RESEARCH ARTICLE

REVISED Influence of auditory-based cognitive training on auditory resolution, executive function, and working memory skills in individuals with mild cognitive impairment – a pilot randomized controlled study

[version 2; peer review: 1 approved, 3 approved with reservations]

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Abstract

Background

Age-related central auditory processing disorder and mild cognitive impairment (MCI) can be concomitant in older adults, making it difficult to communicate, especially in challenging listening conditions. This preliminary study investigated the efficacy of auditory-based cognitive training on the auditory processing abilities and cognitive functions of older adults with MCI.

Methods

In this randomized controlled trial twenty-two older adults with mild cognitive impairment (MCI) were randomly assigned to either an experimental (n=11) or a control group (n=11). The experimental group received 15 cognitive training sessions through tasks involving the auditory domain. The outcome measures of this study included auditory resolution (Temporal gap detection, frequency discrimination, and modulation detection) and cognitive measures (Trail making tests and digit recall), which were administered at three-time points (before training, post-training, and follow-up). The linear mixed model computed the effects of training on the outcome measures.

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Results

A significant improvement was observed in the modulation detection threshold between baseline and follow-up and between post-training and follow-up sessions. However, GDT and FD thresholds did not reveal any statistically significant difference. In the trail making test, Part B showed consistent significance across the time points, whereas Part A and the delayed recall task showed no significant difference.

Conclusion

Auditory-based cognitive training may improve auditory processing and executive function in older adults with mild cognitive impairment (MCI).

Trial registration

CTRI/2019/01/017073, registered on 14.01.2019

Keywords
Mild cognitive impairment, Auditory processing, Cognitive training, older adults, memory.

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REVISED **Amendments from Version 1**

We have made few corrections based on the suggestions of the reviewer. A baseline characteristics table with the statistics is included. Clarifications provided for minimum criterion set for data analysis and for having a no treatment control group.

Any further responses from the reviewers can be found at the end of the article

Introduction

Aging is a natural process that affects people, causing a decline in cognitive and sensory abilities.[1] Aging leads to degenerative changes in the auditory structures and functions in older adults above 65 years, resulting in Presbycusis or Age-Related Hearing Loss (ARHL). Around 65% of adults above 60 experience this hearing loss, with the prevalence rate increasing from 15.4% among older adults above 60 to 58.2% among older adults above 90.[2] ARHL is caused by the loss of sensory cells and degenerative changes in the central auditory nervous system.[3] Another common condition that affects older adults is mild cognitive impairment (MCI). MCI is characterized by a decline in memory, attention, and cognitive function,[4] and it is a precursor of dementia, especially if it is an amnestic type.[5] ARHL makes it difficult to perceive speech, particularly in noisy environments, and can lead to a decline in cognitive function.[6,7] MCI can exacerbate speech perception problems.[8,9] Therapeutic management or training addressing sensory, cognitive, and learning issues may slow down or lessen the impact of aging.

Auditory and cognitive training are important components of rehabilitation for both healthy and aging populations, including those with disorders. Auditory training actively involves the trainees distinguishing the sounds presented systematically.[10] Although auditory training was initially used to enhance sensory refinement of speech sounds (bottom-up), literature shows it can also be beneficial for top-down processes, which are important for listening, especially in challenging conditions.[11,12] Cognitive training involves using standardized tasks that are cognitively challenging to improve an individual's cognitive functions.[13] Studies have shown that cognitive interventions effectively enhance the cognitive function of older adults with Mild Cognitive Impairment (MCI).[14–16] They also improve auditory and cognitive functions, enhancing speech perception in various situations.[17,18]

Many people have shown interest in exploring this type of training to alleviate cognitive and perceptual impairments.[11] In 2009, Smith conducted cognitive training sessions for older adults with normal cognitive function and observed improved auditory memory and attention.[19] Similarly, Yusof et al. (2019) examined the benefits of auditory-cognitive training among older adults with and without neurocognitive impairment.[20] Participants were trained in auditory perception, such as word and sentence recognition in noise, and auditory-cognitive tasks, such as word span, word order, and word position. Though both groups benefited from the training, improvement was more noticeable among individuals with normal cognitive functions in various domains. Similarly, in 2014 Avila and her colleagues studied the effectiveness of auditory training on the auditory and cognitive skills of older adults with Mild Cognitive Impairment. The training stimulated auditory skills such as auditory memory, selective attention, figure-ground, temporal processing, auditory closure, and binaural integration. The training resulted in the improvement of auditory skills but did not generalize to cognitive skills.[21]

A recent study by Kawata et al. (2022) investigated the benefits of auditory and cognitive training in healthy older adults.[22] They provided auditory-cognitive training (ACT), auditory training (AT), and cognitive training (CT). The results indicated that the ACT group exhibited significant differences in brain structure changes compared to the other groups. It is worth noting that the study had a limitation in that it relied solely on pure tone audiometry as an auditory measure.

Murphy et al. (2011) conducted a study on the effectiveness of auditory training in an adult who had suffered a traumatic brain injury. The patient had difficulties with auditory processing and cognitive skills such as temporal processing, verbal memory, working memory, and verbal fluency. The auditory training not only enhanced auditory skills but also led to improvements in central processes (top-down processing), which consequently had a positive impact on cognitive abilities as well. Both auditory and cognitive training can strengthen neural pathways and circuits through training, leading to improved auditory perception and cognitive abilities.[23] Therefore, actively involving older adults in such training can bring about changes in the brain, ultimately enhancing their auditory and cognitive functions.

Numerous studies have demonstrated that cognitive interventions can enhance the quality of life in older adults with and without Mild Cognitive Impairment MCI.[24–26] However, there is a dearth of literature on auditory-based cognitive training, and the few existing studies have varying participant selection, training materials, and assessment measures. One study evaluated auditory-based cognitive measures alongside auditory cognitive training, but they used pure tone audiometry as an outcome measure, which is a peripheral test considered to be less influenced by cognitive function.[20] Therefore, the current study was designed to evaluate the impact of auditory-based cognitive training on auditory processing skills and cognitive abilities of older adults with cognitive impairment.

