Development of a Clinically Feasible Auditory Word-Span Memory Measure

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INTRODUCTION

Research suggests that working memory may play a role in speech-in-noise performance, particularly for older adults with hearing loss (see Akeroyd, 2008 for review). Although, there are working memory measures available, few specifically assess auditory working memory for speech in a clinically-feasible manner. Further, many available measures were not developed specifically to be administered in the auditory domain or use a systematic approach considered to be 'auditory-friendly' for older listeners with auditory/speech perception difficulties. Thus, we strived to develop a test that was 'auditory-friendly,' taking into account a standardized method of administration (CD materials) that could be amplified to overcome audibility issues while controlling for parameters that may influence speech recognition (e.g., talker, lexical variables, etc.).

PURPOSE

The overarching goal of this program of research is to develop a valid and reliable measure that simultaneously provides information on word-recognition abilities as well as on auditory working memory. This study describes the first phase of the development of an auditory working memory span test. The validity of the measure also was evaluated by examining its relation to other available memory measures and to speech- in-noise perception. We hypothesized that our measure would be poorly correlated with free recall or digit span as we are assessing working memory for speech using a procedure that would tax processing as well as storage. We also hypothesized that our measures would be moderately correlated with the accuracy of word recognition on speech-in-noise testing because we decreased the signal-to-noise ratio of the words during recognition testing, thus increasing the difficulty and requiring the participants to utilize additional resources as they progressed through the speech-in-noise task.

Characteristics of the Auditory Working Memory Span Test

Word Stimuli for the Auditory Working Memory Span Test

- monosyllabic words from the PB-50, W-22, and NU No. 6 (Wilson et al., 2008) spoken by a female talker
- carrier phrase "You will cite" was used
- 250-ms silent interval between carrier phrase and word
- 3000-ms silent interval between offset of word and onset of next carrier phrase
- 500-ms, 500-Hz tone was inserted 3000 ms after the last word in each set to provide a non-speech recall prompt
- words distributed across the test balanced for word frequency, neighborhood frequency, and word density (McArdle & Wilson, 2008)
- words distributed across the test based on 50%-point performance in noise of words administered to young listeners with normal hearing (Wilson et al., 2008)
- words distributed across test balanced for processing tasks used in test procedures (described below)

Randomization One Object						
Set Size 2						
Track #		Word	Recognition Response	Object - Yes/No		Recall Response
2	1	SHOVE		No		
	2	BAR		Yes		
3	3	RICE		Yes		
	4	GRACE		No		
4	5	WHAT		No		
	6	CALF		Yes		
5	7	FIST		Yes		
	8	THAT		No		
6	9	RISK		No		
	10	MOON		Yes		

Figure 1. Example scoresheet from set size 2 from the auditory working memory word span test using deep encoding (object versus non-object).

Characteristics of the Auditory Working Memory Span Test

Test Procedure for the Auditory Working Memory Span Test

- procedure was adapted from a sentence auditory working memory span test (Pichora-Fuller et al., 1995) that was a modification of a reading working memory span test (Daneman & Carpenter, 1980) using the materials of the Revised Speech Perception in Noise test (Bilger et al., 1984).
- target stimuli were words following a carrier phrase grouped into 5 sets of 2, 3, 4, 5, and 6 words (100 words total)
- the basic task of the listener was to repeat each word in the set after it was presented (recognition task)
- following the last word of a set, a tone was presented signaling the listener to recall all of the words (2 to 6) that were presented in the set (recall task)
- 3 types of processing tasks were selected to induce different levels of processing (Craik & Lockhart, 1972) to examine their effects on working-memory performance with the new measure:
  1. no extra encoding task (i.e., recall only)
  2. listeners categorized items as belonging to two categories; first (A-L) or second (M-Z) part of alphabet (shallow encoding requiring the listener to attend to the form of the word)
  3. listeners categorized items as belonging to two categories; object or non-object judgment (deep encoding requiring the listener to attend to the meaning of the word)
- results are scored in terms of:
- recognition performance (% correct)
- overall recall performance (% correct) by set size and/or 100 words
- word-span score (set-size 'passed')

Methods

Participants

- 24 young listeners with normal hearing (< 20 dB HL; ANSI, 2004)
  - mean age = 24.0 years, SD = 2.5
  - 6 Males, 18 Females
  - native monolingual English speakers
  - Education
- High School graduate (n = 8)
- Bachelor's (n = 12)
- Master's (n = 4)
- normal cognitive function based on age and education norms (MMSE, M = 29.8, SD = 0.4) (Crum et al., 1993; Folstein et al., 1975)
- normal vocabulary based on age and education norms (WAIS-IV, M = 41.7 SD = 6.4) (Wechsler, 2008)

