Clinical feasibility of auditory processing tests in Japanese older adults: A pilot study

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Abstract

Background: Difficulty in listening comprehension is a major audiological complaint of older adults. Behavioural auditory processing tests (APTs) may evaluate it.

Aims/Objectives: The aim was to assess the feasibility of administering Japanese APTs to older adults at otolaryngology clinics.

Material and Methods: Using computer programs interfaced with an audiometer, APTs (dichotic listening test; fast speech test, FST; gap detection test, GDT; speech in noise test; rapidly alternating speech perception test) were administered to 20 older adults (65-84 years old; mean 75.3 years) and 20 young adults at the 40dB sensation level. Monosyllable speech perception (MSP) and the Mini Mental State Examination (MMSE) were evaluated.

Results: APT results except for GDT were significantly correlated with MSP. The performance on each APT was worse in older adults than in young adults ($p<0.01$). The older adults with good MSP≥80% ($n=13$) or excellent cognitive function (MMSE≥28; $n=11$) also did worse on APTs ($p<0.05$). A ceiling effect was noted in the APT data, with FST showing a minimum ceiling effect and reflecting interindividual variations of data.

Conclusions and Significance: It is feasible to administer APTs to older adults who visit otolaryngology clinics. Among our Japanese APTs, FST may be suitable for further large-scale clinical studies.

Key words: auditory processing test, clinical feasibility for older adults, auditory and cognitive ability, dichotic listening test; fast speech test; gap detection test; speech in noise test; rapidly alternating speech perception test

Introduction

Medical care for hearing problems of older adults is a critical issue in our modern society with rapid population aging. In the 2010s, Japan is one of the most rapidly aging countries among developed countries worldwide. In this country, the population over 65 years old had not reached 5% of the total population in 1950, but it exceeded 7% in 1970, 14% in 1994, and 21% in 2007. The aging rate continued to rise, with the population over 65 years reaching 27.3% in 2016, as reported by the Cabinet Office. In older adults, an age-related decline in auditory function leads to difficulty in communication, mental disabilities such as depression, low quality of life (QoL), and decreased social activity [1].

In clinical practice at otolaryngology clinics, older adults often complain about hearing problems, especially in listening comprehension of conversations. Hearing problems in older adults are caused not only by peripheral hearing loss due to dysfunctions of the outer, middle, and inner ears, but also by the age-related dysfunction of the central auditory systems of the brain, which further provoke difficulty in listening comprehension of conversations. Such pathological phenomena have been termed “central auditory processing disorder (CAPD)” in older adults or “central presbycusis” [2]. Auditory comprehension in older adults is also affected by cognitive decline, such as mild cognitive impairment or dementia due to Alzheimer’s disease [3]. CAPD is a disorder with difficulty in listening comprehension of conversations in daily life of adults and children, and it is one of the syndromes that negatively affect patients’ QoL, along with conductive hearing loss and sensorineural hearing loss (SNHL) in the peripheral auditory systems [4].

In recent years, it has become possible to evaluate subjects’ listening comprehension by auditory processing ability tests (APTs) using audiometry equipment as a sound source for behavioural audiometry. APTs are used to diagnose CAPD. Behavioural tests commonly performed to evaluate auditory processing ability are divided into five categories: dichotic speech test, monaural low-redundancy speech tests, auditory temporal processing and patterning tests, binaural interaction tests, and auditory discrimination tests [5]. Among APTs performed in the present study, the dichotic listening test (DLT) involves the presentation of different verbal sounds to the right and left ears simultaneously. The listener is instructed to attend to and report the stimuli delivered to both ears [4]. The fast speech test (FST) is one of the low redundancy speech tests that evaluate "auditory closure". Auditory closure is the ability to recognize whole words or sentences when there are missing or distorted portions of the auditory signals [5]. The gap detection test (GDT) measures the individual's ability to detect a brief silence embedded in the auditory stimuli and is one of the most common methods used to evaluate the temporal resolution ability of the subject's auditory system [6]. The speech in noise test (SINT) examines speech intelligibility in background noise, evaluating closure ability, similar to the FST. The rapidly alternating speech perception test (RASPT) is one of the binaural interaction tests in which the subjects listen to words that are alternately presented to the right and left ears as a sentence.