Methods

Study design and setting

This study was a pilot randomized controlled trial research, conducted at the Department of Speech and Hearing, Manipal College of Health Professions. This study included an experimental group which received cognitive training and a control group who did not receive any treatment. The assessment and training for all the participants were conducted at participants' home in a silent environment. The procedures of this study were reviewed and approved by the Institutional Ethics Committee, Kasturba Hospital, Manipal (IEC 704/2017) on 15.11.2017, and the Clinical Trials Registry of India CTRI/2019/01/017073, registered on 14.01.2019.

Participants

The participants were recruited from the community (Udupi and nearby districts, Karnataka) through geriatric camps, community visits and screening inmates from old age homes. This preliminary study included 22 older adults with mild cognitive impairment (MCI). The group consisted of 11 males and 11 females, with a mean age of 69.18 (6.35). All participants had a Montreal Cognitive Assessment (MoCA) score between 19 and 25 and had no history of neurological conditions or psychological disorders. The participants were randomly assigned to either the control group (n=11) or the experimental group (n=11). All participants had normal or corrected-to-normal vision in both eyes. They also had a mean (SD) pure tone average of 21.4 (3.61) dBHL in the right ear and 23.4 (4.84) dBHL in the left ear, as assessed across audiometric frequencies (250, 500, 1 kHz, 2 kHz, 4 kHz, and 8 kHz). All participants were native Kannada Speakers with proficiency in reading and writing and had completed at least ten years of education.

Randomization and blinding

The participants were randomly assigned to either the experimental group or the control group using a simple randomization method involving the drawing of chits. The enrolled participants were asked to pick a chit and based on that they were assigned to either of the groups. The primary investigator provided intervention to all the participants in the experimental group, however all the three assessments (pre, post and follow up) were conducted by qualified audiologist and speech and language pathologists who were not a part of this study. The statistical analysis was performed by the primary investigator, but the interpretation was made after discussing with other investigators of this study who were unaware of the group allocation including a statistician.

Participant groups

Experimental group

The group's participants underwent 15 sessions of Auditory-based cognitive training (AbCT) using Smriti Shravan Software Version 2 (Kumar & Maruthy, 2013)[27] [https://sites.google.com/u/0/s/1L2VuSNH1Y6DhrjkLs830TtvUhNjcfmUb/edit?usp=sites_home]. Appropriate permission was obtained for the usage of all the assessment tools, screening checklist and training software for this study. The training was provided to all the participants in a relatively silent environment at their residence based on their preferences. Each session lasted 60 minutes and included various tasks such as Forward Span, Backward Span, Running Span, Ascending Span, Descending Span, and Math Span tasks. The training module for each task consisted of digits from 1 to 9 presented through auditory modality, and the number of digits presented varied from 2 to 9. The stimuli were presented in the Kannada language, and the training was provided through the laptop via speakers set at a comfortable loudness level. Before initiating the training, the baseline of the above-mentioned tasks for all the participants were obtained. For each participant the difficulty level of the training was decided based on their baseline performance. All the participants listened carefully to the digits and repeated them verbally in the required order based on their task.

In the Forward Span task, participants repeated all the digits they heard in the same order as quickly as possible. In the Backward Span task, they repeated the digits heard in reverse order. The Running Span task used digits from 1 to 9, and participants recalled the last n digits of a set of numbers as quickly as possible, where n varied from 2 to 9. In the Ascending Span task, participants repeated the digits in ascending order, while in the Descending Span task, they repeated the digits in descending order. In the Math Span test, participants memorized and recalled sequences of digits ranging from 2 to 6 while solving simple arithmetic operations.

The difficulty level of each task was varied by increasing the number of digits from 2 to 9 based on their performance. To progress to the next level, participants had to achieve an accuracy score of 80%. If they did not meet this requirement, they continued training with the same task until they achieved a score of 80%. All participants' data were included in the analysis since they completed 15 training sessions. Assessments were conducted at three time points - baseline, post-training (after 15 days of training), and follow-up (after one month of post training assessment).

Control group

The control group did not receive any intervention and was observed for the same duration as the experimental group. They remained passive throughout the study as they were not assigned any activity, unlike the training provided to the experimental group. Assessments were conducted for the control group also at three-time points – baseline, post observation (after 15 days of baseline assessment, follow-up observation (after 1 month of post observation assessment).

Auditory resolution measures

The study used Angel Sound^{TM}, a free PC-based interactive listening rehabilitation program developed by Tiger Speech Technology, to measure individuals' auditory resolution measures. The auditory resolution measure refers to an individual's ability to detect the smallest variations in a given stimulus, such as variations in frequency (Hz) and time (dB or ms). This measure aimed to assess the listeners' ability to distinguish subtle acoustic differences in spectral, temporal, and amplitude domains, which form the foundation for complex speech perception. The program uses a two-down/one-up adaptive method presented in a three-alternative-forced-choice paradigm. The adaptive run stops after 30 trials, with at least four reversals. The threshold is calculated as the average response across the reversals, achieving a 71% accuracy convergence.

The Frequency Discrimination (FD) test was conducted using three pure tones lasting 300 ms each, with a rise and fall time of 10 ms. These tones were separated by an interstimulus interval (ISI) of 500 ms. Two of the three tones had a frequency of 1000 Hz, considered the standard frequency, while one had a different frequency. The initial frequency difference between the standard and different frequencies was 25.6 Hz. The software adjusted the step size based on participant responses. It gradually increased the step size for incorrect responses and decreased it for correct responses.

The temporal modulation (MD) task involved three carrier stimuli consisting of broadband noise (BBN). Each stimulus lasted for 350 ms, and there was an inter-stimulus interval (ISI) of 500 ms. Participants were instructed to identify the stimulus that was different (modulated) from the other two stimuli. One of the three intervals was modulated at 10 Hz, whereas the other had no modulation. The modulation depth of the stimulus ranged from no modulation (No) to a minimum of 1% modulation depth (-40 dB) and a maximum of 100% modulation (0 dB). The software adopts a 1 dB step size for stimulus presentation.

