Letter-Number Sequencing; RT = Reaction Time; WASI VIQ = Wechsler Abbreviated Scale of Intelligence Visual Intelligent Quotient.

The LNS, a working memory test that was added to the third version of the WASI-III, emerged as the neurocognitive variable most strongly associated with sentence test performance. Note also that the WASI VIQ was the second strongest variable in sentence score variability (2.5%), but still far behind the LNS. The LNS is described in the technical manual as an auditory working memory test, but Crowe (2000) found in a separate study that the WAIS-III Digits Span Backward test shared significant variance with LNS. This suggests that the Digits Span Backward test as well as other cognitive tests from our battery such as attention tests (BTA) did not enter the regression model with LNS because they do not account for any unique variance aside from the LNS. This potentially makes the LNS test even more clinically useful because it may effectively address the attention factor within this sequencing working memory task. The factor structure of the WAIS-III was investigated in a sample of patients at a VA medical center in the Midwest United States (Ryan and Paolo, 2001). Three of the four factors identified in the analysis of the WAIS-III battery of tests were consistent with those identified in the standardization sample. The fourth, the working memory factor, consisted of only the LNS and Digit Span subtests, whereas the original standardization sample included an arithmetic subtest also. Although the goals of the Ryan and Paolo study were quite different from the current study goals, these findings lend support to the structure of the WM_S component in the current neurocognitive PCA that included only LNS and the Digit Span tests.

Research has suggested other cognitive tests that may be specifically associated with speech recognition in older adults. Some studies have employed tests similar to the LNS in that they employ sequencing tasks as presumed working memory tasks. Among these are two sequencing tasks used by Gatehouse et al (2006) to study the association between hearing aid candidature and cognitive function. One was a visual letter-monitoring task in which one letter was presented on the computer screen at a time and the participant signaled when three consecutive letters constituted a CVC. The second was a similar task, except that a series of individually presented randomized digits were monitored and a sequence of three consecutive digits was signaled by the participant. Humes and Floyd (2005) also employed a unique sequencing task using a research version of the Simon Says memory game. In this study, the sequencing task was moderately correlated with the WAIS-R Digit-Span scores in 22 of the 24 participants, lending it some validity as a working memory task.

These other sequencing tasks differed from the LNS in a number of ways. The two letter- and digit-monitoring tests (Gatehouse et al, 2006) utilized visual rather than auditory stimuli. These tests rely on the ability to recognize a specific sequence in a random list. The LNS potentially carries more cognitive load, however, because it requires the participant to manipulate the entire random series of spoken numbers and letters into two separate sets consecutively ordered and repeat them back to the examiner. The sequencing task used by Humes and Floyd (2005) implemented a research version of the Simon Says game administered in three modalities: auditory only, visual only, and auditory-visual. A significant age effect was found in all three modalities, but only a tentative association with speech recognition measures was observed.

The importance of the temporal sequencing in speech understanding seems self-evident. Spoken speech requires the ability to recognize and interpret specific sequences of phonemes, syllables, and words in order for the listener to construct a meaningful representation of the utterance. The LNS is a sequencing test that provides information about temporal processing at the cognitive level that may prove useful in diagnosis of speech understanding problems, and in the development of aural rehabilitation and training strategies (Gruneberg and Pascoe, 1996; Rebok et al, 1996). It is fast and easy to administer (about 10 min.) and can be interpreted using normative data in the WAIS-III manual. Combined use of the LNS with these and other neurocognitive tests associated with speech recognition may help further clarify speech-related cognitive processes. Another advantage of the LNS test for immediate use in audiology clinics is that it is a standardized test and is included in both the WAIS-III and the WMS(Wechsler Memory Scale)-III. On the other hand, a battery of the sequencing tests mentioned above might prove more effective. These are issues that should be explored by future research.

FUTURE DIRECTIONS

Our neurocognitive test battery was by no means comprehensive. Although the LNS emerged as the most salient test in the current study, the potential existence of other, more sensitive tests cannot be ruled out. As is easily seen in the literature, there is a wide variety of cognitive tests including nonstandardized tests that are available to use in the investigation of cognitive effects on speech perception in older adults. The fact that the LNS, hearing loss, and age together accounted for only 41% of the variance of the speech recognition scores raises the possibility that other cognitive factors may also be significant contributors, which again might suggest a battery rather than a single test approach. A head-to-head comparison of the sequencing tasks mentioned above could prove useful to determine clinical efficacy.

A limitation of the current study was the use of time-compressed speech as a tool for degrading the speech signal and increasing the cognitive load. It is not known whether the LNS, which represents sequencing working memory, would be sensitive to processing demands created by other types of distortion of the speech signal in addition to rapid speech (noise, for example). Also, the IEEE sentences did not show much context effect compared with the anomalous sentences that we developed from the IEEE vocabulary and grammatical structures. It would be informative to perform this experiment with different speech stimuli and different forms of speech degradation. Future research should also include a younger sample to compare with the current results. Possibly the working memory associations with speech recognition in an aging sample may not be useful in a younger sample. The two WASI tests (Full Scale and VIQ) were also highly correlated with CSRS (along with the LNS test) in the older population in the current study. Perhaps in a younger population, where effects of age on working memory changes have not yet begun to manifest, IQ may be an important factor in speech recognition differences in younger listeners, particularly in the ability to make use of the advanced technology in today's hearing aids.

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