Exploring the Relationship Between Working Memory, Compressor Speed, and Background Noise Characteristics

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Objectives: Previous work has shown that individuals with lower working memory demonstrate reduced intelligibility for speech processed with fast-acting compression amplification. This relationship has been noted in fluctuating noise, but the extent of noise modulation that must be present to elicit such an effect is unknown. This study expanded on previous study by exploring the effect of background noise modulations in relation to compression speed and working memory ability, using a range of signal to noise ratios.

Design: Twenty-six older participants between ages 61 and 90 years were grouped by high or low working memory according to their performance on a reading span test. Speech intelligibility was measured for low-context sentences presented in background noise, where the noise varied in the extent of amplitude modulation. Simulated fast- or slow-acting compression amplification combined with individual frequency-gain shaping was applied to compensate for the individual's hearing loss.

Results: Better speech intelligibility scores were observed for participants with high working memory when fast compression was applied than when slow compression was applied. The low working memory group behaved in the opposite way and performed better under slow compression compared with fast compression. There was also a significant effect of the extent of amplitude modulation in the background noise, such that the magnitude of the score difference (fast versus slow compression) depended on the number of talkers in the background noise. The presented signal to noise ratios were not a significant factor on the measured intelligibility performance.

Conclusion: In agreement with earlier research, high working memory allowed better speech intelligibility when fast compression was applied in modulated background noise. In the present experiment, that effect was present regardless of the extent of background noise modulation.

Key words: Compression, Hearing loss, Modulation, Release time, Speech intelligibility, Working Memory.

INTRODUCTION

Working memory can be described as a mechanism used to control and process information during a cognitive task (Baddeley & Hitch 1974). Working memory plays an active role in the maintenance of task-relevant information (Miyake & Shah 1999). Accordingly, working memory has been proposed to play a role in speech intelligibility, particularly when adults with hearing loss listen under complex listening conditions (see Akeroyd 2008; Besser et al. 2013 for reviews).

Many studies on working memory and speech intelligibility have focused on older listeners with hearing loss. Older listeners show deficits in working memory as well as other abilities—such as sequential learning—that may be involved in speech

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intelligibility (e.g., Humes & Floyd 2005). During a conversation, both working memory and sequential learning are involved; sequential learning is required to keep the unidentified signal in memory, while the information of following words requires simultaneous processing and storage by working memory. Older adults with hearing impairment that suffer from both loss of auditory information and a loss of information-processing capacity are, therefore, at a disadvantage in following complex conversations (e.g., Rabbitt 1991). Previous study suggests that retrospective analysis and integration of information might also be especially effortful for older listeners (e.g., Wingfield et al. 1988, 1996).

Previous research expanded work on the role of working memory in communication to demonstrate the importance of working memory with respect to *amplified* speech intelligibility (Gatehouse et al. 2003, 2006a, 2006b; Lunner 2003; Pichora-Fuller & Singh 2006; Foo et al. 2007; Rudner et al. 2007). Specifically, listeners with lower working memory demonstrated reduced speech in noise intelligibility for fast-acting compared with slow-acting compression. In contrast, listeners with higher working memory were able to benefit more from fast-acting compression (Gatehouse et al. 2003, 2006a, 2006b; Lunner 2003; Lunner & Sundewall-Thorén 2007).

The relationship between working memory and compression speed appeared to be present for speech intelligibility when low-context speech material was presented in *modulated* background noise but not for unmodulated backgrounds. A pioneering study in this area (Gatehouse et al. 2003) suggested that cognition might interact with the extent of modulation in the background noise. Specifically, listeners with higher scores on cognitive tests were able to utilize the temporal or spectral gaps in modulated background noise. Those gaps allowed the listener to "glimpse" information about the target signal (Festen & Plomp 1990; Kwon et al. 2012; Ozmeral et al. 2012; Vestgaard et al. 2011), a factor that is minimally present in unmodulated background noise.

The statistical analysis in the Gatehouse et al. (2003) study reflected differences in performance across unmodulated and modulated backgrounds, but stopped short of examining the extent of modulation. In addition, test stimuli (consonant intelligibility in a closed set task) and relatively favorable signal to noise ratios (SNR) may have minimized the need for glimpsing and engagement of working memory, compared with longer speech segments which might tax working memory to a greater extent and also better represent everyday listening demands. Later studies confirmed that the working memory–compressor speed interaction also occurred for sentence material (Lunner 2003; Lunner & Sundewall-Thorén 2007), but did not explore the extent to which the modulation characteristics of the noise influenced that relationship.

