Research Note

A Retrospective Examination of the Effect of Diabetes on Sensory Processing in Older Adults

Larry E. Humes^a

Purpose: The purpose of this article is to examine retrospectively the impact of diabetes mellitus on auditory, visual, and tactile processing in older adults.

Method: Fourteen (10.4%) of a sample of 135 older adults self-reported the presence of diabetes mellitus in a study of sensory and cognitive processing across the adult lifespan. In this study, the performance of the subgroup with diabetes on a number of psychophysical sensory-processing measures was compared with that of the 121 older adults without diabetes. Measures of sensory processing

focused on temporal processing and threshold sensitivity in each of 3 sensory modalities: hearing, vision, and touch.

Results: The subgroup of older adults with diabetes differed significantly ($p < .05$) from the larger group without diabetes only for measures of auditory temporal-order and temporal-masking identification tasks.

Conclusion: This retrospective study provides additional evidence in support of higher level auditory-processing deficits in older adults with a positive history of diabetes mellitus.

According to the U.S. Centers for Disease Control and Prevention (CDC, 2014), one in four Americans age 65 and over has diabetes mellitus. For the overwhelming majority, this is late-onset type 2 diabetes. There are many known health consequences associated with type 2 diabetes in older adults, including cardiovascular, visual, and renal dysfunction (CDC, 2014).

There has been a long interest in the consequences of type 2 diabetes on the auditory function of older adults (e.g., Kurien, Thomas, & Bhanu, 1989; Wackym & Linthicum, 1986). More recent population-based epidemiological studies (e.g., Bainbridge, Cheng, & Cowie, 2010; Bainbridge, Hoffman, & Cowie, 2008; Dalton, Cruickshanks, Klein, Klein, & Wiley, 1998) and systematic reviews or meta-analyses (Akinpelu, Mujica-Mota, & Daniel, 2014; Horikawa et al., 2013) support increased prevalence and incidence of hearing loss among adults with type 2 diabetes, although the strength of this association tended to weaken with advancing age. The systematic review and meta-analysis by Akinpelu et al. (2014) also observed prolonged auditory brainstem response

Wave V latencies among diabetics, suggesting an impact on higher level auditory processing. Konrad-Martin et al. (2016), in a study of 222 older veterans, about half with type 2 diabetes and half without, found significantly longer latencies for cortical auditory evoked potentials, especially the P2 component. Thus, there is mounting evidence that type 2 diabetes in older adults can have a negative impact on the periphery, affecting measures of hearing loss, as well as auditory portions of the central nervous system from the brainstem through the cortex.

We had the opportunity to investigate this further through retrospective analysis of an extensive dataset of sensory and cognitive processing measures obtained from 245 young, middle-aged, and older adults (Humes, Busey, Craig, & Kewley-Port, 2013). Here, we focus on just the 135 older adults in that study because none of the young or middle-aged adults self-reported diabetes in their case history. The participants in this study completed an extensive battery of psychophysical measures of threshold sensitivity and temporal processing in hearing, vision, and touch. The auditory measures of temporal processing included those commonly reported to be sensitive to higher level auditory-processing problems in older adults—specifically, gap-detection thresholds, temporal-order identification, and temporal-masking measures (see review by Humes et al., 2012). They also completed a full cognitive evaluation. Of the 135 older adults in that study, about 10% ($n = 14$)

^aDepartment of Speech and Hearing Sciences, Indiana University, Bloomington

Correspondence to Larry Humes: humes@indiana.edu

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self-reported diabetes. The purpose of the present report is to compare the performance of the diabetic subgroup of older adults with those without diabetes on this extensive set of sensory-processing measures.

Methods

Participants

As noted, there were a total of 135 older adults in this study, 14 of whom had self-reported diabetes in their completed case histories. The mean age for the 14 (six women, eight men) diabetic participants was 71.3 years, and for the 121 (69 women, 52 men) nondiabetic participants, it was 70.8 years, which was not a statistically significant difference in age, $t(133) = 0.16$, $p > .10$. The two groups had similar ranges of age as well—60–82 years for the diabetics and 60–87 years for the nondiabetics. There were also no significant differences between these two groups in terms of socioeconomic status, $\chi^2(4) = 6.13$, $p > .10$, or years of education, $\chi^2(7) = 7.72$, $p > .10$. Last, there was no significant difference in the bilateral average of pure-tone thresholds at 1000, 2000, and 4000 Hz between the two groups (27.1 dB HL for the diabetics and 26.4 dB HL for the controls; $t[133] = -0.20$, $p > .10$) or in the bilateral pure-tone average at 500, 1000, and 2000 Hz (20.53 dB HL for the diabetics and 19.5 for the controls; $t[133] = -0.35$, $p > .10$).