The Gap Detection Task (GDT) consisted of three bursts of Broadband Noise (BBN) sounds, each lasting 250 ms, with a 500-ms pause between them. One of the three intervals contained a silent gap in the middle of the noise bursts, while the other two contained only noise bursts. The duration of the silent gap varied from trial to trial based on the participant's response. The software adopts a step size of 1 ms (0 to 10 ms), 2 ms (10 to 20 ms), 5 ms (20 to 50 ms), 10 ms (50 to 100 ms), 20 ms (100 to 200 ms) and 50 ms (200 to 500 ms) respectively between the presentations.

The stimuli used in the test were played through a MAICO MA53 clinical audiometer calibrated beforehand via speakers in a quiet environment. The intensity of the sounds was adjusted to each participant's most comfortable level (MCL).

Cognitive measures

The study assessed the cognitive abilities of the participants using the Neurocognitive Toolbox (ICMR-NCTB), which The Indian Council of Medical Research developed. For this study, two tests from the toolbox were considered: the Trail Making Test (TMT) and the Verbal Learning Test. The TMT (Black & White) evaluates a person's executive function through two segments: TMT Part A and TMT Part B. In TMT Part A, the participant must draw a line sequentially connecting 25 numbered circles on a page as quickly as possible. In TMT Part B, the participant must connect circles while alternating between numbers and circles in two colors, black and white. The TMT Part B is more challenging and takes longer time than TMT Part A. Both parts are timed, and the time taken to complete the task is recorded as the response. The difference in time to complete the task between Part A and Part B estimates the person's executive function index (Part B-A).

The Verbal Learning Test measures the participants' episodic memory and records their immediate and delayed recall and recognition memory. The test presents a set of ten unrelated words orally to the participants over three trials. After each trial, the participants are asked to recall the words immediately in any order, and their responses are recorded. After 20 minutes, the participants are asked to recall the set of 10 words and identify the 10 words from a list of similar words. A diagram of participant flow is shown in Figure 1.

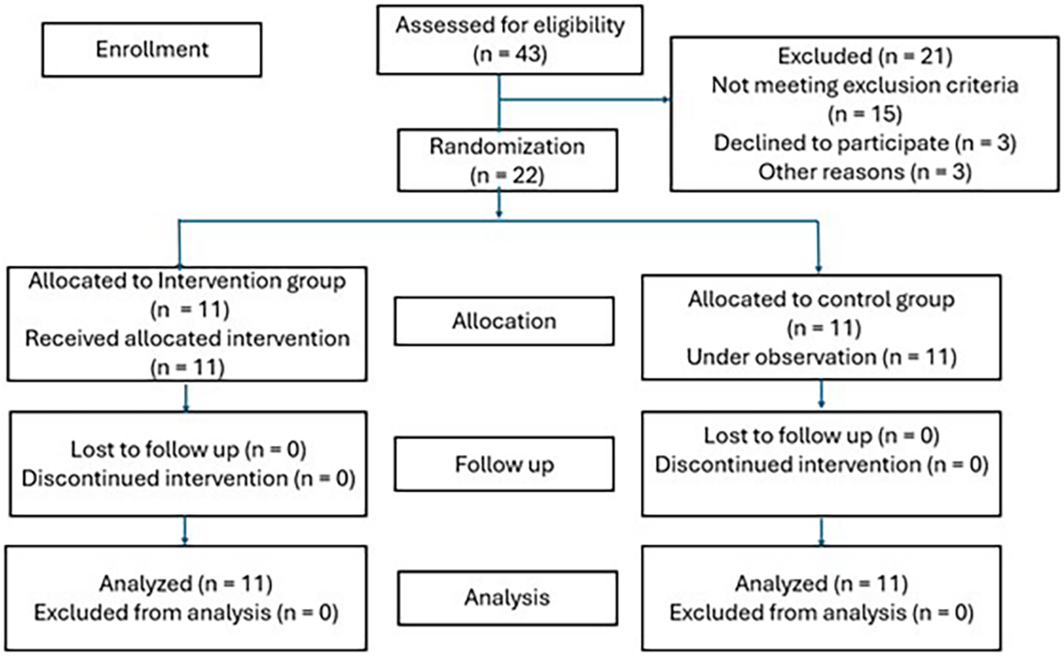

Figure 1. Participant flow diagram.

Data analysis

Linear mixed model analyses were performed on the scores obtained during pre-, post, and follow-up performances. The dependent variables were the responses from Trail Making Tests, auditory resolution tasks, and delayed recall. We added fixed effects of cognitive assessment across time and group and the possible interaction between group and time. We used Jamovi software (version 2.3.28) to compute statistical data.

Results

During the study period, out of 43 participants who were assessed for eligibility, 22 of them were enrolled in the study. All 11 participants in the experimental group completed the training, and their data was included in the analysis. The statistical analysis indicated no significant differences in baseline assessments between the control and experimental groups for most outcome measures, except for TMT Part B-A (Table 1). Table 2 presents the mean and SD values for auditory resolution tasks, TMT, and DR outcome measures. The study found that AbCT was effective in three outcome measures: MD, TMT-B, and TMT B-A. The MD task showed a significant main effect of group versus time interaction (p=0.038). However, no significant main effect was observed for either group (p=0.497) or time (p=0.186). No significant main effect of time, group, or interaction between time and group was found for the FD and GDT tasks.

Table 1. Baseline demographic information.

Variables	Experimental group (n=11) Mean (SD)	Control group (n=11) Mean (SD)	p-value
Age (years)	70.4 (5.71)	68.0 (7.18)	0.403
MoCA	22.2 (1.99)	21.5 (2.16)	0.481
FD	129.36 (119.20)	56.45 (41.45)	0.070
MD	-13.75 (2.32)	-14.02 (3.83)	0.847
TGD	22.71 (42.48)	9.65 (3.88)	0.322
TMT Part A	98.27 (46.29)	99.27 (29.15)	0.952
TMT Part B	289.73 (120.36)	217.73 (47.82)	0.080
TMT Part B-A	191.45 (80.71)	118.45 (33.09)	0.012*
DR	4.55 (3.45)	5.55 (2.30)	0.433

*Level of Significance (p<0.05).

