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Efficacy of a newly developed auditory–cognitive training system on speech recognition, central auditory processing and cognitive ability among older adults with normal cognition and with neurocognitive impairment

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Aim: To evaluate the efficacy of a newly developed auditory–cognitive training system on speech recognition, central auditory processing and cognition among older adults with normal cognition (NC) and with neurocognitive impairment (NCI).

Methods: A double-blind quasi-experiment was carried out on NC (n = 43) and NCI (n = 33) groups. Participants in each group were randomly assigned into treatment and control programs groups. The treatment group underwent auditory–cognitive training, whereas the control group was assigned to watch documentary videos, three times per week, for 8 consecutive weeks. Study outcomes that included Montreal Cognitive Assessment, Malay Hearing in Noise Test, Dichotic Digit Test, Gaps in Noise Test and Pitch Pattern Sequence Test were measured at 4-week intervals at baseline, and weeks 4, 8 and 12.

Results: Mixed design ANOVA showed significant training effects in total Montreal Cognitive Assessment and Dichotic Digit Test in both groups, NC ($P < 0.001$) and NCI ($P < 0.01$). The NC group also showed significant training effects in the Malay Hearing in Noise Test (quiet) ($P < 0.01$), Gaps in Noise Test ($P < 0.001$) and Pitch Pattern Sequence Test (humming) ($P < 0.05$). All training effects were sustained up to 4 weeks after the training ended.

Conclusions: The present study suggests that the newly developed auditory–cognitive training system has the potential to improve general cognition and some of the auditory processing abilities in both the NC and NCI groups. Because of the short test–retest intervals used in the present study, it is possible that the training effects were influenced by learning effect and, therefore, should be considered cautiously. **Geriatr Gerontol Int 2019; ••: ••–••.**

Keywords: auditory processing, auditory–cognitive training, cognition, elderly, speech recognition.

Introduction

Age-related hearing loss has been projected to be among the top leading causes of disease burden by 2030.[1] The most prominent problem among older adults with age-related hearing loss is the difficulty in understanding speech, especially in noisy environments.[2] There are three hypotheses to explain age-related decline in speech understanding experienced by older adults:[1] the peripheral hypothesis,[2] the central–auditory hypothesis[3] and the cognitive hypothesis.[3] Although hearing acuity plays a primary role in speech recognition, cognition and central auditory function also contribute significantly, especially, in noisy environments.[4–6]

In view of multiple factors contributing to speech recognition difficulties, it is expected that hearing aid use alone cannot produce the listening skills required for communication.[7] A more comprehensive rehabilitation approach, which includes auditory–cognitive training, might produce better results.[8] Because the central nervous system, including the auditory system, retains its plasticity even in old age,[9] training paradigms, which use brain plasticity-based techniques, should at least partially restore diminished sensory and cognitive functions.[10]

Deficits in working memory and inhibitory control can impair speech comprehension in older adults. Working memory involves the temporary storage and manipulation of information, necessary for a wide range of cognitive activities, whereas inhibitory control is the ability to suppress cognitive interference from irrelevant information that interferes with the task in hand.[11] Cognitive interference occurs when new learned materials cause disturbance in memory retrieval.[12] Proactive interference is when old memories inhibit retrieval of new memories, whereas retroactive interference is when new memories prevent recovery of old memories.

Verbal working memory is correlated with recall accuracy among older adults, and therefore, impacts their speech comprehension.[13] Additionally, working memory capacity also affects the ability to suppress irrelevant information in order to handle multiple streams of information, and comprehend and store information extracted from speech for later recall.[14]

Available evidence outlines the critical role of working memory and cognitive interference elements in the development of an auditory–cognitive training system (ACTS) as a hearing rehabilitation tool, so to alter plasticity among older adults.[15] However,

Table 1 Demographic characteristics of the trained and control groups for the normal cognition and neurocognitive impairment participants

Characteristics	NC (*n* = 43)		NCI (*n* = 33)	
	Trained (*n* = 23)	Control (*n* = 20)	Trained (*n* = 17)	Control (*n* = 16)
Age (years)	67.6 (4.5)	65.8 (3.6)	69.2 (5.9)	67.1 (5.6)
Sex (male)	7	3	3	6
Sex (female)	16	17	14	10
Hearing level				
4FA right ear (dBHL)	26.3 (8.0)	24.5 (7.3)	28.9 (7.3)	30.2 (8.7)
4FA left ear (dBHL)	24.3 (9.0)	26.5 (5.7)	28.3 (8.1)	30.6 (9.3)
Education level				
Did not attend school/primary school	7.0 (30.4%)	9.0 (45.0%)	14.0 (82.3%)	13.0 (81.3%)
Secondary school	16.0 (69.5%)	10.0 (50.0%)	3.0 (17.6%)	3.0 (18.8%)
College or university	0 (0%)	1.0 (5.0%)	0 (0%)	0 (0%)

