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Evaluation of Home-Delivered Live-Voice Auditory Training with Communication Partners for Adult Hearing Aid Users: A Randomised Controlled Trial

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ABSTRACT

Objective: To examine the benefits of home-delivered auditory training for adult hearing aid users using live-voice conversations in the presence of a single-talker distractor (experimental group) or in quiet (active-control group).

Design: Randomised controlled trial. The experimental group held conversations with their communication partner in the presence of a single-talker distractor set to a challenging level, 30 minutes/day, five days/week over four weeks. The active-control group held comparable conversations in quiet. Behavioural outcome measures of speech-in-noise perception, cognition and self-reported hearing were assessed pre- and post-training. Subjective measures of participant feedback were obtained.

Study Sample: Thirty-nine hearing aid users (32 males, 7 females, mean age=73.02 years, SD=4.71 years) and their communication partners.

Results: The experimental group significantly improved and outperformed active-controls for words-in-noise perception. Both groups achieved improvements in self-reported hearing difficulty while only the experimental group improved on the dual-task. Subjectively, both groups found live-voice conversations beneficial and reported increased concentration and listening skills.

Conclusions: Home-delivered live-voice auditory training with communication partners shows potential to improve outcomes for adult hearing aid users, regardless of the presence or absence of a competing speech distractor. Further research is required to assess mechanisms of benefit and distractor effects within carefully controlled experiments.

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INTRODUCTION

Hearing loss is a major public health challenge, a leading global burden of disease, and one of the greatest contributors to years lived with disability globally (Wilson et al., 2019). The most common management option for hearing loss is amplification by hearing aids, which has been shown to be clinically effective (Ferguson et al., 2017). However, levels of satisfaction are lowest for hearing aid use in noisy situations and residual disability in background noise is a commonly reported reason for hearing aid non-use (McCormack & Fortnum, 2013). These problems can make it more difficult for people with hearing loss to participate in social interactions, which may in turn lead to them becoming socially withdrawn and isolated (Heffernan et al., 2016; Shukla et al., 2020). Hearing aids (i.e., sensory management) are only one component of aural rehabilitation; others include instruction, counselling and perceptual training (Boothroyd, 2007). Auditory and cognitive training programs offer additional and supportive rehabilitation options with the aim being to overcome outstanding communication difficulties (Lawrence et al., 2018; Stropahl et al., 2020).

Auditory training has been the subject of research interest over the past few decades with the development of several early computer-based active auditory training interventions for adults (Sweetow & Henderson Sabes, 2006). Computer-based auditory training has consistently shown improvements in trained tasks (i.e., on-task learning) for a range of stimuli for adults with hearing loss and hearing aid users (Ferguson & Henshaw, 2015b; Henshaw & Ferguson, 2013; Lawrence et al., 2018; Sweetow & Palmer, 2005; Tye-Murray et al., 2016). However, for a training program to be considered effective it should also show generalised functional benefits in real-world listening (i.e., off-task learning; Ferguson & Henshaw, 2015b), and users must be willing to engage with the program sufficiently (Henshaw & Ferguson, 2013; Sweetow & Henderson Sabes, 2010). Evidence from systematic reviews for the effectiveness of these interventions for adults with hearing loss is mixed (Henshaw & Ferguson, 2013; Lawrence et al., 2018; Sweetow & Palmer, 2005), and has shown to be impacted by a myriad of factors including the training stimuli and outcome measures employed (Henshaw & Ferguson, 2014), adherence to training schedules (Chisolm et al., 2013; Sweetow & Henderson Sabes, 2010), and participant motivation and engagement (Henshaw et al., 2015). Furthermore, computer-based auditory training programs typically require the use of specialist software, which can be costly and may not be accessible for all people with hearing loss (Henshaw et al., 2012; Office for National Statistics, 2019).