Table 2. **Statistical results from linear mixed model along with Mean (standard deviation) values for auditory and cognitive measures of both the groups.**

	Experimental Group			Control group				
	Baseline	Post training	Follow-up	Baseline	Post training	Follow-up		
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	F	P value
FD	129.36(119.20)	105.95 (82.24)	67.25 (74.02)	56.45 (41.45)	53.97 (47.09)	67.76 (53.96)	2.79	0.096
MD[bc]	-13.75 (2.32)	-13.15 (4.61)	-15.77 (1.71)	-14.02 (3.83)	-16.13 (2.40)	-14.76 (3.55)	3.58	0.038
TGD	22.71 (42.48)	10.29 (6.11)	7.15 (2.23)	9.65 (3.88)	8.20 (3.45)	8.00 (3.80)	0.943	0.346
TMT Part A	98.27 (46.29)	93.00 (35.13)	76.45 (27.58)	99.27 (29.15)	87.64 (37.39)	95.36 (45.93)	1.700	0.196
TMT Part B[ac]	289.73(120.36)	225.36 (82.36)	221.91 (89.53)	217.73 (47.82)	209.18 (84.46)	219.00 (84.80)	4.161	0.023
TMT B-A[ac]	191.45 (80.71)	132.36 (56.36)	145.45 (64.85)	118.45 (33.09)	121.55 (51.30)	123.64 (60.34)	4.20	0.023
DR	4.55 (3.45)	5.45 (3.70)	6.91 (2.77)	5.55 (2.30)	6.36 (2.58)	7.27 (2.49)	0.562	0.575

F – F valuep – p value (Level of Significance <0.05).
[a]Significant between baseline and post-training.
[b]Significant between post-training and follow-up.
[c]Significant between baseline and follow-up.

For the TMT-A task, there were no significant differences in time (p=0.164), group (p=0.733), and the interaction between group and time (p=0.196). However, significant main effects of time and group versus time interaction were observed in Part B and Part B-A, respectively, while the group effect was insignificant. There was a significant difference in the delayed recall tasks over time (p<0.001), but not between groups (p=0.525) or group versus time (p=0.575).

Post hoc analysis revealed a significant score difference between baseline-follow-up and post-follow-up in the Modulation Detection task. Furthermore, TMT-B and TMT B-A had statistically significant differences (p=0.023) during the TMT in the baseline-post and baseline-follow-up conditions.

Discussion

This study aimed to investigate the benefits of AbCT in improving auditory processing and cognitive functions among older adults with mild cognitive impairment. The results revealed that AbCT positively impacted MD function, but no significant improvements were observed in FD and GDT. Similarly, TMT-B (executive function) showed significant differences compared to TMT-A and DR.

The positive impact of AbCT can be explained by two mechanisms involved in auditory processing. The first mechanism is the neurocognitive mechanism of acoustic signals, which discriminates and recognizes specific functions. The second mechanism is the attentional process, involving phenomena such as attention and memory.[23] Anderson et al. (2013) conducted a study to evaluate the effect of auditory training with six modules designed to increase the speed and accuracy of auditory processing cognitive training on the temporal precision of subcortical speech processing in noise using frequency following response (FFR).[17] They observed that the trained group exhibited faster neural timing and experienced improvements in memory, processing speed, and speech-in-noise perception compared to the control group. Song et al. (2012) investigated training-related malleability using a program that included cognitive based listening exercises to enhance speech-in-noise perception.[28] The trained individuals showed significant improvements in speech-in-noise perception, sustained even after six months of training. The subcortical responses in noise showed enhancements in the encoding of pitch-related cues, particularly for the time-varying portion of the syllable most susceptible to perceptual disruption. Similarly, Carcagno and Plack (2011) observed that the robustness of FFR neural phase locking to the sound envelope increased significantly more in trained individuals (pitch contour training) than in the control group.[29] These studies support the neurocognitive process and suggest that auditory cognitive training, or AbCT, can improve auditory processing.

Attentional processes and working memory are crucial in speech perception, especially in the presence of background noise. A study by Wong et al. (2010) found that activity in the prefrontal cortex and regions associated with memory and attention in speech perception in noisy environments increased, indicating that cognitive compensation may play a crucial role in aiding hearing in noisy environments and that the recruitment of general cognitive areas accompanies declines in sensory processing.[30] Similarly, O'Brien et al. (2017) provided auditory cognitive training (Brain fitness) to healthy older adults and observed that a P3b event-related potentials amplitude, latency, and P1-N1-P2 complex significantly improved post-training. However, no advantage was found in auditory perceptual processing.[31] Studies have shown that P3b originates from temporal-parietal activity associated with attention and appears related to subsequent memory processing.[32] Therefore, our study emphasized that AbCT could improve the efficiency of attention allocation and working memory, which might explain the training-related changes in the auditory processing and neurocognitive processes.

The differences in performance between the GDT and TMTF tests may be due to the sensitivity and reliability of the training and testing methods. A study by Yusof et al. (2019) investigated the impact of auditory-cognitive training on older adults with normal cognitive function and neurocognitive impairment.[20] They found that there was an improvement in some auditory measures such as HINT (quiet), GIN, PPST (humming), and DDT but not in HINT (Composite) and PPST (verbal) for both normal cognitive (NC) and neurocognitive impairment (NCI) groups. Additionally, they observed that the NC group showed more significant improvements than the NCI group, suggesting a higher potential for learning among NC participants. Furthermore, Shen (2014) reported no correlation between GDT and TMTF, and that age and hearing status had no impact on the tests. However, TMTF sensitivity improved as hearing thresholds decreased and worsened with age.[33]