In the DLT, enhanced laterality dominance in word listening by the right and left ears reflects dysfunction of the corpus callosum conveying sound information to the right and left cerebral hemispheres [7]. Cerebral hemisphere dominance can be detected by this test as the right ear advantage in right-handed persons [8]. In a Japanese language literature, brain injury in the auditory cortex or the acoustic radiation shows a "damage effect (lesion effect)" in the DLT, with a listening performance decrease on the side opposite to the injury [9].

Regarding the FST, Zatorre et al. proposed that rapid temporal resolution of sound may be preferentially processed in the left auditory cortex compared to the right auditory cortex [10]. In a Japanese literature, a hearing-impaired person wearing hearing aids or cochlear implants shows decreased performance on this test, whereas a non-handicapped person does not [11].

In the GDT, the auditory cortex neurons play an important role in detecting silent gaps inserted in continuous background noise [12]. The GDT has been used as an index to assess functional consequences of left temporal cortex atrophy associated with mild cognitive impairment and Alzheimer’s disease [3].

The SINT reflects the cocktail party phenomenon in the daily conversational situations of the patients, which may be attributable to functions of the brainstem [13] and auditory cortex [14].

The RASPT examines binaural integration ability of sounds, which is processed in the central auditory pathways in the brainstem [15] and the higher auditory cortex [4,16].

A systematic review of the English literature on central presbycusis reported that negative effects of age were almost always observed in APT performances of older adults [2]. In the English literature, there are a few reports using Japanese APTs in adults [17,18], but there has been no report of their use in older adults.

In order to make it possible to administer APTs to patients in clinics, a test battery of APTs needs to be established for each specific language. It is necessary for clinicians to know whether the older adult patients can perform and complete several APTs in one session at otolaryngology clinics and to understand which APT is suitable for older adults to be performed at clinics.

The current study aimed to assess if it was feasible to administer Japanese APTs to older adults who visit otolaryngology clinics, and to investigate which APT is suitable for further large scale studies. For these objectives, audiological evaluations of outpatients ≥65 years old at our otolaryngology clinics were performed by APTs, and their data were compared with those of a control group of young adults. Monosyllable speech perception and cognitive function were also assessed in order to discuss the relationships of these factors with APT performances in older adults.

Materials and methods

This was a cross-sectional descriptive study. The study protocol was prospectively approved by the Institutional Ethics Committee at Okayama

University Hospital (Principal Investigator: Y.M.; protocol number: 1709-008) and conducted in compliance with the Declaration of Helsinki. Written, informed consent was obtained from each subject prior to participation in this study.

Study subjects

The study subjects included older adults ≥65 years old, as well as normal healthy young adult volunteers as the control cohort. The older adults visited the outpatient clinic at the Department of Otolaryngology, Okayama University Hospital, from October 2017 to October 2018, with symmetric SNHL of presbycusis. The otoscopic findings of all subjects were normal, and subjects with middle and inner ear diseases were excluded. Almost all of the older adults had complained of hearing problems in listening comprehension of conversations in daily life. The young adult controls were health care workers at the Otolaryngology Department of the University Hospital and their family, and were invited to participate in the study.

Auditory and cognitive evaluations before auditory processing tests (APTs)

Prior to the APTs, the average pure tone threshold (average PTT) was determined as the mean threshold at 6 frequencies (250, 500, 1000, 2000, 4000, and 8000 Hz) in all subjects by an audiometer (AA-78, RION Co Ltd, Kokubunji, Japan). It was verified that the difference between the right and left average PTT was less than 10 dB in the older adults with symmetric SNHL and in young adult controls. The sound stimuli of the APTs were delivered to the ears, as described in the following paragraphs, at stimuli levels 40 dB above the average PTT in each subject of the older and young adults (hereafter described as the "40 dB sensation level, 40 dB SL"). This standard of stimuli levels of the APTs was selected in order to adjust the audible sound stimuli between the older and young adults.