The 14 participants who self-reported diabetes, as well as the 121 who reported that they were not diabetic, did so reliably in that there were two separate case histories at different sessions of this 40-session large-scale study, one during the audiological examination and one during the optometric examination. Further, in the audiological case history, there is an opportunity to list all current medications taken by the participant. In 12 of the cases of self-reported diabetes, medications designed to help control diabetes were included in their list, consistent with their self-report of diabetes. All 14 indicated that their diabetes was controlled via diet or medication, and it is assumed that the two who failed to separately list any medications to control diabetes later in the case history were controlling their diabetes through dietary changes. Self-reports of diabetes are common in large-scale studies and have been found to be very accurate when compared with medical records for those same patients (e.g., Kriegsman, Penninx, van Eijk, Boeke, & Deeg, 1996; Okura, Urban, Mahoney, Jacobsen, & Rodeheffer, 2004).

Stimuli and Procedures

The details of the stimuli and procedures used in the study by Humes et al. (2013) can be found in that publication or earlier papers from that project (Busey, Craig, Clark, & Humes, 2010; Craig, Rhodes, Busey, Kewley-Port, & Humes, 2010; Fogerty, Humes, & Kewley-Port, 2010). In brief, a total of 40 psychophysical measures were obtained in hearing, vision, and touch, with an emphasis on threshold sensitivity and temporal processing. Temporal-processing measures included gap-detection thresholds

for bands of noise, temporal-order identification thresholds for various stimulus sequences (two or four items in the sequences), and temporal masking (forward and backward masking) of stimulus identification. For hearing, the stimulus sequences made use of four brief (70 ms for temporal order and 40 ms for temporal masking) vowels excised from the center of naturally produced tokens in a /p/-vowel-/t/ phonetic context. For vision, the stimulus sequences were composed of four orthographic letters displayed briefly on an oscilloscope screen. Last, for touch, one of four geometric patterns of tactile vibration was presented on the fingertip.

For all three senses, stimuli were created or manipulated in various ways to minimize the impact of peripheral processing limitations on sequence- or target-identification performance. For hearing, stimuli were presented at a high sound pressure level (83 dB SPL) and low-pass filtered (1800 Hz) to minimize any impact of likely high-frequency hearing loss on the identification of these vowels. For all three senses, this was verified directly by requiring all participants to correctly identify each of the stimuli used in these closed-set identification tasks with at least 80% correct performance when presented in isolation. The performance level targeted for each of these measures was well below 80% correct identification, typically 50% correct.

For all of the psychophysical measures of threshold sensitivity or temporal processing, rigorous interleaved adaptive or constant-stimuli methods were used to estimate the desired level of performance. Multiple performance estimates were obtained for each stimulus and condition with a final estimate of performance on the basis of 200–250 stimulus trials.

In addition, the full 13-scale Wechsler Adult Intelligence Scale—Third Edition (WAIS-III; Wechsler, 1997), plus two optional incidental-learning tests, were completed. The full battery of cognitive and psychophysical sensory measures required about 40 sessions of 90 min for a total of approximately 60 hr of data collection from each of the 245 participants.

There was considerable redundancy among the 40 psychophysical measures completed by the 245 adults in Humes et al. (2013). As a result, principal-components factor analysis was used to reduce the 25 sensory-processing measures to eight factors and the 15 cognitive-processing measures to three factors. For all the results presented here, we made use of the ensuing factor scores generated in Humes et al. (2013) for the cognitive and sensory measures from the entire sample of 245 adults. Because all of the measures are factor scores, all with a mean of 0 and a standard deviation of 1, relative comparisons between diabetic and nondiabetic older adults can make use of the same scale.

Results and Discussion

As expected (e.g., Salthouse, 2010), for the entire sample of 245 participants, there were three cognitive factor scores that emerged from the analysis of the WAIS-III measures: (a) *process*, sometimes previously referred to as fluid or nonverbal intelligence; (b) *product*, also known

previously as crystallized or verbal intelligence; and (c) *incidental learning*. The latter factor represented performance on the two additional optional measures included from the WAIS-III, but is seldom reported in other studies, and is not discussed further here as a result.

Because the variance of several of the sensory-processing and cognitive-processing measures was unequal between the two groups, the nonparametric median test for independent groups was used, rather than *t* tests, to examine group differences. With regard to the process and product factor scores from the WAIS-III, the median test indicated that there were no significant differences ($p > .10$) between the diabetic and nondiabetic groups.