The other finding of our study revealed that the AbCT training positively impacted central executive function and attention, as indicated by a significant improvement in TMT-B and TMT B-A, while TMT-A and DR remained unaffected. This suggests that the training primarily influenced cognitive abilities related to attention and executive function rather than psychomotor skills or working memory. This observation agrees with the study by Kawata et al. (2022). They compared four groups - an auditory cognitive training group, an auditory training group, a cognitive training group, and a control group. The results showed that the auditory cognitive training group demonstrated more significant changes in regional gray matter volume in several brain regions than the other groups. The auditory training group significantly improved auditory measures and increased regional gray matter volume and functional connectivity (FC) in the left temporal pole.[22] These observations suggest there exists a functional connectivity between the auditory and cognitive processes. Therefore, auditory and cognitive training can improve cognitive and auditory skills in healthy older adults. However, they used a pure tone audiometer as an outcome measure that was less influenced by cognitive and auditory training. A study by Ruscheweyh et al. (2013) reported that executive function is related to regional gray matter volume, also a biomarker, in healthy older individuals.[34,35] These studies justify the improvement in executive function. Given the significant differences observed at baseline for TMT Part B-A, post training significance should be interpreted cautiously before generalizing. No significant difference in digit recall could be attributed to the persistence of benefits for speed of processing/auditory processing but not for memory, which is consistent with the findings of Borella et al. (2010), who showed that older adults maintained training enhancements for fluid intelligence and speed of processing but not for memory.[36]

The current study results evaluated the potential of AbCT on the auditory and cognitive skills of older adults with MCI. However, these findings may not be generalized to a wider population due to several concerns. First, the relatively smaller sample size and the absence of electrophysiological tests, which are considered the highest level of evidence for assessing training-related benefits. Second, the characteristics of the participants involved in the study, where recruitment was based on MoCA screening rather than clinical diagnosis of MCI, may have influenced the results. This is mainly due to challenges in obtaining consent from the participants to undergo detailed cognitive and audiological assessment due to practical issues, less motivation, and family consent. Additionally, the number and duration of the training sessions were determined based on a literature search. An interventional study recommended an optimal dose of 12 to 14 sessions for cognitive training and 15 to 20 sessions for multidomain training. Variations in the individual characteristics of the participants were also observed in the study, which directly impacted the optimal dose and dose-response functions.[37]

The secondary concern is that the heterogeneity of the MCI population makes it challenging to apply the findings broadly. Though all the participants were recruited based on the cut off score of MCI, their performance on the auditory, cognitive and baseline assessment before training were highly variable. Participants in this study performed slightly poorer in digit span tasks (forward and backward) when compared to a normative data obtained from older adults with MCI.[38] Including an active control group in this study would have eliminated the possibility of a placebo effect in the experimental group. Additionally, various factors, such as participant motivation and health condition on the day of assessment, could have influenced their performance. Furthermore, the literature supports the absence of evidence indicating differences between the active and passive control groups in cognitive interventions.[39] We also observed significant variability in the baseline data of the experimental and control groups, which we tried addressing using linear mixed models for statistical analysis, accounting for unbalanced data. As this was a preliminary study, future randomized controlled trials (RCTs) must consider these variations and address these limitations.

Conclusion

This current preliminary study suggests that AbCT seems to restore age-related deficits in temporal processing in the brain, promoting better cognitive and perceptual skills, particularly in older adults with MCI. The results also suggest that auditory temporal skills could be adaptable and can be a favorable prognostic indicator. However, further research in this area is warranted with a large sample size to determine whether such auditory cognitive training can change auditory and cognitive functions.

Ethics and consent

This study protocol was reviewed and approved by the Institutional Ethics Committee, Kasturba Hospital, Manipal (IEC 704/2017) on 15.11.2017, and the Clinical Trials Registry of India (CTRI/2019/01/017073). Written informed consent was obtained from all the participants who participated in this study.

Data availability

Underlying data

Name of the repository: Open Science Framework

Project Title: Influence of Auditory-Based Cognitive Training on Auditory Resolution, Executive function, and Working Memory Skills in individuals with Mild Cognitive Impairment – A Preliminary study, DOI: 10.17605/OSF.IO/3J67R.[40]

This project contains the following underlying data:

- Data for repository.xlsx
- Clinical Trial Protocol.pdf

Extended data

Name of the repository: Open Science Framework

Project Title: Influence of Auditory-Based Cognitive Training on Auditory Resolution, Executive function, and Working Memory Skills in individuals with Mild Cognitive Impairment – A Preliminary study, DOI: 10.17605/OSF.IO/3J67R.[40]

This project contains the following underlying data:

- CONSORT 2010 Checklist & Flowchart.pdf

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Open Peer Review

Current Peer Review Status: ? ✔ ? ?

Version 2

Reviewer Report 07 April 2025

https://doi.org/10.5256/f1000research.176423.r370402

?

Dr Pinki Singh
NSCB Medical college, Jabalpur, India

In this study, impact of auditory cognitive training has been studied for the rehabilitation of healthy and aging population with MCI in terms of facilitating auditory processing skills & cognitive abilities.
It has been observed that author has incorporated the changes suggested by previous reviewers.

Introduction:
- Well written but as per the recent researches it has been found that MCI coexist with ARHL, so study suggesting the significance of cognitive training via auditory modality helps in managing MCI could have been added.

Methods:

Randomization & Blinding- Three assessment (pre, post & follow up) timings have been specified after review but it is required to mention the criteria's of audiologist & SLP like,-1. fluency in specific language which will be required for instruction, 2. brief training was provided to them to conduct recommended tests , 3. About minimum years of clinical experience.

Participant group- - how 15 sessions were scheduled, was it scheduled daily, alternate or some other pattern of interval...
- Screening checklist- are authors talking about MoCA OR some other checklist? Found difficult to interpret.
- Training- was it provided at home to every participants? For every sessions? By primary investigators? If not then please specify the details. It is difficult for primary investigators to observe 11+11 participants individually for 15 days at participant's home situation.
- Items: Items for the following tasks e.g. forward span, backward span, running span, ascending & descending span & math span tasks should be attached in appendix for better comprehensibility.
- Training to participants were provided before performing the tasks? Was there any practice trial/items for the respective tasks?
- Difficulty level has been mentioned throughout i.e. participant's difficulties level was increased but nowhere difficulties level has been specified. E.g. difficulty level 1.: 3 digits stimulus was given/1-2 repetition of digits were done etc. Difficulty level 3: 5 digits tasks

were given , no repetition of tasks etc. has to be mentioned otherwise this study could not be generalized. It is required because as it has been stated “to progress to the next level, participant had to achieve an accuracy score of 80%......”
- During the tasks, participants were provided with paper & pen/pencil or only mental task was allowed.
- Was there any sequence of tasks presentation to avoid any familiarity or adaptation effects?