Typically, auditory training has used tasks employing auditory stimuli designed to refine auditory skills (bottom-up demands), but the field is increasingly recognising the importance of cognitive skill enhancement (top-down demands) in training (Lawrence et al., 2018). Many auditory training studies for people with hearing loss include speech-in-noise perception as the primary outcome measure as improvement in communication is often the main goal for this population (Henshaw & Ferguson, 2013; Stropahl et al., 2020). However, cognitive function (e.g., working memory and executive control) has also been shown to play an important role in listening and speech comprehension, particularly for noisy or challenging listening situations and when speech is degraded (Anderson et al., 2013; Ferguson & Henshaw, 2015b). In a randomised controlled trial (RCT) of phoneme discrimination auditory training in adults with mild hearing loss, post-training improvements were demonstrated for complex cognitive tests (i.e., divided attention and working memory), whereas there were no improvements shown for simple cognitive tests (e.g., digit span; Ferguson et al., 2014). Similarly, Saunders et al. (2016) did not show any improvement on the digit span test (i.e., simple working memory) following Listening and Communication Enhancement (LACE) training, which might be expected if training is more likely to improve complex cognitive control (e.g., executive function). Indeed, when the authors examined a more cognitively demanding speech task, a significant improvement was shown for participants in the experimental group over active-controls. Sweetow and Henderson Sabes (2006) also showed that participants completing LACE training improved on measures of executive function. Cognitive training programs have also been associated with improved auditory perception particularly when auditory stimuli are included in the training paradigm (Anderson et al., 2013). While compliance with auditory training programs is generally high in the research literature (80%; Ferguson et al., 2014), within a real-world clinical population compliance with the LACE program has been shown to be lower, just 30% (Sweetow & Henderson Sabes, 2010). Motivation plays a significant role in compliance with health interventions (Vermeire et al., 2001) particularly where participants are required to use and engage with interventions over several weeks, as is often the case for auditory training programs. It has been suggested that to increase motivation, auditory training should be tailored to the communication needs of the individual (Barcroft et al., 2011). Henshaw et al. (2015) reported that participants were primarily motivated to enrol in an auditory training program by a desire to improve their listening abilities.

Most training programs use speech packages with unfamiliar voices on the assumption that improvements will carry over to familiar voices (Burk et al., 2006). Tye-Murray et al. (2016) used a different approach and instead focused on training participants to understand familiar voices. The participants in their study completed a six-week training program using the clEAR training program with speech stimuli recorded by their spouse presented in a background of speech babble. Stimuli for testing were also recorded by their spouse and participants demonstrated significant improvement on a four-alternative forced-choice test (trained task) but not on the Build-a-Sentence test (untrained task). Tye-Murray et al. (2016) also included the Client Orientated Scale of Improvement (COSI) as a self-reported outcome measure, with situations for improvement tailored to the individual; seven out of 10 participants reported improvements on the COSI. It was suggested that further studies involving frequent communication partners should be carried out using speech stimuli that would be more commonly experienced in the participant's daily life.

One legacy criticism of formal (or active) auditory training programs is that they may offer no additional benefits over and above informal listening practice, however the increased "time-on-task" and positive feedback from well-designed programs are expected to enhance learning (Boothroyd, 2007). Whilst hearing could be considered a largely passive activity, listening involves active interaction with the subject matter. Greater involvement of communication partners in rehabilitation is known to be associated with better outcomes for adults with hearing loss (Barker et al., 2017; Hickson et al., 2014; Manchaiah et al., 2012). With this in mind, we developed an ecologically valid auditory training approach that was underpinned by one of the main challenges faced by people with hearing loss, that of listening and understanding speech within competing background speech. The intervention was developed so that it could be delivered at home without the need for specialist software or IT equipment. The use of frequent communication partners in our intervention increased their contribution to the rehabilitation process of the adult with hearing loss, as well as providing a familiar and relevant voice with which to train.

The main aim of this study was to assess the effectiveness of live-voice auditory training with a communication partner for adult hearing aid users in terms of generalised (untrained or 'off-task') benefits measured by tests of (i) speech-in-noise perception, (ii) cognition, and (iii) self-reported hearing difficulties. Importantly, we also investigated whether the additional perceptual and cognitive challenge of holding those conversations in the presence of a single-talker distractor (experimental group) would result in any incremental benefits. A secondary aim was to explore participants' subjective experiences with the training program to better understand their experiences and inform future training program research and development.

MATERIALS AND METHODS

This study is reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) statement (Schulz et al., 2010). The CONSORT checklist is available in Supplementary Information 1.