4FA, four frequency average; NC, normal cognition; NCI, neurocognitive impairment.

systematic reviews on ACTS for older adults revealed the lack of cognitive interference elements in any of the training systems.[10,16]

Therefore, the present study aimed to evaluate the efficacy of a newly developed ACTS that included cognitive interference element among older adults with NC and with NCI. Cut-off scores of 22 out of 23 for Mini-Mental State Examination were adopted.[17] We predicted that the ACTS would increase speech recognition, central–auditory processing and cognitive abilities in older adults with NC, as well as with NCI.

Methods

Participants

Participants were recruited from three senior citizen activity centers in Kuala Lumpur. Study procedures were approved by and carried out in accordance with the Research Ethics Committee of the National University of Malaysia (approval number NN-038-2013). All participants signed an informed consent and were compensated with RM300 for their complete participation in the study. Of 112 older adults (aged ≥60 years) screened, 80 fulfilled the inclusion criteria, and just 76 could commit to the training schedule. Individuals who were literate, native Malay speakers, right handed, had symmetrical hearing level with four frequency average of 0.5–4.0 kHz ≤40 dBHL in the better hearing ear, and had good vision and dexterity were included in the present study. Additionally, participants had to be free from ear and neurological diseases, and dementia. Table 1 summarizes the participants' sociodemographic data.

Design

A double-blind quasi-experimental approach was implemented: (i) the testers of auditory tests were blinded to the participants' cognitive status; and (ii) the participants were blinded to the types of intervention programs. Figure 1 shows the framework of the study.

General description of the ACTS

The training system is computerized software that comprises five adaptive training modules designed to improve speech-in-noise reception ability, enhance working memory capacity and suppress cognitive interference (Table 2).

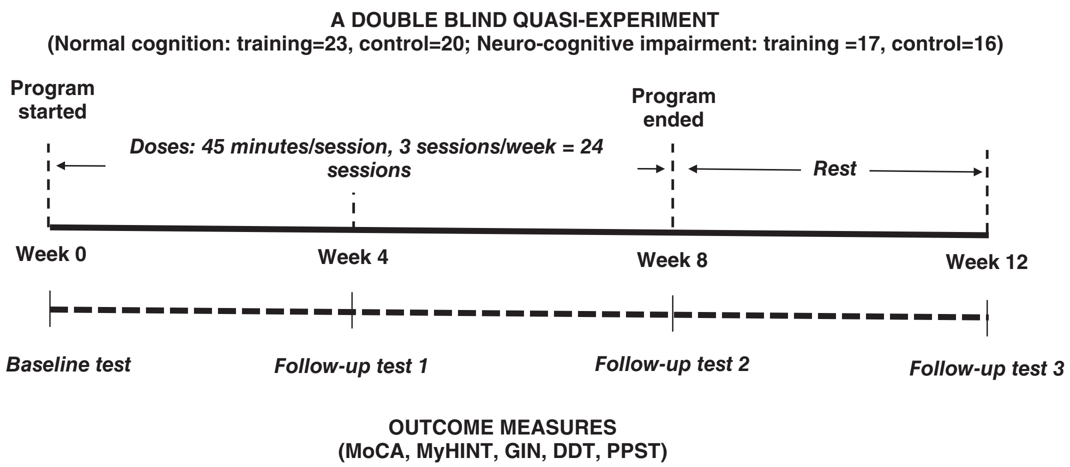

Figure 1 After eligibility screening and randomization, all participants carried out a battery of behavioral tests to evaluate baseline functioning in speech recognition, central auditory processing and cognition including the Malay Hearing in Noise Test (MyHINT), Gap in Noise (GIN), Pitch Pattern Sequence Test (PPST), Dichotic Digit Test (DDT) and Montreal Cognitive Assessment (MoCA). Participants began the 8 weeks of interventions within a week of the baseline assessment. For both the training and active control programs, participants came to the respective senior citizen activity center (PAWE) three times a week to undergo the intervention. The total intervention time was 18 h for the entire 8 weeks. All participants were again administered the same test battery at weeks 4, 8 and 12.