The reasons that the working memory–compression speed association appears to occur only in modulated background noise are not well understood. Successful glimpsing requires the integration of disconnected speech information to restore the content of

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the speech signal. This requires the listener to store already-heard segments of speech until enough information is received to make sense of the content of a stream of speech information. Then, the stored speech glimpses for the whole sentence must be processed to derive meaning from the separate pieces of speech information.

A drawback of some compression amplification systems is that they introduce a variety of signal alterations that may impact use of modulation. For example, fast-acting compression (release times <200 msec) results in a compressor output with reduced modulation depth, and therefore in reduced sensitivity to the information-bearing modulations in the speech signal (e.g., Greenberg & Ainsworth 2004; Brennan et al. 2013). Fast-acting compression may also increase similarity between the envelope modulations of the signal and the envelope modulations of a masking noise (e.g., Stone & Moore 2008). Such effects may make it more difficult to discriminate among important envelope differences (Festen & Plomp 1990). Finally, in modulated noise, the gain function of the compressor is dictated by the overall levels of the combined signal and noise. Responding to the greater overall signal variations from modulated noise is likely to create more distortion (due to a more dramatically increasing and decreasing signal level) compared with when unmodulated background noise (and a relatively constant gain function) is applied.

Why would we expect altered signal modulation to interact with working memory? The ease of language understanding model (Rönnberg et al. 2008) describes the engagement of explicit processing resources when the listener is presented with a mismatch between the phonological information of a speech signal and its phonological representation in long-term memory. Such a mismatch could be caused by the acoustic consequences of hearing-aid signal processing (Foo et al. 2007; Arehart et al. 2013). This idea is supported by Rudner et al. (2009), who demonstrated that working memory was related to speech perception for listeners acclimatized to slow compression then fit with fast compression. In contrast, listeners acclimatized to fast compression then fit with slow compression did not show such a relationship. Rudner et al.'s data suggest that the fast compression setting introduced signal distortion, resulting in a phonological mismatch and hence dependence on the listeners' working memory capacities.

The present study investigated the interaction between compression release time, speech intelligibility in modulated noise, and working memory. The influence of working memory was analyzed by testing two groups of older adults, one characterized by lower working memory and the other by higher working memory (based on their performance on a Reading Span Test [RST]). Measures of sentence intelligibility in noise were used in which compression release time and modulation properties were varied. We hypothesized that adults with lower working memory would demonstrate better scores for slow compression, whereas adults with higher working memory would demonstrate better scores for fast compression; and that the working memory-by-compression speed relationship would be stronger when the noise contained greater modulation (such that there were greater opportunities for glimpsing).

METHODS

Participants

The present study included 26 participants (14 males, 12 females), ranging in age from 61 to 92 years (mean age 73.92 years, SD = 9.2). All participants had mild to moderate sensorineural hearing loss with pure-tone thresholds ranging from 25 to 70 dB HL at octave frequencies between 250 and 6000 Hz. All participants were tested monaurally in their better ear, were in good health (by self-report), had no significant history of neurologic disorders, and were native speakers of American English. Three participants were binaural hearing aid users with multi-channel compression hearing aids. Of these, two participants were using fast compression and one participant was wearing slow compression for the low frequency range and fast compression for the high frequency range. All study procedures were reviewed and approved by the Northwestern University Institutional Review Board. The participants completed an informed consent process and were compensated for their time.

Working Memory

The working memory of the participants was evaluated with a RST designed by Rönnberg et al. (1989). This test was originally designed in Swedish but was translated to English at Linköping University in Sweden. The test was designed to simultaneously tax memory storage (by recalling words from sentences) and information processing (by making semantic judgments). The test material consisted of 54 five-word sentences displayed at a rate of one word or word combination per 0.8 seconds (e.g., "The captain," "sailed," "his ship") on a 26-inch computer monitor. The test required the participants to perform two tasks. The first task was to report whether or not a sentence had a sensible meaning. Half of the presented sentences made semantic sense ("The pilot flew a plane"), whereas half did not ("The train sang a song"). The second task was to recall either the first (subject) or the last (object) word of a sequence of sentences in correct serial order. The participants were informed whether the first or the last word in a sentence should be recalled after a block of sentences was presented. The number of sentences in a block started with three and increased to four, five, and finally to six sentences within a block. The RST score was the percentage of first or last words correctly recalled by the test participants.