At the time of inclusion of the older adults in the study, the uncomfortable sound level (UCL), monosyllable speech perception (MSP), and cognitive status of the subjects were evaluated. During APTs in subjects with hearing loss severer than mild hearing loss, the stimuli levels were adjusted so that they did not exceed UCL to avoid distressing sounds for the subjects. MSP was determined as the percentage of speech intelligibility of the Japanese 67-S monosyllable list, measured according to the previously published description [19]. Briefly, the monosyllable word list was monaurally presented to the right and left ears by female vocalization through headphones in quiet. The word stimuli were presented initially at a sound level 40-50 dB above the average PTT and then successively at decreasing sound levels with 10-dB decrements. MSP was defined as the percentage of the best speech recognition at these sound levels. The cognitive status of the older adults was assessed using the questionnaire of the Mini Mental State Examination-Japanese (MMSE-J; cut off value at ≤23 for dementia, ≤27 for mild cognitive impairment). The data of older adults were analysed for 3 groups of subjects: 1) all older adults; 2) older adults with MSP≥80%, which means older adults with excellent MSP; and 3) older adults with MMSE-J≥28, which means older adults with excellent cognitive function.

Auditory processing tests (APTs)

The computer program of the Japanese APT battery was developed by the authors of this paper (C.O and T.H) and ran on a laptop personal computer (PC). In the recording of speech stimuli in the APT battery, a female professional announcer read out the word/sentence lists in a sound studio room. Regarding selection of the speech stimuli using words, the words which are frequently used in Japanese language were selected, and the numbers of vowels and consonants were counterbalanced among the words. Regarding selection of stimuli using sentences, each sentence consisted of 3 words, and the total numbers of morae were counterbalanced among the sentences.

During APTs from the subjects, the sound stimuli of the APTs were delivered by a headphone and the audiometer connected to the laptop PC in a soundproof room. The test sound was presented at the 40 dB sensation level to each subject. In older adults, MSP was measured on the day of the initial visit to the clinic. The data of APTs were acquired on the day of the next visit to the clinic. The Japanese APT battery included test sessions described in the following paragraphs, performed by the following order in one session for all the subjects. Administering all parts of the APTs in our test battery took 1-1.5 hours and the older adults were given pauses during the test session to minimize fatigue.

Dichotic listening test (DLT)

In this test, different speech stimuli were simultaneously presented to the right and left ears, and subjects were requested to report what they perceived with the same attention by each ear. The stimuli used in this test were words (for example, “tako” which can mean both “an octopus” and “a kite” in the Japanese language, 20 trials), and sentences (10 trials), all in the Japanese language. The laterality index (LI, by percentage) was calculated by the following formula: 100×|number of correct answers by the left ear - number of correct answers by the right ear|/ (number of correct answers by the left ear + number of correct answers by the right ear).

Fast speech test (FST)

The stimuli in this test were non-contextual short sentences in which the speaking speed was altered to three patterns: normal speed, 1.5 times faster, and 2.0 times faster. For example, a non-contextual Japanese sentence, “niwani isuo maku” was presented to the subjects. Twenty sentences were presented at normal speed, 1.5 times faster, and 2.0 times faster by this order for all the subjects (total 60 sentences for each subject), and the subjects were asked to repeat the sentences they heard. If the subject was able to exactly follow the sentence, this was regarded as a correct answer. The percentage of correct answers was calculated for each speech speed.

Gap detection test (GDT)

The stimuli in this test were white noise with a silent gap, with gap durations ranging from 2 to 32 ms. Each trial contained 4 successive presentations of noises (numbers from 1 to 4) that included one gap within one of the four noises. The subjects were required to judge the presence of a gap in each trial. Adaptive GDT was used in this study in which the stimuli were automatically varied adaptively so that the thresholds of gap duration yielding a 50% correct performance could be measured. A computer program was developed to present subjects with visual information on a monitor so that the subjects could visually recognize icons of the noise (numbers from 1 to 4) they heard. The subjects were asked to touch the monitor to indicate which noise included a silent gap.

Speech in noise test (SINT)

The stimuli in this test consisted of 36 words and speech-spectrum noises presented equally to both ears. The signal/noise ratio (SNR; SNR is defined as the difference between the sound pressure level of the signal and the sound pressure level of the background noise) ranged by 5 dB steps at -15, -10, -5, 0, 5, and 10dB. In this test, the words and noises were presented simultaneously and randomly, and the subjects were asked to repeat the words they heard. For example, a Japanese word “shika”, which can mean “a deer” was presented to the both ears under noise. SNR varied randomly in each trial without an adaptive procedure. The reception threshold, determined as the SNR at which 50% correct performance was achieved, was determined.