Table 2 Summary of the newly developed auditory–cognitive training system

Training task	Category	Description
Word in noise	Auditory	Identify word with the presence of background noise
Sentence in noise	Auditory	Identify targeted word in a sentence with the presence of background noise
Word span	Auditory–cognitive	Identify all words with the presence of cognitive interference
Word order	Auditory–cognitive	Identify words in sequence with the presence of cognitive interference
Word position	Auditory–cognitive	Identify a specific word at a specific position with the presence of cognitive interference

Word in noise

The stimulus was single words presented with multi-talker babbles or with a single competing speaker. The noise was fixed at 65 dB. The participant listened to the word and then selected the picture that matched the word, from multiple pictures that were presented on the laptop screen just after the stimulus ended. Three trials were presented at each signal-to-noise ratio (SNR) level. When the participant responded correctly to all three words, the difficulty of the next trials was increased by reducing the SNR. Conversely, the SNR was increased if the participant failed to identify all three stimuli. The training continued in this manner for seven SNR presentation levels (21 words). For each training session, the lowest SNR in which all the three stimuli were correctly identified was recorded. The next word in noise training would start at dB above that SNR level.

Sentence in noise

The sentence in noice module comprised short sentences presented with multi-talker babble or with a competing speaker. The module used the identical paradigm as the word in noise module. The participant listened to the sentence, then he/she identified the target word that was one of the words in the sentence, from a visually presented multiple choice option.

Word span

The participant listened to a string of words (2–9 words). Then, a group of pictures were presented on the computer screen. The participant had to select pictures that matched the words, in any order. If the participant correctly identified the all words, the next word string length was increased by one word. In contrast, if the participant was not able to identify all words in the string correctly, the next presentation was shorter by one word.

Cognitive interference (secondary task) was embedded in the training once a participant achieved a mastery word span level of five words. It consisted of simple questions with four multiple choice answers. The secondary task was introduced either before or after the primary task. The participant had to listen to the primary and secondary stimuli, and then answer the secondary task first before responding to the primary task. The training paradigm was identical to the training without secondary task, as described earlier.

Word order

The participant listened to a string of words (2–9 words). Then a group of pictures was presented on the computer screen. The participant had to select pictures that matched the words sequentially, in the order they were presented. If the participant responded correctly, the next word string length was increased by one word. In contrast, if the participant was not able to identify all words in the string correctly, the next presentation was shorter by one word.

Cognitive interference (secondary task) was embedded in the training once a participant achieves a mastery word span level of five words. It consisted of simple questions with four multiple choice answers. The secondary task was introduced either before or after the primary task. The participants had to listen to the primary and secondary stimuli, and then answer the secondary task first before responding to the primary task. The training paradigm was identical to the training without secondary task, as described earlier.

Word position

The participant listened to a string of words (2–9 words). Then a group of pictures was presented on the computer screen. The participant had to select a picture that appeared in a specific position in the word string (for example, the first or second word in the string etc.). If the participant responded correctly, the next word string length was increased by one word. In contrast, if the participant was not able to identify all words in the string correctly, the next presentation was shorter by one word. The only difference being that the participant had to identify the word that appeared in specific positions in the word string.

Similar to that in word span and word order tasks, the secondary task was also embedded using similar materials and paradigm.

Interventions

After the completion of eligibility screening and baseline assessment, participants were randomized to the training or active control group. The training group received auditory training using the newly developed ACTS, whereas, the active control group was assigned to watch a documentary video program. Both intervention programs were 45 min, 3 days per week, for 8 consecutive weeks. They were supervised by an assistant researcher to ensure on-task participation, to clarify tasks guidelines and manage the technical difficulties whenever necessary.

Training program

The training was presented through headphones at the participant's comfortable level from a touch screen laptop computer. The participants responded to each task by touching the photo grid options and/or multiple choice answers on the laptop screen. For each task, participants were screened in order to establish the initial training level. After that, training began at the screened level, and its difficulty was adaptively adjusted to the user's performance to maintain an approximately 80% correct rate. Therefore, participants with highly accurate performance on the tasks progressed on to more difficult tasks, and those with lower accuracy performance received additional practice on lower level tasks until performance criteria were reached.

Control program

The control program matched the training program in terms of training duration and frequency, audiovisual presentation and computer use. Each participant used laptops to watch digital video disc-based documentary programs on history and literature. Participants listened to the documentary through headphones.

Adherence to intervention

All participants successfully completed 8 weeks of training, and assessment at weeks 0, 4, 8 and 12.