Participants

Participants were recruited from a population of existing adult hearing aid users attending reassessment appointments at Wrexham Maelor Hospital Audiology Service in Betsi Cadwaladr University Health Board (BCUHB), Wales, UK. Participants were invited by letter to participate following their reassessment appointment (total n=647). Inclusion criteria were (1) aged between 65 and 85 years, (2) four-frequency average hearing thresholds across 0.5-4 kHz greater than 20 dB HL in both ears, (3) a need in their individual management plan relating to improvement in speech-in-noise perception, (4) a regular communication partner who was willing to take part in the training program, (5) fluent and comfortable conversing in English, (6) no significant self-reported memory or neurological problems and (7) no reported colour-blindness due to the need to recognise colours in one test. A total of 50 participants (38 male, 12 female) were recruited into the study between June 2015 and November 2018 following completion of their reassessment pathway to ensure that they were aided for their individual needs and preferences in line with best clinical practice. They were allocated to either the experimental (n=25) or active-control group (n=25), see Supplementary Information 2 for CONSORT flow chart.

Auditory Training

Participants in the experimental group were instructed to hold a conversation with their chosen communication partner at home in the presence of a single competing talker presented in sound field via a loudspeaker for 30 minutes, five times per week for a period of four weeks. Participants were not given specific instructions on where to position the sound source in order to allow flexibility for individual room set up. The single-talker distractor was formed from a selection of 30-minute extracts from four commercially available English language BBC audiobooks, including both male and female voices, provided on CDs. A single-talker distractor was chosen as studies have shown that the informational masking from an intelligible single-talker has a greater masking effect on performance than energetic masking from speech-shaped noise (Brungart, 2001). Participants were instructed to play the distractor at a level where it was “challenging” to hold a conversation. This was described as a level where it started to become difficult for them to understand their partner but not loud enough to be uncomfortable. The experimental group's training design aimed to train the ability to understand target speech and inhibit competing speech. Participants in the active-control group followed the same schedule of conversation with a communication partner but without the distractor and were advised to complete these conversations in quiet. Both groups completed their training sessions while wearing their hearing aid(s) in the default program. Participants were requested to complete their training in English rather than Welsh in order to increase the informational masking effect of the (English) distractor and due to limited availability of Welsh Language outcome measures. To assess training adherence, at the end of each training session participants were asked to log a spoken letter in order to demonstrate completion of the training on that day. To facilitate this within the active-control group these participants were given CDs to play during their training sessions containing 30 minutes of silence followed by the spoken letter.

Design

The study design was an RCT with equal allocation to groups. Randomisation was via a dynamic adaptive allocation algorithm (Hoare et al., 2013) with an allocation ratio of 1:1 using stratification variables of age (<75 years: ≥75 years) and sex (male:female) using the North Wales Organisation for Randomised Trials in Health online randomisation system. Participants were aware which training group they were allocated to but were not informed whether this was the experimental group or the active-control group. The researcher conducting outcome assessments was not blinded to the participants' group allocation.

The primary outcome measure was the Quick Speech in Noise test (QuickSIN; Killion et al., 2004). Based on the mean signal to noise ratio (SNR) and the reported effect size of 0.8 from Olson et al. (2013) *a priori* sample size calculation indicated that 25 participants were required in each group to give a power of 80% at 5% significance for a one-tailed test.

Study Procedure

Outcome measures were obtained at the pre-training session (T1) and four weeks later post-training (T2), with the training sessions being undertaken by participants at home in between. The training intervention was described to the participants at T1 by the lead researcher (SCL), and supporting information was provided in a training workbook. At each session, otoscopic examination was performed and a subjective listening check carried out on their hearing aid/s using stetaclips to ensure that they were functioning as expected. At T1 the participant's hearing aid "datalogging" provided the average daily hearing aid use. All outcome measures were assessed in the aided condition.

The study was approved by North Wales Research Ethics Committee (Central & East) and the Internal Review Panel at BCUHB. Written informed consent was obtained from all participants by the lead researcher at T1. Written information was offered bilingually in English and Welsh in line with Welsh Language Standards. Participants were offered travel expenses for each session and were entered into a draw to win a £25 book voucher if all training sessions were completed.