Rapidly alternating speech perception test (RASPT)

For this test, sentence recitation was divided into brief segments that were rapidly and alternately presented to the right and left ears. For example a Japanese sentence “asagohanni panwo taberu”, which means “I eat bread for breakfast.” was delivered alternately to the right and left ears by dividing the sentence into brief segments. The subjects were asked to repeat the sentences they heard. If the subjects were able to exactly follow the sentence, this was regarded as a correct answer. Twenty sentences were presented, and the percentage of correct answers was determined.

Statistics

As the raw data of DLT, FST, GDT, SINT, and RASPT did not follow normal distribution, the data analysis was performed non-parametrically. The

Kolmogorov-Smirnov test rejected the null hypothesis that the raw data obtained by these APTs follow normal distribution ($p<0.05$).

Since DLT, FST, SINT, and RASPT are APTs with verbal sound stimuli, correlations of the APT results in older adults with MSP were examined by Spearman's rank correlation coefficient. The APT data of all older adults ($n=20$), older adults with MSP≥80% ($n=13$), and older adults with MMSE-J≥28 ($n=11$) were compared with those of young adults ($n=20$) by the Mann-Whitney *U*-test (significance level $p<0.05$). Statistical analysis was performed using Excel and SPSS ver 19 software (SPSS, Chicago, IL).

Results

As summarized in Table 1, 20 young adults (8 females and 12 males; mean±S.D. age 32.9±5.2 years; age range 23-41 years) and 20 older adults (12 females and 8 males; 75.3±6.2 years; 65-84 years) were enrolled in this study. Their average PTT as the mean of the right and left ears was 8.7±2.1 dB HL (mean±S.D.) in the young adults and 41.7±8.6 dB HL in the older adults. The levels of the APT stimuli, expressed in dB, were 49.8±1.1 dB for the young adults and 79.8±7.0 dB for the older adults. Accordingly, the levels of the APT stimuli, expressed in dB sensation level, were 41.0±2.0 dB SL for the young adults and 38.0±3.8 dB SL for the older adults. MSP as the mean of the right and left ears was 97.5%±2.7% in the young adults and 83.6%±12.6% in the older adults, and significantly different between the two groups ($p<0.01$, Mann-Whitney *U*-test). The MMSE-J score in the older adults was 27.7±2.1. Sixteen older adults out of the 20 older adults wore hearing aids, and their data of MSP and APTs were measured under unaided condition as described in the materials and methods section.

As listed in Table 2, MSP was significantly correlated with the DLT score of words ($|r|=0.663$; $p<0.01$), DLT score of sentences ($|r|=0.636$; $p<0.01$), FST(x1) ($|r|=0.629$; $p<0.01$), FST(x1.5) ($|r|=0.790$; $p<0.01$), FST(x2.0) ($|r|=0.791$; $p<0.01$), SINT ($|r|=0.631$; $p<0.01$), and RASPT ($|r|=0.804$; $p<0.01$). MSP was not correlated with the test result of GDT ($|r|=0.176$; *n.s.*), which is not based on verbal sound stimuli. The MMSE-J score was also significantly correlated with the DLT score of sentences ($|r|=0.497$; $p<0.05$).

Figures 1A-H are plots of each APT result comparing the data from the young and older adults. In the data for DLT of words, the LI was significantly higher in all older adults (19.5%±20.2%; $p<0.01$), older adults with MSP≥80%

(10.7%±9.4%; *p*<0.01), and older adults with MMSE-J≥28 (15.0%±18.5%; *p*<0.01) than in young adult controls (2.1%±2.7%) (Figure 1A).

In the DLT score of sentences, the LI was significantly higher in all older adults (47.6%±37.8%; *p*<0.01), older adults with MSP≥80% (29.4%±26.8%; *p*<0.05), and older adults with MMSE-J≥28 (40.9%±42.5%; *p*<0.05) than in young adult controls (8.3%±10.2%) (Figure 1B).