Evaluations

After intervention programs, participants repeated the same behavioral tasks as completed at baseline.

Malay Hearing in Noise Test

The Malay Hearing in Noise Test (MyHINT) by Quar *et al.*, which comprises HINT (quiet), HINT (noise front), HINT (noise right) and HINT (noise left) conditions,[18] was administered with headphones. The results for MyHINT (quiet) and MyHINT (composite noise) were used as measures of speech reception in quiet and in noise, respectively. HINT (noise composite) = [2 HINT (noise front) + HINT (noise right) + HINT (noise left)] / 4.

Gaps in Noise test

The Gaps in Noise (GIN) test was used to assess the temporal resolution.[19] The GIN stimuli comprise of a series of 6-s segments of broadband noise containing zero to three silent intervals, which vary between 2 to 20 ms per noise segment. The gap detection threshold, defined as the shortest gap duration correctly identified in at least four of six presentations, was obtained.

Pitch Pattern Sequence Test (PPST)

The Pitch Pattern Sequence Test (PPST) procedure was based on Mukari *et al.*[20] A series of 40 test stimuli consisting of triads of two different frequencies of pure tones (880 Hz and 1430 Hz) were presented binaurally.[20,21] Participants were tested using two different response modes; verbal labeling and humming responses. The participants' performance was scored based on the percentage of stimulus patterns correctly labeled or hummed.

Dichotic Digits Test

The Malay Dichotic Digits Test (DDT) in free recall, which requires the participant to repeat four numbers (2 pairs, with the members of each pair presented to each ear simultaneously), was carried out.[22] The right-ear and left-ear scores were defined as the percentage of correctly repeated digits in the particular ear. The ear-advantage value, defined as the difference between the right-ear and left-ear scores, was analyzed.[22]

Montreal Cognitive Assessment

The Malay Montreal Cognitive Assessment (MoCA) was used to assess the cognitive outcomes.[17] The test protocol was based on that of Nasreddine *et al.*[23] The total MoCA score and delayed memory domain were analyzed.

Statistical analysis

Statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS) version 22.0 (IBM Corp, Armonk, New York, USA). Means and standard deviations were calculated. For both the NC and NCI groups, mixed design analyses of variance (ANOVA) were used for all outcome variables (within subject factor: weeks 0, 4, 8 and 12) and (between subject factor: training and control group). In measures where training effects were present, Bonferroni corrections were applied in post-hoc analyses for pairwise comparison between week 8 and week 12. For DDT, because the scores at baseline were higher in training group than in the control group, the adjusted means for the effects of the covariate were included to partial out the training effect.

Results

Sociodemographic characteristics

Table 1 summarizes the sociodemographic characteristics of the participants by cognitive and intervention groups. The majority of the participants (75%) were women, 43 had NC and 33 had NCI. The mean ages for the two groups were similar ($P < 0.05$). For

Table 3 Descriptive data of outcome measures at baseline, and week 4, 8 and 12, and training effects from mixed ANOVA analysis among the normal cognitive group

Outcome measures	Training group (n = 23)				Control group (n = 20)				F	P	Partial η^2
	Week 0	Week 4	Week 8	Week 12	Week 0	Week 4	Week 8	Week 12			
HINT (quiet)	29.3 (5.2)	28.9 (5.6)	27.5 (5.1)	26.8 (5.7)	25.8 (5.6)	27.0 (5.2)	26.2 (6.4)	27.1 (5.9)	5.842	**0.001**	0.125
HINT (composite)	−6.2 (1.1)	−6.5 (1.2)	−6.7 (1.0)	−6.7 (1.3)	−6.3 (1.5)	−6.4 (1.3)	−6.7 (1.4)	−6.8 (1.3)	0.291	0.832	0.007
GIN	14.0 (4.1)	10.9 (2.7)	10.1 (2.9)	10.5 (2.9)	13.7 (4.3)	12.8 (3.7)	12.9 (3.6)	12.9 (3.7)	7.718	**0.001**	0.158
PPST (humming)	81.5 (13.6)	87.8 (11.9)	92.8 (8.1)	89.6 (12.1)	85.0 (12.0)	86.3 (10.4)	85.0 (9.2)	87.5 (9.2)	3.021	**0.032**	0.069
PPST (verbal)	70.9 (19.4)	74.6 (22.7)	80.0 (21.4)	78.9 (22.9)	63.8 (27.6)	78.0 (26.9)	74.3 (25.3)	83.0 (20.5)	1.636	0.192	0.038
DDT (REA)	†20.1 (13.9)	11.1 (6.1)	7.3 (5.4)	6.7 (6.9)	†11.8 (14.5)	10.1 (13.7)	9.2 (11.3)	10.5 (14.3)	7.748	**0.001**	0.159
Delayed Memory	1.9 (1.5)	2.6 (1.4)	4.3 (1.2)	4.5 (0.9)	1.9 (1.2)	2.0 (1.2)	2.0 (1.4)	2.2 (1.4)	20.331	**<0.001**	0.331
MoCA	20.8 (2.7)	24.4 (3.9)	26.8 (2.7)	27.1 (2.4)	20.2 (3.2)	19.2 (5.4)	21.5 (4.5)	21.9 (4.0)	19.908	**<0.0001**	0.327