Results:
Above mentioned changes could be helpful for result section for better comprehensibility in terms of sequence of presentation of tasks and difficulties level.
In table 1: In footnote, abbreviation’s extended form should be mentioned for “column A Variables”
Discussion: it is well written, future directions could be added. It will be helpful for other researchers as well.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cognitive disorders, Neuro Speech & Language Disorders

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 02 April 2025

https://doi.org/10.5256/f1000research.176423.r370406

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Sangamanatha Ankmnal Veeranna

College of Nursing and Health Professions, School of Speech and Hearing Sciences, J.B. George Building, University of Southern Mississippi, Hattiesburg, Mississippi, USA

Abbreviations are often used in manuscripts to simplify the presentation of frequently repeated terms. However, it is important to use them consistently to prevent confusion. To enhance clarity, abbreviations should be spelled out the first time they appear, followed by the abbreviation in parentheses.
Throughout the manuscript, there is a lack of consistency in using abbreviations. Several terms have been abbreviated, but not always in a consistent manner. For example, the abbreviation "MD" is used for temporal modulation tasks, but this term is not clearly defined or consistently applied throughout the manuscript.
In the discussion, the abbreviation "TMTF" is introduced without any prior explanation, making it unclear to the reader what it represents. Additionally, the abbreviation "DR" is used multiple times throughout the manuscript, but its meaning is not explained. The abbreviation "TGD" is also mentioned in the result table (Table 2), but its definition is not provided, leaving the reader confused about its meaning. I assume that it is Temporal Gap Detection. Moreover, the abbreviation "MCI" is used inconsistently alongside the full term "Mild Cognitive Impairment."

To improve readability and clarity, the authors should consider removing most of these abbreviations, especially those that are not commonly used or that could easily be understood without abbreviation. The manuscript would benefit from more careful attention to consistent terminology, with each abbreviation clearly defined upon its first use.

Introduction:
Paragraph 3 in the introduction: The authors need to maintain consistency when describing the study findings. For instance, the explanation of Smith's (2009) study lacks clarity, while other studies are described in detail. This paragraph should be rewritten to improve its clarity and flow, providing more concise and coherent information. Additionally, the findings from Kawata et al. are not clearly presented, which further detracts from the overall understanding of the study.
Last Paragraph in the introduction: The authors mention that there are numerous studies yet only cite three. This statement should be rephrased to better reflect the intended message. The paragraph seems to emphasize the need for study but lacks strength. The authors should revise this section to strengthen the rationale behind the research. It would be helpful to clearly explain why this study is being conducted. Moreover, much of the relevant literature is discussed in the manuscript's discussion section, rather than being appropriately included in the introduction. The authors should ensure that key studies are introduced earlier in the manuscript to set a stronger foundation for the research.

Method:
There is no clear explanation of how individuals with Mild Cognitive Impairment were identified and diagnosed. Was the diagnosis solely based on the Montreal Cognitive Assessment? If so, how was the Montreal Cognitive Assessment administered? Was it translated into Kannada for the

participants? More information on the diagnostic criteria and procedures would help clarify this point.
The authors calculated the hearing threshold average for all frequencies, but typically, averages are calculated for either three (0.5, 1, and 2 kHz) or four frequencies (0.5, 1, 2, and 4 kHz). It would be helpful for the authors to justify their decision to use all frequencies in this study, as it deviates from standard practice.
The "Auditory Resolution measures" used by the authors lack proper justification. Why were these specific measures selected, and not others? Are these measures particularly relevant to auditory perception? Do they have a greater likelihood of showing changes with cognitive training compared to other measures? Additionally, it would be useful to know if previous studies have used similar auditory resolution measures and whether they have been effective in assessing auditory perception in populations with cognitive impairment.
Regarding the psychoacoustic testing, were participants given any training prior to the tests? This detail is crucial to understand whether the participants were familiar with the testing procedures and to assess the validity of the results.
For the frequency discrimination task, what was the step size used?
Furthermore, were stimuli presented in a free-field setup? There is no information provided on how the calibration was performed, which is a critical aspect of ensuring the reliability and replicability of the study. Clear calibration procedures should be outlined to allow other researchers to replicate this study accurately. How was the most comfortable level determined?
Providing more information on these aspects would significantly strengthen the manuscript and enhance the clarity and transparency of the methodology.

Results:
The statistical analysis is difficult to follow. It is unclear how the linear mixed model was conducted. The authors should explain the specific factors and covariates included in the model, as well as any interactions considered. Furthermore, there is no justification for the sample size, which is important for assessing the statistical power of the analysis. Providing more detailed information about the statistical methods and sample size would improve the clarity of the results.

Discussion:
The discussion section needs to be reorganized for better clarity and flow. Currently, it is difficult to follow, and the focus is more on previous research findings than on the implications of the current study's findings. To improve readability, the section would benefit from subsections that guide the reader through the key points.
While referencing past studies is essential for providing context, the primary focus should be on the current study's findings and implications. The authors should emphasize how their results contribute to the existing body of knowledge, and how they support or challenge previous research. Addressing any discrepancies or gaps in the literature will offer a clearer understanding of the study's significance and enhance its relevance to the field.
The authors will provide a more coherent discussion by shifting the focus to the study's specific findings and their broader implications.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Psychophysics

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 28 February 2025

https://doi.org/10.5256/f1000research.176423.r368254

Sandeep Maruthy
Department of Audiology, All India Institute of Speech and Hearing, Mysuru, Karnataka, India

The authors have effectively addressed all the concerns I raised regarding version 1. I have noticed a significant improvement in version 2, with enhanced clarity and a more comprehensive approach. I recommend version 2 for acceptance.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Audiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 05 February 2025

https://doi.org/10.5256/f1000research.176423.r358929

?

Karen Banai
University of Haifa, Haifa, Haifa District, Israel

Introduction: As detailed in the original review, the reason(s) for attempting auditory training are not clear. I suggested some relevant references in the original review

Data analysis: The statistical model is still not described in full. What were the random effect(s)?