With regard to sensory processing, the Tukey boxplots in Figure 1 display the medians and interquartile ranges for each of the eight sensory-processing factors from Humes et al. (2013). Of these eight sensory measures, the only one that revealed a significant difference between groups was the auditory temporal-order/temporal-masking

Figure 1. Tukey boxplots show the medians (horizontal line within box) and interquartile ranges (upper, 75th percentile, and lower, 25th percentile, bounds of each box) for the 14 older adults with self-reported diabetes (black) and the 121 older adults with no reports of diabetes (red) for each of eight measures of sensory processing. The error bars represent the range unless some data points fell outside the boundaries set by 1.5 times the interquartile range (IQR) below the 25th percentile or $1.5 \times$ IQR above the 75th percentile. When data points fell outside this range, the error bars were set to the corresponding $1.5 \times$ IQR boundary and the resulting outliers appear as dots. Each of the eight measures of sensory processing appears on the x-axis and the measures were identified through factor analyses of the data from the full dataset of 245 adults in Humes et al. (2013). For each of the eight measures, the initial sets of capital letters indicate the sensory modality: AUD = auditory, TAC = tactile, and VIS = visual. The lowercase letters following the underscore denote the nature of the task: totm = temporal order, temporal masking; gd = gap detection; thr = threshold sensitivity; ff = flicker fusion; and toloc = temporal order locate. The latter was a special version of the temporal-order identification task in which the participant only needed to determine the location sequence of two stimulus presentations (left-right or right-left) rather than identify the specific vowels, letters, or tactile patterns in the sequence.

factor score (median test, $p < .05$). The diabetic subgroup (black boxplots) shows significantly higher factor scores on this auditory temporal-processing measure than the non-diabetic control participants (red boxplots). For all eight factor scores in Figure 1, higher factor scores reflect worse performance. For threshold-sensitivity measures, this means higher stimulus amplitudes or contrasts were needed by the diabetics for the detection of a signal. For the temporal processing measures, this means longer intervals between successive stimuli were required by the group of diabetics to achieve the target performance level. For the auditory temporal-order/temporal-masking factor in particular, the diabetic group needed more time separation between the vowels in the two- and four-vowel sequences (temporal order) or between the target vowel and the masker (temporal masking) to achieve the target vowel-identification performance levels.

Note that there are two other auditory measures included in Figure 1: gap detection threshold and hearing threshold. Because hearing loss and tactile-sensitivity loss were strongly correlated in these 245 adults, the threshold sensitivity measures for both of these senses emerged as a single factor. Nonetheless, for auditory gap-detection threshold and hearing threshold, no significant differences between the diabetic and control groups were observed. The lack of differences in hearing thresholds between groups was also confirmed with the pure-tone averages obtained audiometrically, as was reported above in the description of the study participants. Identification of the correct vowel sequence, however, is clearly a higher level auditory process than either hearing threshold (detection of the presence of a pure tone) or gap detection (detection of silence inserted in a noise). Not only is the task of identification from among a closed set of options a higher level process than simple detection, but the stimulus sequences used also require linguistic processing to label the vowels in each sequence for the identification tasks.

The fact that this is the only significant difference between groups among the eight measures that make up this profile of sensory-processing measures suggests that this is a modality-specific auditory processing deficit rather than an amodal cognitive processing problem in the older adults with diabetes (Humes, 2008; Humes, Burk, Coughlin, Busey, & Strauser, 2007; Humes et al., 2012). Note, for example, that a close visual analog of the vowel-sequence tasks, one which made use of visual letter sequences in temporal-order and temporal-masking measures (VIS_totm), failed to demonstrate a significant difference in performance between the diabetic and nondiabetic groups. However, the situation is less clear for the tactile analog, TAC_totm. Here, the separation between the medians of the two groups is actually a bit larger than for the auditory version of these same measures, with the diabetic group again performing noticeably worse than the nondiabetic controls. Examination of the interquartile range for the diabetic group on the tactile temporal-order and temporal-masking tasks, however, reveals that the main reason this difference did not reach statistical significance is the larger variability among the diabetic

participants. Thus, one should only cautiously conclude that the observed difference between the groups of diabetic and nondiabetic older adults on auditory temporal-order and temporal-masking measures is modality specific while awaiting further confirmation of this prospectively.

The observation that auditory temporal processing of a sequence of speech sounds was worse in the participants with diabetes is of particular interest given the lack of differences in age, hearing loss, and cognition between these two groups. If one considers running speech to be a steady stream of brief sound sequences, then diabetes may have a negative impact on the processing of such speech—that is, given two older adults of equivalent age, hearing loss, and cognitive function, if one has diabetes and the other does not, the diabetic may have difficulty processing sequences of brief speech sounds and this may lead to difficulties in understanding everyday running speech. This assumes, however, a link between the auditory temporal-order identification task used in Humes et al. (2013) and the perception of everyday speech, a link that has not, as yet, been examined.

Given the retrospective nature of this report, the group with diabetes was composed of a small number of participants ($n = 14$) compared to those without diabetes ($n = 121$). This likely contributed to the inequality of variance in the two groups on several of the sensory-processing factor scores, which necessitated the use of nonparametric statistics. As a result, these findings must be viewed cautiously and should be corroborated prospectively in the future. Further, as noted, although self-reported diabetes is commonly used in studies and has been validated against medical measures of the presence of diabetes, the latter would be ideal to include in a future prospective study. This, or other measures, could also be used to assess the severity of the disease stage for the diabetics, another variable that was not available in these retrospective data.

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