Bold values highlight that they are statistically significant. †Covariates appearing in the model were evaluated at the following values: Malay Dichotic Digits Test (DDT) (right ear advantage) baseline = 16.2. GIN, Gaps in Noise Test; HINT, Malay Hearing in Noise Test; MOCA, Montreal Cognitive Assessment; PPST, Pitch Pattern Sequence Test.

Table 4 Descriptive data of outcome measures at baseline, and week 4, 8 and 12, and training effects from mixed ANOVA analysis among the neurocognitive impairment group

Outcome measures	Training group (n = 17)				Control group (n = 16)				F	P	Partial η^2
	Week 0	Week 4	Week 8	Week 12	Week 0	Week 4	Week 8	Week 12			
HINT (quiet)	30.2 (5.2)	29.1 (6.2)	28.2 (6.9)	28.2 (7.2)	31.4 (6.5)	32.1 (5.8)	30.0 (5.6)	30.1 (5.0)	1.075	0.364	0.034
HINT (composite)	−4.5 (2.0)	−4.8 (2.5)	−5.6 (1.5)	−5.7 (1.6)	−4.2 (2.9)	−4.8 (1.6)	−5.3 (1.9)	−5.4 (1.9)	0.212	0.836	0.007
GIN	14.4 (3.9)	12.5 (3.1)	12.2 (3.2)	11.8 (2.9)	14.4 (5.3)	12.4 (3.8)	12.3 (3.7)	12.4 (3.6)	0.253	0.683	0.008
PPST (humming)	73.5 (20.7)	74.1 (23.1)	79.1 (14.5)	80.6 (16.2)	74.6 (17.7)	72.5 (22.6)	82.5 (11.2)	80.9 (15.1)	0.186	0.842	0.006
PPST (verbal)	67.1 (21.1)	58.8 (27.9)	64.7 (27.1)	67.4 (29.7)	63.1 (21.9)	68.8 (18.2)	70.9 (18.9)	70.6 (18.1)	0.958	0.416	0.030
DDT (REA)	†18.7 (17.9)	17.9 (13.3)	14.9 (9.5)	11.4 (9.0)	†12.0 (7.7)	11.6 (7.2)	12.3 (6.3)	12.1 (5.7)	5.005	**0.006**	0.139
Delayed memory	0.4 (0.7)	1.9 (1.8)	2.9 (1.9)	2.9 (1.8)	0.4 (1.0)	0.8 (1.1)	0.8 (1.4)	1.2 (1.5)	6.768	**<0.001**	0.179
MoCA	14.1 (3.2)	19.2 (5.4)	21.5 (4.4)	21.9 (4.0)	13.8 (3.6)	14.1 (2.9)	15.3 (4.3)	16.4 (4.8)	30.344	**<0.0001**	0.495

Bold values highlight that they are statistically significant. †Covariates appearing in the model was evaluated at the following values: Malay Dichotic Digits Test (DDT) (REA) baseline = 15.4. GIN, Gaps in Noise Test; HINT, Malay Hearing in Noise Test; MOCA, Montreal Cognitive Assessment; PPST, Pitch Pattern Sequence Test.

each cognitive group, comparisons of age, four frequency average hearing threshold and Mini-Mental State Examination between the experimental and control groups using the *t*-test were not significant ($P > 0.05$).

Efficacy of the auditory–cognitive training

Tables 3 and 4 summarize the effects of training on outcome measures among the NC and NCI group, respectively.