Based on their results on the RST task, the participants were separated into two groups: high and low working memory. Most studies have defined their criteria for categorizing low versus high working memory groups according to the mean or median of the test group, with criterion scores ranging from 36% to 44% correct (Classon 2013). For this study, participants with scores less than or equal to 41% correct were categorized as having low working memory. The 41% criterion was based on a review of several previous datasets with greater weight given to larger datasets (e.g., Arehart et al. 2013; Classon 2013; Souza & Arehart 2015). Based on this criterion, nine participants were categorized as having high working memory (mean scores 47.5% correct, range from 43.0% to 50% correct). Their average age was 73.0 years. Seventeen participants were categorized as having low working memory (mean scores 29.2% correct, range from 18.5% to 40.7% correct). Their average age was 74.4 years. No significant difference in age was observed between the two groups [$t(24) = 0.41$, $p = 0.69$, $\alpha = 0.05$]. Both groups had similar average audiograms (see Fig. 1 for test ear audiograms). This was confirmed with a repeated measures analysis of variance with frequency as a within-subject factor and group (low or high working memory) as a between-subjects
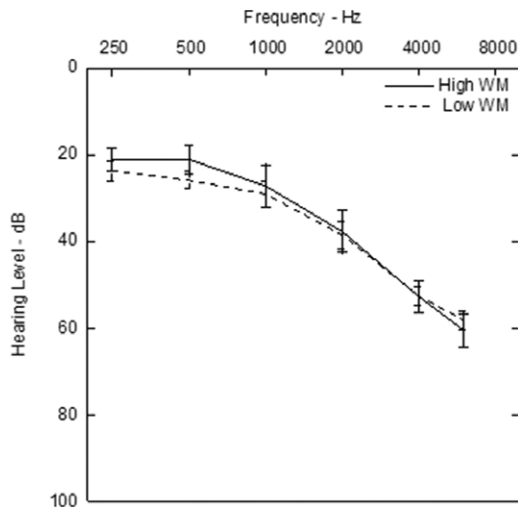
Fig. 1. Mean test ear hearing thresholds for the high (*solid line*) and the low (*dashed line*) working memory group. Error bars show 95% confidence intervals.

factor. The main effect of group was not statistically significant [$F(1,24) = 0.58$ for $p = 0.45$]. The main effect of frequency was significant [$F(5,100) = 71.36$ for $p > 0.01$], as expected since hearing threshold varied across frequency in these sloping audiograms. The interaction between frequency and working memory group was not significant [$F(5.100) = 0.33$ for $p = 0.89$]. That is, the degree of hearing loss and pattern of hearing loss across frequency was statistically similar for both working memory groups.

Hearing Aid Compression

Amplitude compression was simulated using a modified version of the implementation (in Matlab) by Kates (2008). In brief, a six-channel filter bank was followed by a peak detector that reacted to increases in the within-band signal level with a fast attack time and decreases in the signal level with a longer release time. The speech and the noise signals were separately compressed before the SNRs were computed based on the signal's root mean square values. The speech signal and the background noises were simultaneously presented through insert earphones. In this way, listeners heard a signal much like what would occur with a wearable hearing aid, but with greater experimental control and flexibility. The input speech level was 65 dB SPL. The attack time was always 5 msec. Two release times were applied: 40 msec (short) or 640 msec (long). The compression threshold was set at 45 dB SPL and a compression ratio of 2:1 was used. Following compression, National Acoustic Laboratories (NAL) shaping (Byrne & Dillon 1986) was applied according to the individual's hearing threshold.

Stimuli

We deliberately selected low-context sentence material to facilitate comparison to previous work, and to encourage decoding of acoustic information rather than guessing key words based on context (please see discussion for consideration of alternate materials). The sentences were sufficiently long to ensure that modulations—either in the signal or background noise—would allow for acoustic differences between

fast and slow compression. The Basic English Lexicon sentence test (Smiljanic & Calandruccio 2012) was used, and a female talker was chosen. Each sentence included four key words at a moderate vocabulary level, for example, "The eggs need more salt." This test consisted of 20 test lists with 25 sentences each, including 2000 keywords.