Behavioural Outcome Measures

Auditory stimuli for speech-in-noise perception and cognitive measures were delivered in a sound-attenuating audiometric booth at 70 dB HL via a free-field speaker at 1.7m azimuth with the participant wearing their hearing aid(s) on their default settings. For each of these measures, one practice list was administered that was not included in the analysis. Different test lists were presented at each visit. Visual stimuli for the dual-task and Modified Coordinate Response Measure (MCRM; Hazan et al., 2009) tests were presented using a 15.5-inch screen positioned at a comfortable reading distance for the participant. Self-report questionnaires were completed in written (paper) format by the participants during the clinic session. All outcome measures were obtained at both T1 and T2 sessions except for the post-training feedback questionnaire which was only completed at T2.

Speech-in-Noise Perception

QuickSIN (Killion et al., 2004). The test consists of 12 lists of six IEEE sentences containing five key words presented in four-talker babble. A descending paradigm established the participant's SNR loss relative to a person with normal hearing. Each participant completed three lists. The participant was asked to repeat the sentence they heard and the number of correct key words was scored (maximum score of 30 per list) and used to calculate the SNR loss.

Arthur Boothroyd (AB) words-in-noise test (Boothroyd, 1968). Four lists of five words were presented in ICRA six-talker babble at 0 dB SNR. Participants were asked to repeat the words they heard, with a maximum score of 20 words correct.

Modified Coordinate Response Measure (Hazan et al., 2009). This measure is similar to the experimental group's trained task as it focuses on understanding competing speech. It is based on the Coordinate Response Measure (Bolia et al., 2000) modified to replace call signs with animals. Two sentences were spoken simultaneously by a female (target) or male (distractor) voice and participants were asked to identify the colour and number spoken by the female talker. A visual display showing the possible colour number combinations was given to the participants to reference during the test. The test used an adaptive 1-up 1-down staircase method and was performed twice at each visit. In each case, the participant's speech reception threshold (SRT) was calculated based on the average of the last two reversals for each track.

Cognition

Dual-task of listening and memory (Howard et al., 2010). This test provided a measure of listening effort. The same AB words-in-noise paradigm described above was used but with counterbalanced word lists presented flanked by a memory task. Participants were asked to retain in memory a string of five digits presented visually on a computer screen for five seconds. One list of AB words-in-noise was then completed after which participants were asked to recall the digits that had been presented previously. Four lists were presented at each session. The digit task was scored based upon whether the digit was correctly recalled in the right position (maximum score of 20 digits correct) and this was added to the word list score to give the total dual-task score out of a maximum score of 40. This cognitive measure was included to assess whether the inhibition skills involved in the experimental group's competing speech training could be applied to another cognitive task.

Self-Reported Outcome Measures

Hearing Handicap Inventory for the Elderly (HHIE; Ventry & Weinstein, 1982). This self-report questionnaire comprises two subscales of social/situational (HHIE Situational) and emotional impact (HHIE Emotional) of hearing loss. The questionnaire consists of 25 questions where participants respond as "yes" (score=4), "sometimes" (score=2) or "no" (score=0). Scores were calculated for social/situational (13 items, maximum score 52) and emotional subscales (12 items, maximum score 48), as well as the overall total (25 items, maximum score 100).

Glasgow Hearing Aid Benefit Profile (GHABP; Gatehouse, 1999). The subscale aided hearing activity limitations (residual disability) was administered for the pre-specified situation "Having a conversation with several people in a group". This subscale was chosen based upon the finding of Ferguson et al. (2014) who demonstrated that this situation was the most sensitive to the effects of auditory training. Participants were asked to rate using a five-point scale (1=no difficulty to 5=cannot manage at all). The score was converted to a percentage.

Participant Feedback

A questionnaire adapted from Henshaw et al. (2015) was delivered following completion of behavioural and self-reported outcome measures at T2, to assess participants' subjective experiences with the training intervention. This was administered in paper format to all participants and consisted of two sections:

1. *Statements:* participants rated their agreement for 14 statements (see Supplementary Information 3) describing their experiences with the training using a five-point Likert scale (strongly agree to strongly disagree).

2. *Open-ended questions*: participants were asked four open-ended questions assessing the (i) worst and (ii) best aspect of the training program, along with (iii) any changes that they would make and (iv) any other comments.

Participants also completed training diaries during the training period detailing the date and time that training was completed. They were given a blank space to add any additional comments regarding that training session if they wished to. Participants were not given any guidance as to the type of information that they may wish to include.