Normal cognitive group

The auditory–working memory, as measured from the delayed memory score of the MoCA, showed a significant training effect (F [2.5, 101.5] = 20.3, $P < 0.001$, $\eta^2 = 0.33$). Similarly, significant training effects were also seen in the overall MoCA (F [3, 123] = 5.8, $P < 0.001$, $\eta^2 = 0.21$), DDT (F [1.8, 75.3] = 7.8, $P < 0.01$, $\eta^2 = 0.16$), HINT (quiet) (F [3, 123] = 5.8, $P < 0.01$, $\eta^2 = 0.1$), GIN (F [1.8, 73.8] = 7.7, $P < 0.01$, $\eta^2 = 0.2$) and PPST (humming) (F [3, 123] = 19.9, $P < 0.05$, $\eta^2 = 0.3$). There was no training effect on HINT (composite).

Neurocognitive impairment group

Significant training effects were also present in the NCI group, albeit in limited domains; delayed memory (F [3, 93] = 6.8, $P < 0.01$, $\eta^2 = 0.2$), overall MoCA (F [3, 93] = 10.2, $p < 0.001$, $\eta^2 = 0.2$) and DDT (F [2.4, 74.5] = 5.0, $P < 0.01$, $\eta^2 = 0.1$).

Follow-up analyses

Among the NC group, MyHINT in quiet, GIN, PPST by humming, DDT, delayed memory and total MoCA showed no significant alteration between the mean scores at weeks 8 and 12 (paired *t*-test, $P > 0.05$). Similarly, among the NCI group, pairwise comparison showed no significant difference ($P > 0.05$) between weeks 8 and 12 mean scores of DDT, delayed memory and total MoCA, indicating that the training effects were sustained for at least 1 month post-training.

Discussion

The present study aimed to determine the efficacy of a newly developed ACTS in improving speech recognition, central auditory processing and cognition among older adults with NC and with NCI. The results showed that the ACTS produced significant and sustained training effects on speech recognition in quiet, and some of the central auditory processing and cognitive functions. These effects were, however, dissimilar across cognitive groups.

For HINT in quiet, the training effect was observed among NC older adults ($P < 0.01$). This finding further supports a past study that suggests the possible role of auditory training in improving speech recognition ability.[24] However, a similar effect was not found in the NCI group. A possible explanation could be the NCI group requires more training than that used in the current study. For speech recognition in noise (HINT in noise composite), there was no training effect seen in both the NC and NCI groups. Generally, small improvements of HINT in noise performance were seen in both the trained and control groups, suggesting a likely test–retest improvement effect. It is possible that other speech recognition test, such as QuickSIN, which utilizes multi-talker babble noise, would be more sensitive in capturing the training effect. For example, Sweetow and Sabes found training effects of an auditory–cognitive exercise when assessed using QuickSIN, but not using HINT.[25]

For central auditory processing, the training effect was seen in DDT ($P < 0.01$) in both cognitive groups. Nevertheless, due to the repetition of measures with 4-week intervals, especially in DDT, the effect of the ACTS should be considered cautiously. At baseline, the ear advantage was larger in the training group than in the control group. However, as the training progressed, the mean score of the ear advantage in the training group reduced, whereas no remarkable changes were seen among the control group. Given a large ear advantage in dichotic listening is associated with difficulty listening in noise, it is possible that ACTS can improve listening ability in noisy environments.[26] Among the NC group, significant training effects were also seen in GIN ($P < 0.01$) and PPST humming. These could be due to improved attention after the training using ACTS.

Both cognitive groups showed significant training effects in the total MoCA score and in the delayed memory domain. This suggests that the ACTS can promote brain plasticity in NC, as well as in NCI older adults.[27] The use of the MoCA test, rather than a diagnostic cognitive test battery in the present study makes it impossible to confirm which domains of cognition are significantly affected by the auditory–cognitive training. A more specific test, such as operation span task, could better assess the working memory capacity.[28]

For a training program to be useful, its effectiveness must be retained even after the training ends.[29] We found training effects were retained up to at least 1 month post-training, which corroborates past studies.[30] However, the effects of the auditory–cognitive training shown in the present study must be interpreted with caution, because it was carried out in a controlled situation, in which the training dose was carefully monitored for all participants. Adherence to a training schedule might be a challenge in real situations where individuals are to use the ACTS at home without supervision.

In conclusion, the present study showed that the newly developed ACTS can produce training effects in speech recognition (in quiet), auditory processing and in cognition. This study has also shown that the training effects were sustained at least up to 1 month post-training. Additionally, training effects were seen in more domains in the NC group than those in the NCI group, suggesting a higher learning potential among the NC participants.

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Disclosure statement

The authors declare no conflict of interest.

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