Sentences were presented in a modulated background noise at one of three SNRs: −4, −2, and 0 dB. The selected SNR values were selected based on pilot testing to provide an appropriate range of scores without floor or ceiling effects. Three artificial noise signals with speech-like spectral and temporal properties from the collection of the International Collegium for Rehabilitative Audiology (ICRA) by Dreschler et al. (2001) were used: one-, two-, and six-talkers. The noise signals were designed for hearing instrument assessment and psychophysical evaluation. In brief, the noises were created by filtering running speech into three bands; transforming the output of each band to signal-correlated noise (Schroeder 1968); refiltering using the same three bandpass filters; and mixing the band-filtered outputs together. The resulting speech-spectrum noise preserves low-frequency modulations within the low-frequency carrier band; mid-frequency modulations within the mid-frequency carrier band, and high-frequency modulations within the high-frequency carrier band. A final, overall shaping ensures that the final noise is representative of the long-term average speech spectrum for speech produced with normal vocal effort. A detailed analysis of modulation characteristics reported by Dreschler et al. confirms that the three noises have substantially different modulation spectra, such that the one-talker ICRA noise offers the most modulation (and therefore the most opportunity for glimpsing the signal), whereas the six-talker ICRA noise offers the least. To illustrate this, broad-band envelopes of the three noises are plotted in Figure 2.

Outcome Measurements

Speech intelligibility scores (as percent correct) were obtained in each of the 18 test conditions (three fixed SNRs,
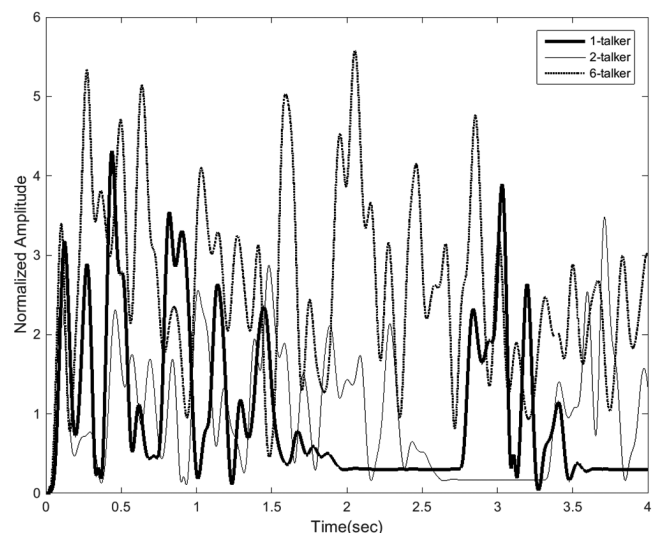

Fig. 2. Comparison of amplitude envelopes (20 Hz low pass envelopes) for 4-second segments of the three ICRA noises: one-talker (*thick line*), two-talker (*thin line*), six-talker (*dotted line*). Note the larger gaps in the one-talker noise at approximately 2 and 3.5 seconds.

the three different background noises described above, and two compression release times).

RESULTS

Mean speech intelligibility scores (in percent correct) for each group, compression speed, noise condition, and SNR are shown in Table 1. Across all conditions, mean scores ranged from 23% to 79%. Higher scores were demonstrated at more favorable SNRs and in background noise with a smaller number of talkers (i.e., one-talker ICRA). Given the large number of conditions and that the result of greatest interest was the difference between fast and slow compression, the percent correct data were transformed in the following way. First, percent correct scores were converted to rationalized arcsine units (rau) to normalize variance across the performance range (Studebaker 1985). Next, data were reduced by subtracting the intelligibility scores for the slow compression speed from the scores observed for fast compression speed for each participant.

The resulting rau difference scores are shown in Figure 3 (for each SNR) and Figure 4 (collapsed across SNR). Positive values indicated that performance was better with fast than with slow compression. Negative values indicated that performance was better with slow than with fast compression. On average, participants with higher working memory showed positive difference scores, whereas participants with low working memory showed negative difference scores. With regard to the hypothesis that the compression–working memory relationship would depend on the extent of noise modulation, the high working memory group appears to have a larger effect of compression speed for the one-talker ICRA noise, and the smallest for the six-talker ICRA noise. For the participants with low working memory, the effect seemed to occur in the opposite way.