Results:
1) It is still not clear what the F values in Table 2 stand for (full model? interaction? one of the main effects)?
2)Please provide full statistical details about the time x group interactions for all outcome measures since this is the only indication of effectiveness. If those are the F values reported in Table 2, please explain.

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Partly

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cognitive hearing science; perceptual learning of speech.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Version 1

Reviewer Report 24 December 2024

https://doi.org/10.5256/f1000research.167573.r332064

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Sandeep Maruthy
Department of Audiology, All India Institute of Speech and Hearing, Mysuru, Karnataka, India

Introduction
The introduction is well-written, with the authors providing a strong justification for the study by critically evaluating existing research in the field.
Method
Rephrase: to 'The participants were randomly assigned to either the experimental group or the control group using a simple randomization method involving the drawing of chits.'

Smriti Shravan Software Version 2 was developed by (Kumar & Maruthy, 2013). Correct it.

post-training (after 15 days): after 15 days of what?
follow-up (after one month): after 1 month of what?

The authors' decision to use 8 sessions as the criterion for considering data for analysis should be justified.

The time points at which the control group was tested should be defined

The control group did not receive any training. In such a case how do you judge that auditory-cognitive training made the difference in the performance. It could be mere training of any form. Include explanation for this.

Give an operational definition of '
Auditory resolution measures'
'ms' is a standard abbreviation for milliseconds. Consider using the abbreviation.
The authors state that 'The step size was adjusted according to individual subjects.' - how was it adjusted? please provide more details.

In the sentence 'The task of detecting temporal modulation (MD) involved three carrier stimuli of broadband noise (BBN), each lasting 350 milliseconds, with an inter-stimulus interval (ISI) of 500 milliseconds.', it is not clear as to what is the task of the subject. Please rephrase.

Results
Figure 1 can be moved to the end of Method section.
It is appreciated that the subjects were randomly assigned to the control and experimental groups. However, it is recommended to statistically confirm that there is no significant difference between the two groups in the baseline assessment.

It is stated that "All 22 participants completed the training or observation," which is incorrect. Only 11 participants underwent the training.

Discussion
The discussion is well-written; however, using this research design makes it challenging for the authors to attribute the observed improvements solely to auditory cognitive training. This limitation will remain a caveat of the study.

General comment: The manuscript would benefit from a more thorough proofreading to enhance its readability.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Audiology

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 01 Jan 2025

Gopee Krishnan

Revision 1:
Reviewer Comments

1.Method
Rephrase: to 'The participants were randomly assigned to either the experimental group or the control group using a simple randomization method involving the drawing of chits.'
Corrections: Comments accepted and modified
Location: Methods section, Randomization and Blinding paragraph

2.Smriti Shravan Software Version 2 was developed by (Kumar & Maruthy, 2013). Correct it.
Corrections: Comments accepted and incorporated
Location: Methods section, Experimental group 1st paragraph

3.The authors' decision to use 8 sessions as the criterion for considering data for analysis should be justified.
Clarification: It was the minimum criterion set earlier for inclusion of data for analysis and to minimize loss of data due to attrition. All participants completed fifteen training sessions. Therefore, the phrase "8 sessions as the criterion for considering data for analysis" can be removed.
Location: Methods section, Experimental group 3rd paragraph

4.post-training (after 15 days): after 15 days of what?
follow-up (after one month): after 1 month of what?
Corrections: Comments accepted and modified as [post-training (after 15 days of training) Follow-up (after one month of post-training assessment)]
Location: Methods section, Experimental group 3rd paragraph

5.The time points at which the control group was tested should be defined
Corrections: Suggestion accepted and incorporated. Assessments were conducted for the control group at three-time points: baseline, post-observation (15 days after the baseline assessment), and follow-up observation (one month after the post-observation assessment).

Location: Methods section, Control group paragraph

6.Give an operational definition of 'Auditory resolution measures'
Corrections: The auditory resolution measure refers to an individual's ability to detect the smallest variations in a given stimulus, such as variations in frequency (Hz) and time (dB or ms).
Location: Methods section, Auditory resolution measures paragraph

7.'ms' is a standard abbreviation for milliseconds. Consider using the abbreviation.
Corrections: Comments accepted and modified
Location: Auditory resolution measures, 2nd paragraph

8.The authors state that 'The step size was adjusted according to individual subjects.' - how was it adjusted? please provide more details.
Corrections: The software adjusted the step size based on participant responses. It gradually increased the step size for incorrect responses and decreased it for correct responses.
Location: Auditory resolution measures, 2nd paragraph

9.In the sentence 'The task of detecting temporal modulation (MD) involved three carrier stimuli of broadband noise (BBN), each lasting 350 milliseconds, with an inter-stimulus interval (ISI) of 500 milliseconds.', it is not clear as to what is the task of the subject. Please rephrase.
Corrections: Suggestion accepted and modified. “The temporal modulation task involved three carrier stimuli consisting of broadband noise (BBN). Each stimulus lasted for 350 milliseconds, and there was an inter-stimulus interval (ISI) of 500 milliseconds. Participants were instructed to identify the stimulus that was different (modulated) from the other two stimuli”.
Location: Auditory resolution measures, 3rd paragraph

10.Results
Figure 1 can be moved to the end of Method section.
Corrections: Accepted and moved.
Location: Methods section

11.It is stated that "All 22 participants completed the training or observation," which is incorrect. Only 11 participants underwent the training.
Corrections: All 11 participants in the experimental group completed the training, and their data was included in the analysis.
Location: Results section, 1st paragraph

12.It is appreciated that the subjects were randomly assigned to the control and experimental groups. However, it is recommended to statistically confirm that there is no significant difference between the two groups in the baseline assessment.
Corrections: Suggestion accepted.
A table for Baseline Demographic Information is included below. The explanation related to

the table is included in the text.
"The statistical analysis indicated no significant differences in baseline assessments between the control and experimental groups for most outcome measures, except for TMT Part B-A".
Location: Results section, 1st paragraph

Given the significant differences observed at baseline for TMT Part B-A, post-training significance should be interpreted cautiously before generalizing.
Location: Discussion section, 5th paragraph

13.Discussion
The discussion is well-written; however, using this research design makes it challenging for the authors to attribute the observed improvements solely to auditory cognitive training. This limitation will remain a caveat of the study.
Corrections: Thank you for the suggestion. This limitation is included in the revised manuscript.