In the FST (x1, normal speed), the percentage of correct answers was significantly lower in all older adults (88.0%±10.9%; *p*<0.01), older adults with MSP≥80% (90.8%±10.6%; *p*<0.01), and older adults with MMSE-J≥28 (90.0%±8.7%; *p*<0.01) than in young adult controls (98.3%±2.4%) (Figure 1C).

In the FST (x1.5, 1.5 times faster than normal speed), the percentage of correct answers was significantly lower in all older adults (77.3%±15.4%; *p*<0.01), older adults with MSP≥80% (83.8%±10.0%; *p*<0.01), and older adults with MMSE-J≥28 (79.5%±13.7%; *p*<0.01) than in young adult controls (98.5%±2.4%) (Figure 1D).

In the FST (x2.0, 2.0 times faster than normal speed), the percentage of correct answers was significantly lower in all older adults (48.5%±23.3%; *p*<0.01), older adults with MSP≥80% (58.1%±20.4%; *p*<0.01), and older adults with MMSE-J≥28 (52.3%±22.7%; *p*<0.01) than in young adult controls (85.8%±8.0%) (Figure 1E).

In the GDT, the gap detection threshold was significantly higher in all older adults (6.8±2.5 ms; $p<0.01$), older adults with MSP≥80% (6.5±2.7 ms; $p<0.01$), and older adults with MMSE-J≥28 (6.7±2.2 ms; $p<0.01$) than in young adult controls (5.2±6.4 ms) (Figure 1F).

In the SINT, the SNR was significantly higher in all older adults (0.8±5.3 dB; $p<0.01$) and older adults with MMSE-J≥28 (0.9±5.8 dB; $p<0.01$) than in young adult controls (-4.5±2.2 dB). The SNR in the SINT was not different between the older adults with MSP≥80% (-1.3±5.3dB; *n.s.*) and the young adult controls (Figure 1G).

In the RASPT, the percentage of correct answers was significantly lower in all older adults (70.5%±29.6%; $p<0.01$), older adults with MSP≥80% (85.8%±18.0%; $p<0.01$), and older adults with MMSE-J≥28 (72.7%±28.0%; $p<0.01$) than in young adult controls (99.8%±1.1%) (Figure 1H).

In the test data of DLT, GDT, SINT, and RASPT in the older and young adults, the ceiling effect was noted (shown in Figure 1). The FST (at 2 times faster than normal speed) showed a minimum ceiling effect and evenly reflected interindividual differences of the subjects' performance on the test (shown in Figure 1E).

Discussion

The experience of this pilot study showed that it was possible to complete APTs in older adults who visit our otolaryngology clinic, and accomplished the objective of the study to demonstrate the clinical feasibility of APTs. Pilot data of APTs were obtained from Japanese older adults visiting our otolaryngology clinic.

First, the results of APTs using verbal stimulation (all APTs except for GDT) showed significant correlations with MSP. This is because performances of APTs with verbal stimulation depend on speech intelligibility which can be expressed as MSP. It can be hypothesized that such correlation of the APT performance with MSP at least partially reflects central auditory dysfunction in older adults, as the sound stimuli were delivered at the constant sensation level across the subjects in APTs of this study. Second, in the data of all older adults examined, the results of all APTs were worse than those of young adult controls. We assume that the APT results in older adults were impaired by a combination of age-related central auditory dysfunction, peripheral SNHL, and cognitive decline. It is noteworthy that the data of GDT were also significantly worse in older adults than in young adult controls. The GDT is an APT depending on non-verbal sound stimuli and generally thought to be less affected by decline of speech intelligibility or cognitive status [2].