To evaluate these patterns, the rau difference scores were used to perform a repeated-measures analysis of variance. The within-subject variables were the three different SNRs
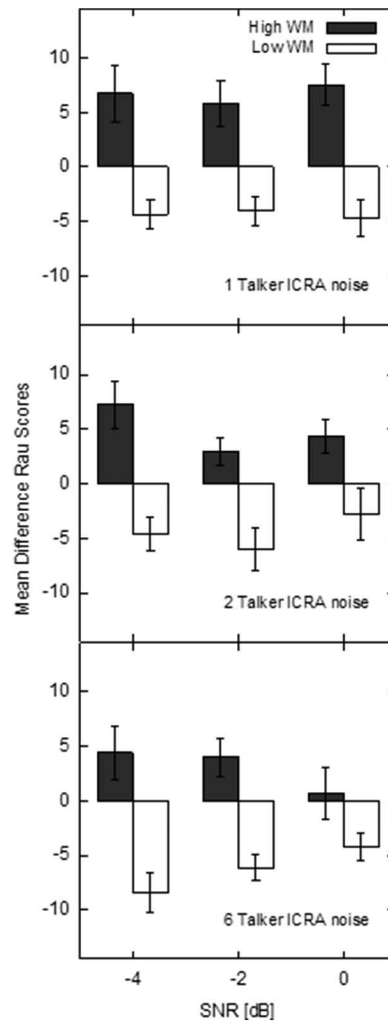

Fig. 3. Mean rau difference scores separated for the number of talkers in the ICRA noises (*top*: one-talker ICRA, *middle*: two-talker ICRA, and *bottom*: six-talker ICRA noise) for the low working memory group (*white*) and the high working memory group (*gray*) across three SNRs (−4, −2, 0 dB). Positive scores correspond to better percentage correct scores measured under fast compression (RT = 40 msec), negative scores correspond to better performance measured when slow compression (RT = 640 msec) was applied.

(−4, −2, 0 dB), and the three different numbers of talkers (one-, two-, and six-talkers) in the background noises. The between-subject variable was working memory (high or low). The three-way interaction between ICRA noises, SNRs, and working memory was not statistically significant [$F(4,96) = 0.91$ for $p = 0.46$, $\eta^2_p = 0.04$].

Next, the three two-way interactions were considered. The interaction between ICRA noises and working memory group was not significant [$F(2,48) = 0.53$, $p = 0.59$, $\eta^2_p = 0.02$]. The interactions between SNRs and ICRA [$F(4,96) = 0.61$ with $p = 0.65$ ($\eta^2_p = 0.03$)], and between SNR and working memory [$F(2,48) = 1.80$ with $p = 0.18$ ($\eta^2_p = 0.07$)], were also not significant.

In view of the nonsignificant interactions, we considered the three main effects of working memory, ICRA noises, and SNRs. As suggested by Figures 3 and 4, there was a significant effect of working memory [$F(1,24) = 56.96$ with $p < 0.01$ ($\eta^2_p = 0.70$)]. The effect of ICRA noises was statistically
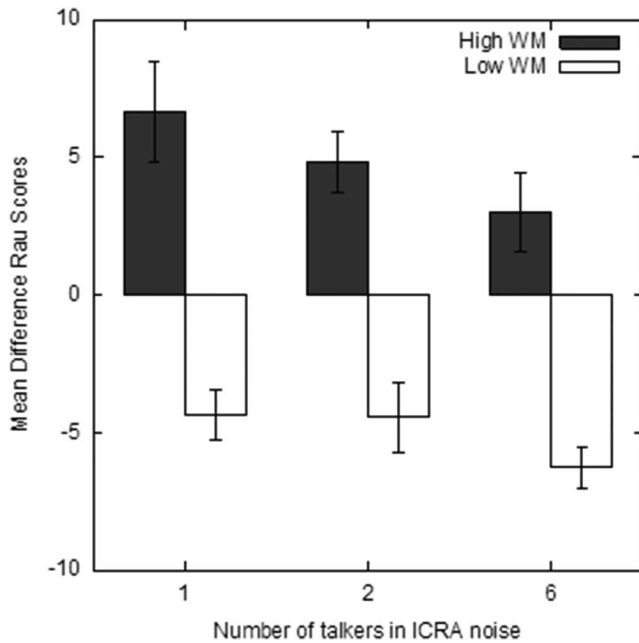
TABLE 1. Mean intelligibility scores (in percent correct) for low and the high working memory group across nine test conditions