14.The control group did not receive any training. In such a case how do you judge that auditory-cognitive training made the difference in the performance. It could be mere training of any form. Include explanation for this.
Corrections: We agree that the difference in performance of the control group needs explanation. Including an active control group in this study would have eliminated the possibility of a placebo effect in the experimental group. Additionally, various factors, such as participant motivation and health condition on the day of assessment, could have influenced their performance. Furthermore, the literature supports the absence of evidence indicating differences between the active and passive control groups in cognitive interventions (Au et al., 2024).
Location: Discussion section, 7th paragraph

General comment: The manuscript would benefit from a more thorough proofreading to enhance its readability.

Table 1 Baseline Demographic Information
Variables
Experimental group
(n=11) Mean (SD)
Control group
(n=11) Mean (SD)
***p*-value**

Age (years)
EG: 70.4 (5.71)
CG: 68.0 (7.18)
p-value: 0.403

MoCA
EG: 22.2 (1.99)
CG: 21.5 (2.16)
p-value: 0.481

FD
EG:129.36 (119.20)
CG: 56.45 (41.45)
p-value: 0.070

MD
EG: -13.75 (2.32)
CG: -14.02 (3.83)
p-value: 0.847

TGD
EG: 22.71 (42.48)
CG: 9.65 (3.88)
p-value: 0.322

TMT Part A
EG: 98.27 (46.29)
CG: 99.27 (29.15)
p-value: 0.952

TMT Part B
EG: 289.73 (120.36)
CG: 217.73 (47.82)
p-value: 0.080

TMT Part B-A
EG: 191.45 (80.71)
CG: 118.45 (33.09)
p-value: 0.012*

DR
EG: 4.55 (3.45)
CG: 5.55 (2.30)
p-value: 0.433

*Level of Significance (p<0.05)

Competing Interests: The authors declare that they have no conflict of interest.

Reviewer Report 25 October 2024

https://doi.org/10.5256/f1000research.167573.r329238

Karen Banai
University of Haifa, Haifa, Haifa District, Israel

In this preliminary study, the potential contribution of auditory-cognitive training to auditory processing and to performance on two cognitive tasks (recall and trail making) was studied using a RCT. Participants were 22 older adults with MCI randomized to an intervention and a control group. The intervention group participated in 15 1-hour training sessions focused on auditory span tasks using digits. All participants were tested on the auditory and cognitive outcome measures at three time points: pre- post- and follow-up. Some improvements in the outcome measures were observed over time , but it is unclear whether they can be consistently attributed to training.

The study is generally well designed, and used tester-blinding to minimize researcher-related bias. Note that my review did not cover the inclusion criteria and the diagnosis of MCI. Comments on specific aspects of the study are listed below. These should be addressed to make the study sounder.

General
1) Although are-related hearing loss and MCI often co-occur, no model of the potential causal associations is presented. Therefore, it is not clear why auditory memory training should have influenced auditory processing as assessed by the gap, frequency and modulation tasks.
2) On a related note, one of the motivations for this study was that only few previous studies delivered cognitive training via the auditory modality to people with MCI. However, if auditory processing is one of the contributing factors to the cognitive profile of people with MCI, why is it desirable to deliver training via the auditory modality?
3) One recent systematic review on the effects of cognitive training in MCI is cited, but others are not (e.g., Kudlicka, A., Martyr, A., Bahar-Fuchs, A., Sabates, J., Woods, B., & Clare, L. (2023 [Ref - 1]). Cognitive rehabilitation for people with mild to moderate dementia. The Cochrane database of systematic reviews, 6(6), CD013388. https://doi.org/10.1002/14651858.CD013388.pub2).

Methods
1) Age, hearing and MOCA are not reported separately for each group, making it hard to determine whether the randomization yielded well matched groups. This is a concern given some of the data reported in Table 1 which would suggest that the two groups may not have been well matched on the outcome measures at the onset of the study.
2) It is not clear whether the same versions of the cognitive outcome measures were used across the pre- post- and follow-up tests or if parallel forms were used.
3) Whereas the title and the abstract of the paper suggest that auditory working memory was targeted as an outcome measure, a verbal learning test is described in the methods, which has a working memory component, but may not be as clear index of working memory as other tests.
4) Although testers during the pre- post- and follow-up tests were blind to whether participants received training or not, the use of an untrained group that received no alternative or sham

intervention would make it hard to determine whether outcomes are a byproduct of the specific intervention or of participants having received any sort of intervention (see Jacoby, N., & Ahissar, M. (2013 [Ref - 2]). What does it take to show that a cognitive training procedure is useful? A critical evaluation. *Progress in brain research*, *207*, 121–140. https://doi.org/10.1016/B978-0-444-63327-9.00004-7).
5) How were the training session distributed? Daily? Weekly? Some other schedule?
6) What was the schedule for the pre- post- and follow-up tests? Did the two groups follow the same schedule?

Data presentation and analysis
1) The statistical model used is not fully reported.
(a) What were the random effects?
(b) What kind of follow-up or planned comparisons were used to obtain the effects between test times that are reported with the a,b,c indices in Table 1?
(c) It is not clear whether the F-values in Table 1 describe group, time or interaction effects.
(d) Table 1 suggests that the significance in modulation detection may have been driven by pre- to post- changes in the control group. In the absence of a more detailed description of the statistical outcomes and tests, it is hard to justify the discussion statement that “The results revealed that AbCT positively impacted MD function...”.

References
1. Kudlicka A, Martyr A, Bahar-Fuchs A, Sabates J, et al.: Cognitive rehabilitation for people with mild to moderate dementia.*Cochrane Database Syst Rev*. 2023; **6** (6): CD013388 PubMed Abstract | Publisher Full Text
2. Jacoby N, Ahissar M: What does it take to show that a cognitive training procedure is useful? A critical evaluation.*Prog Brain Res*. 2013; **207**: 121-40 PubMed Abstract | Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Cognitive hearing science; perceptual learning of speech.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.