The APT data in the present study is a pioneer report showing declined APT performances in older adults of Japanese speakers. In previous papers written in English, central presbycusis was shown as impaired performances of APTs using speech stimuli (such as DLT, FST, and SINT) and nonspeech stimuli (in most cases GDT) in older adults. A systematic review of these English papers by the American Academy of Audiology reported that SNHL of the peripheral auditory system and cognitive decline are thought to be confounding factors that may affect the results of APTs in older adults [2]. Cognitive elements such as attention and working memory (WM) may affect the results of APTs in older adults, similar to the impact of attention/WM on APT performance that is well documented in children [20]. Impaired MSP is also a confounding factor that affects APT results, as discussed in the preceding paragraph. In the present study, all APTs were performed at the 40 dB sensation level both to the older adults and the young adult controls in an attempt to equalize the stimulus levels across groups. In the present data, the APT data were further analysed in older adults with MSP≥80%, as well as older adults with MMSE-J ≥28. APT results were clearly impaired even in these older adults with good MSP and excellent cognitive status in all APTs except for the SINT in subjects with good MSP.

Practically, through our experience administering the APTs to older adults who visited the otolaryngology clinic, one must take into account that administering all parts of the APTs may impose a physical and mental burden on older adults. It may be necessary to select only one or two APTs to administer to older adults as a clinical test. One other shortcoming of these APTs was the ‘ceiling effect’ in the data, as illustrated in Figure 1. In the present study, the ceiling effect was noted in the test results of DLT, GDT, SINT, and RASPT, which hampers the detection of differences in auditory processing ability in individual older adults. The ceiling effect was more apparent in the data of DLT, GDT, SINT, and RAPST in young adults. Because normative data of APTs in adult patients<65 years old are also important to perform APTs in clinics, such ceiling effect in the data may become a problem in future studies to establish APTs in adult patients. The FST at 2 times faster than normal speed showed less of a ceiling effect (Figure 1E), and, therefore, the FST can be selected as a suitable APT that evenly reflects interindividual differences of auditory processing ability in young and older adults.

Limitation of the study

The impaired APT results shown in older adults of this study is thought to be at least partially attributable to central auditory dysfunction, but peripheral SNHL and cognitive impairment are also significant confounding factors that affect APT results. The effects of peripheral SNHL, age-related central auditory dysfunction, and cognitive impairment on APT results should be distinctively analysed by further studies. To this end, multivariate analysis of APT outcomes with variables of peripheral SNHL, subjects' age, and cognitive status needs to be performed in larger cohorts of adult patients. Such studies should also be addressed to compare young adults and a subgroup of older adults with both MSP comparable to young adults and the MMSE-J score>28 in larger cohorts.

Conclusions

The present study showed that it is feasible to administer Japanese APT tests to older adults in otolaryngology clinics. Of our Japanese APT test battery, FST may be one auditory test that is suitable for administration in large-scale clinical studies in the future.

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Legends

Figure 1. Data of auditory processing tests in older adults compared to young adult controls.

The data of the dichotic listening test (words) (A), dichotic listening test (sentences) (B), fast speech test (x1, normal speed) (C), fast speech test (x1.5, 1.5 times faster than normal speed) (D), fast speech test (x2, 2 times faster than normal speed) (E), gap detection test (F), speech in noise test (G), and rapidly alternating speech perception test (H) in all older adults examined, older adults with monosyllable speech perception≥80%, and older adults with Mini Mental State Examination-Japanese (MMSE-J) score≥28 are compared to those in young adult controls. *p<0.05, **p<0.01 by the Mann-Whitney *U*-test.

Table 1. Characteristics of the young adults and older adults enrolled in the study. Age, average pure tone threshold, stimulus level used in the auditory processing tests (expressed in dB and dB sensation level), monosyllable speech perception, and Mini Mental State Examination-Japanese (MMSE-J) scores are tabulated for young adult controls and older adults. The average pure tone threshold is the average of thresholds at 250, 500, 1000, 2000, 4000, and 8000 Hz, and the average of the right and left ears. Monosyllable speech perception is the average in the right and left ears.

Table 2. Correlations of auditory processing test (APT) results with monosyllable speech perception (%) in 20 older adults.

For each of the APTs examined in the 20 older adults, Spearman's rank correlation coefficients with monosyllable speech perception (%) are shown. *$p<0.01$.

Table 3. Data of auditory processing tests in young adult controls and older adults.

The data of each APT (mean±S.D.) are tabulated for young adults (n=20), all older adults examined (n=20), older adults with monosyllable speech perception≥80% (n=13), and older adults with Mini Mental State Examination-Japanese (MMSE-J) score≥28 (n=11).

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