Compression	Number of Talkers in ICRA Noise	SNR	Low Working Memory	High Working Memory
Fast	1	−4	49.8	57.7
		−2	57.7	70.6
		0	62.9	78.7
	2	−4	37.2	48.0
		−2	47.4	57.9
		0	56.8	73.6
	6	−4	23.1	34.0
		−2	36.1	51.7
		0	51.6	64.1
Slow	1	−4	55.0	50.6
		−2	61.1	64.8
		0	68.2	71.8
	2	−4	41.5	40.3
		−2	53.8	54.9
		0	59.6	69.8
	6	−4	29.7	29.2
		−2	43.5	47.3
		0	56.0	63.7

Fig. 4. Averaged RAU difference scores for low (*white*) and high (*gray*) working memory, for one-, two-, six-talkers ICRA noise, averaged across the different SNRs. Positive scores correspond to better percentage correct scores measured under fast compression (RT = 40 msec), negative scores correspond to better performance measured when slow compression (RT = 640 msec) was applied.

significant [$F(2,48) = 4.10$, $p = 0.02$ ($\eta^2_p = 0.15$)]. That is, the magnitude of the score difference (fast versus slow compression) depended on the number of talkers in the background noise. Post-hoc means comparisons (with Bonferroni correction for number of comparisons) indicated that the one- and two-talker ICRA noise and the two-talker and the six-talker ICRA noise were not significantly different from each other ($t = 0.75$, df = 77, $p = 0.46$ for one- versus two-talker; $t = 1.72$, df = 77, $p = 0.09$ for two- versus six-talker), whereas the six-talker ICRA noise was significantly different from the one-talker ($t = 2.62$, df = 77, $p = 0.01$) condition. SNR was not identified as a significant factor [$F(2,48) = 0.34$ with $p = 0.72$].

The key results of the analysis can be summarized as follows. On average, listeners with good working memory performed better with fast compression, whereas listeners with poor working memory performed better with slow compression. That relationship was constant across SNR. Regarding the effect of background noise modulations, the magnitude of the fast–slow performance difference depended on the number of background talkers, but only with substantially different background modulation characteristics (one- versus six-talker ICRA noises).

DISCUSSION

Working Memory and Compressor Speed

In the present study, older adults with hearing loss were divided in two groups based on working memory. Speech intelligibility was measured for sentences processed by fast and slow amplitude compression. When participants had high working memory, fast compression provided more benefit than slow compression. When the participants had low working memory, slow compression appeared to be more beneficial than fast compression. There

was agreement with previous work where similar test materials were used, such as Lunner (2003) and Lunner and Sundewall-Thorén (2007) (open test set for low context sentences) and for studies where different test materials were used, such as Gatehouse et al. (2003, 2006a) (closed test set of single target words embedded in carrier phrase). Our findings were consistent with previous results even though different compression implementations (six-channel wide-dynamic range compression [WDRC] here versus two-channel WDRC in previous work) were used.

Similar to previous authors, we interpret our data to suggest that participants with high working memory have better abilities to store and process information simultaneously, which allows them to cope with distortion introduced by the fast compressor. One positive expectation of fast compression is the potential to amplify brief speech segments exclusive of subsequent noise segments. The high working memory group seemed to have the ability to use those amplified speech segments and, perhaps, to distinguish between helpful and disturbing information, such as distortion. In contrast, the low working memory group showed a greater benefit from the less-distorting slow compressor.

Modulation and Compressor Speed

The relative effects of fast versus slow compression (i.e., the difference score) depended on type of ICRA noise. In particular, the six-talker ICRA noise differed from the one-talker ICRA noise, such that the magnitude of the compression speed effect was reduced when less modulation was present in the background. Previous work (e.g., Souza 2002; Souza et al. 2006) demonstrated that compression can degrade speech recognition—especially in modulated noise—by altering the signal envelope. In the present study, the participants had to glimpse the speech information in the gaps of the instantaneous amplitude of the ICRA noises and store and process this information to make sense of the whole sentence, presumably while suppressing signal distortion.

It is interesting to contrast the magnitude of the effect shown here to results by previous authors who used similar approaches. Gatehouse et al. (2003) reported fairly small differences—on the order of 3% to 4%—between their low- and high-cognition groups. The effects shown here were substantially larger, on the order of 10% to 15%. One factor may be our use of unfavorable SNRs, in which the need for glimpsed information should be high. However, the difference between fast and slow compression did not significantly differ across the three SNR conditions in the present study. Another factor may be the use of sentences, in contrast to the Gatehouse et al. use of closed set words which differed in initial or final consonant. It is likely that for sentences a listener must obtain glimpsed information and retain and assemble that information over time, engaging working memory to a greater extent than would be the case for a test that is, essentially, consonant intelligibility.