Materials

- Auditory Working Memory Span Test as described above
- Words-In-Noise [WIN] test: The WIN is a test in which 10 NU-6 words are presented at 7 signal-to-noise ratios (S/N) from 24- to 0-dB in 4-dB decrements (Wilson, 2003; Wilson et al., 2003, Wilson & McArdle, 2007). The WIN threshold (dB S/N) is calculated in terms of the 50% correct word recognition point calculated from the Spearman-Kärber equation (S-K). The 70-word WIN test has been divided into two, 35-word lists.
  - modified recording of WIN with the same speaker used in the auditory working memory span test

Methods

  - modified recording of WIN with the same speaker used in the auditory working memory span test
- modified WAIS-IV Digit Span test (Wechsler, 2008)
  - modified for audio CD presentation with the same female speaker as in the WIN and the auditory working memory span test
  - balanced numbers throughout the test
  - replaced 7 with 10 to have only monosyllabic numbers
  - incorporated a prompt tone for recall
- auditory free recall test adapted from Rabbitt (1991)
  - 15 monosyllabic words presented one at a time with one second inter-stimulus intervals
  - same female speaker as in the WIN, auditory working memory span test, and modified digit span test
  - prompt tone incorporated for recall
  - participants asked to write the words recalled in any order on a scoresheet
  - participants given 3 minutes to complete recall portion
- visual free recall test adapted from Rabbitt (1991)
  - 15 monosyllabic words presented one at a time with one second inter-stimulus intervals via power point on computer monitor
  - yellow screen with the word "RECALL" prompted the participant of recall portion of the test
  - participants asked to write the words recalled in any order on a scoresheet
  - participants given 3 minutes to complete recall portion

Study Procedures

- auditory test materials were reproduced on a CD player routed through an audiometer and delivered via insert earphones monaurally (right ear for odd numbered participants and left ear for even numbered participants).
  - 3 randomizations of auditory working memory span measure with the 3 processing tasks were counterbalanced across participants and administered at 80-dB SPL (in quiet)
  - WIN lists were counterbalanced and administered with babble constant at 80-dB SPL and words 104- to 80-dB SPL in 4-dB decrements
  - Modified digit span was administered at 80-dB SPL
  - Auditory free recall test adapted from Rabbitt (1991) was administered at 80-dB SPL
- Visual free recall test adapted from Rabbitt (1991) was administered via power point presentation on computer monitor

Results

Table 1. Descriptive data for speech and memory materials.

		Digit Span			Free Recall[1]	
	WIN	Forward	Backward	Sequencing	Auditory	Visual
Mean	4.7	9.2	8.0	10.0	8.5	8.5
SD	1.0	2.3	2.3	2.2	2.5	2.2
Min	3.2	6.0	1.0	5.0	4.0	4.0
Max	7.0	15.0	12.0	14.0	15.0	12.0

[1]adapted from Rabbitt (1991)

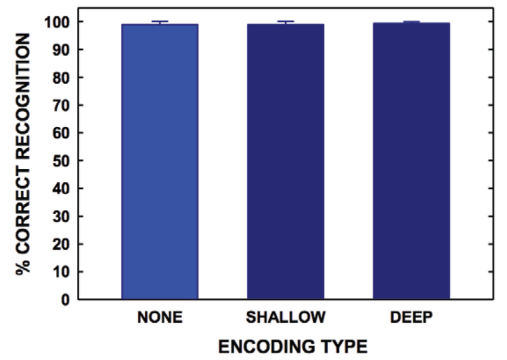

Figure 2. Mean recognition performance (percent correct) of words in the auditory working memory span test as a function of processing task. Error bars represent one standard deviation.

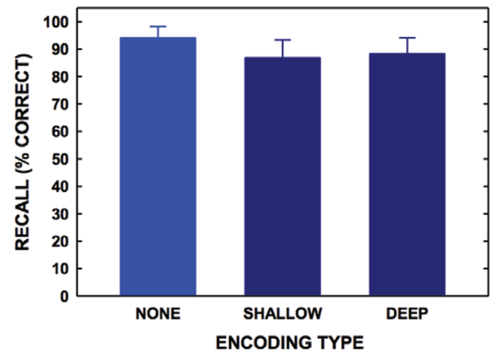

Figure 3. Mean overall recall (percent correct) as a function of processing task. Error bars represent one standard deviation. Recall was significantly better for the none processing task (lighter blue) compared to shallow or deep encoding, but was not significantly different between the shallow and deep processing tasks (dark blue), F (2, 46) = 25.6, p = .000, partial η2 = .53.