Relationships Between Background Noise Modulation, Compressor Speed, and Working Memory

The nonsignificant interaction between working memory group and ICRA noises indicated that the high working memory group did not have a significantly larger advantage across the different amplitude modulations in the ICRA noises than the low working memory group. This finding was a surprise,

considering results from earlier research such as by Lunner and Sundewall-Thorén (2007), which indicated that high working memory allowed better performance under fast compression when the ICRA noise had substantial modulations (two-talker noise in that case); as well as the significant effect of noise type across modulated and unmodulated backgrounds noted by Gatehouse et al. (2003).

The answer to the discrepancy may lie in the noise itself. Originally, we anticipated that the smaller number of modulations in the six-talker noise (as quantified by Dreschler et al. 2001) would make it similar to unmodulated noise, which Lunner and Sundewall-Thorén found not to have a compression-by-working memory interaction. On the other hand, and as illustrated in Figure 2, the six-talker noise does have spectral and temporal gaps which allow the listener to glimpse speech elements and/or to make better use of those glimpsed components (e.g., Rosen et al. 2013). Some work (e.g., Simpson & Cooke 2005) has suggested that glimpsing opportunities might be present with larger numbers of talkers. In light of this, perhaps the presence of even brief spectral and/or temporal gaps in the six-talker noise resulted in a different outcome than the unmodulated noise considered in Lunner and Sundewall-Thorén's study.

Generalization to Realistic Communication and Clinical Implications

In this controlled study, low-context sentences were deliberately chosen to encourage reliance on acoustic information and to suit study goals. Previous authors (e.g., Lunner 2003; Lunner & Sundewall-Thorén 2007) have used similar approaches. However, in everyday listening additional factors would be present, including visual and/or contextual cues. At least one group of researchers (e.g., Cox & Xu 2010) noted that the level of context in the test materials can substantially affect the comparison of low- and high-working memory groups. Specifically, although Cox and Xu's data affirmed a relationship between working memory and compression speed, they also suggested that listeners with low working memory might receive greater benefit from slow compression for low-context materials, and greater benefit from fast compression for high-context materials. Furthermore, measures of working memory capacity and speech recognition were not reliable predictors for compression speed preferences and most listeners preferred slow compression in daily listening, conflicting with laboratory data. Rudner et al. (2009) demonstrated that the type of speech material in combination with acclimatization to a certain hearing aid setting play an important role for successful speech recognition in noise. In that study, a measure of explicit cognitive capacity (estimated with the RST) was a good predictor of aided speech recognition performance in noise for constrained sentence material when listeners were presented with compression speeds that were dissimilar to those they were accustomed to. However, for less constrained sentence material, hearing thresholds were a stronger predictor of sentence recognition than was cognitive ability, regardless of the acclimatized hearing aid settings.

The composition of the background noise might also be different in everyday listening situations in which the background is comprised of other talkers. Here, the ICRA noise contained spectral and temporal variations similar to everyday speech, but would have had minimal to no informational masking. Some previous study suggests that similar patterns would be present even when there is informational content in the noise (e.g., Souza & Sirow 2014) but to our knowledge, this issue has not been studied in detail. Future study is necessary to untangle these factors and develop realistic expectations of the role of compression speed and working memory in everyday situations.

CONCLUSION

This study, together with earlier studies (e.g., Gatehouse et al. 2003, 2006a, 2006b; Lunner & Sundewall-Thorén 2007) provides continuing evidence for the consideration of cognitive performance in relationship to fast and slow compression for speech intelligibility in modulated background noise. The results indicated that high working memory (measured via a RST) resulted in better speech intelligibility scores when low-context sentences in modulated noise were processed with fast compression. On the other hand, participants with low working memory performed better under slow compression for the same materials. This relationship was apparent even when the noise contained minimal spectral and temporal gaps (i.e., six-talker background), which would be expected to generate relatively few opportunities for glimpsing. Simply put, *any* degree of background modulation appears to allow advantages of fast-acting compression for listeners with high working memory, at least under controlled circumstances. Considering that few everyday listening situations employ true steady-amplitude noise, this encourages exploration of fast-acting compression for listeners with high working memory.

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