Results

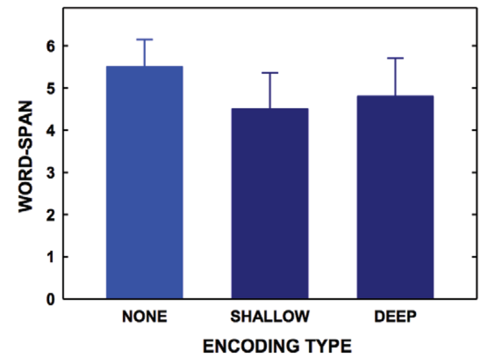

Figure 4. Mean word-span recall performance in terms of span size as a function of processing task. Error bars represent one standard deviation. Recall was significantly better for the none processing task (lighter blue) compared to shallow or deep encoding, but was not significantly different between the shallow and deep processing tasks (dark blue), F (2, 46) = 16.1, p = .000, partial η2 = .41.

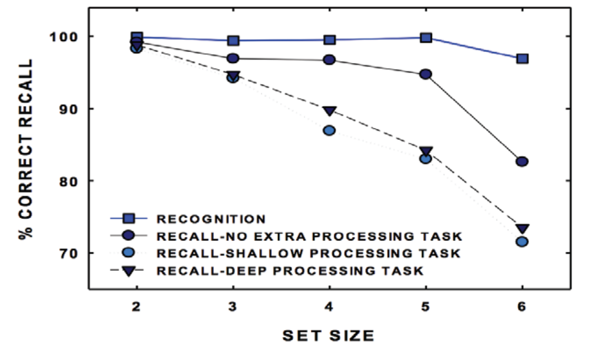

Figure 5. Mean recall performance (percent correct) as a function of set size is illustrated for each processing task. Also illustrated is the mean recognition performance (blue squares). A within-subjects, repeated measures ANOVA revealed a significant main effect of processing task [F (2, 46) = 25.6, p = .000, partial η2 = .53] and set size [F (4, 92) = 80.4, p = .000, partial η2 = .78] and a significant processing task by set size interaction [F (8, 184) = 4.8, p = .000, partial η2 = .17].

Table 2. Correlations among word span measures, other memory measures, and speech-in-noise materials. Significant correlations (p < .05) are illustrated in bold italics.

	WS (None)	WS (Shallow)	WS (Deep)	Forward	Backward	Sequencing	Rabbitt-A	Rabbitt-V	WIN
WS (None)									
WS (Shallow)	***.51***								
WS (Deep)	***.43***	***.45***							
Forward	***.43***	.18	.25						
Backward	.11	-.22	.04	.29					
Sequencing	.21	.16	.16	.29	.17				
Rabbitt-A	.37	.15	.15	-.11	-.03	-.17			
Rabbitt-V	.27	.19	.26	.16	-.03	-.19	***.59***		
WIN	***-.47***	***-.49***	***-.45***	-.22	-.14	-.13	.06	-.10	
Vocabulary	***.48***	.37	.13	***.45***	.31	***.45***	-.05	-.06	-.08

Conclusions

- word-recognition in quiet was at ceiling and recognition was the same regardless of processing load
- recall was significantly better for the 'none' processing task compared to the shallow or deep processing tasks, when measured in terms of percent correctly recalled or in word span
- on the tasks intended to induce shallow and deep processing, listeners showed similar performance and thus may be accessing similar working memory encoding processes, at least with these materials
- working memory is taxed more by higher memory load (i.e., higher set-sizes) and by higher processing loads (i.e., shallow/deep vs no extra processing task)
- all three word-span measures were significantly and moderately correlated with word recognition in noise (WIN), further supporting the notion that there is a relation between memory and speech recognition in noise performances
- word-span measures with a processing load were not correlated with free recall or with digit span suggesting overall that the word span measures with a processing load are tapping into memory differently than the digit span or free recall tasks, presumably because of more processing demand in the span task
- word-recognition in noise (WIN) was not correlated with either free recall tasks or with any digit span task
- vocabulary was significantly correlated with the word span with no processing task (i.e., none), forward digit span, and sequencing, but not with any other measure

Future Directions

- incorporate various types of noises (e.g., babble, interrupted noise) into next version of auditory working memory span test to be presented at 60%- and 85%-point recognition performance to examine the effect of different types of competing noise on working memory performance at various levels of recognition difficulty
  - expect memory performance to be poorer at poorer signal-to-noise ratio
  - expect differences in memory performance based on noise type
- expand the study to include older listeners with hearing loss
- examine success with different technologies/therapies according to memory abilities

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