Data Analysis

Quantitative data was analysed using IBM SPSS v.27. Demographic characteristics of participants were analysed using independent t-tests for continuous variables and chi-square tests for categorical variables. To assess whether the experimental group demonstrated any significant auditory training-related improvements on behavioural outcome measures and self-reported hearing abilities between T1 and T2 compared with the active-control group for the same period, repeated measures ANOVAs were used to analyse group differences on each outcome measure, where time was the within-subjects factor and group (experimental or active-control) the between-subjects factor. Significant interactions were explored using post-hoc t-tests. Change scores were the difference in performance between T1 and T2, with scores reversed where necessary (i.e., QuickSIN, MCRM, HHIE and GHABP) so that a score of greater than zero indicated improved performance, and scores of less than zero indicated a deterioration in performance. For all analyses, outliers were classed as +/-2 SD of the mean. There were no outliers. Significance was set to $p<0.05$. Effect size was calculated using Cohen's *d*, where 0.2, 0.5 and 0.8 were considered small, medium and large effect sizes respectively.

Participants' responses to statements on the feedback questionnaire were grouped according to participant training experience and program design, and then ranked by most frequent response. Responses to the open questions and comments from the training diaries were thematically analysed by two researchers (SCL and JW) following the methods of Braun and Clarke (2006) to develop mutually exclusive themes that identified the content of participants' responses. Any disagreements on themes between researchers were resolved through discussion. Results are presented using a narrative synthesis.

RESULTS

Participant Demographics

The demographic characteristics of participants who completed the study (18 in the experimental group and 21 in the active-control group) are shown in Table 1. At T1 there were no significant differences between the demographics of the experimental and active-control groups for mean age, better-ear four-frequency average hearing thresholds, hours of hearing aid use, sex or number of hearing aids issued.

Behavioural Outcome Measures

Means and standard deviations for all outcome measures at T1 and T2 are shown in Table 2. Outcome data were normally distributed as confirmed by visual inspection and Shapiro Wilks $p>0.05$. Repeated measures ANOVA results are shown in Table 3.

Speech-in-Noise Perception

T1 to T2 change scores for experimental and active-control groups for QuickSIN are shown in Figure 1A which shows that both groups improved, but not significantly. Results from the repeated measures ANOVA indicated a significant main effect of time for the primary speech-in-noise outcome measure QuickSIN with a large effect size ($F(1,37)=6.24$, $p=.017$, $d=0.82$), but no significant two-way interaction of time x group. No main effect of time was shown for perception of AB words-in-noise but there was a significant two-way interaction of time x group with a medium effect size ($F(1,37)=4.75$, $p=.036$, $d=0.72$). As seen in Figure 1B, results from post-hoc independent samples t-tests of change scores showed significantly greater improvements for individuals in the experimental group (mean change=1.78 points) than for those in the active-control group (mean change=-0.90 points; $t(37)=-2.18$, $p=.036$, $d=0.71$). There was no significant main effect of time or two-way interaction of time x group for MCRM.

Cognition

For the dual-task test, repeated measures ANOVA results indicated a medium significant main effect of time ($F(1,37)=5.07$, $p=.030$, $d=0.74$), but no significant time x group interaction. Figure 1D shows that, although performance was significantly improved pre- to post-training for the experimental group ($t(17)=-2.56$, $p=.020$, $d=0.69$), this did not represent a statistically significant between-group difference.

Self-Reported Outcome Measures

Results from repeated measures ANOVA revealed a large significant main effect of time for the HHIE total score ($F(1,37)=15.73$, $p=.000$, $d=1.31$). There was no significant two-way interaction of time x group for HHIE total score. Similarly, both subscales of HHIE show a large main effect of time (situational subscale $F(1,37)=12.00$, $p=.001$, $d=1.14$; emotional subscale; $F(1)=11.61$, $p=.002$, $d=1.24$), but non-significant two-way interactions of time x group. Examination of mean scores (Table 2) using paired samples t-test showed small pre- to post-training improvements (reductions in hearing-related participation restrictions) for the experimental group on both subscales (situational subscale $t(17)=3.94$, $p=.001$, $d=0.49$; emotional subscale $t(17)=2.24$, $p=.039$, $d=0.37$) and the active-control group on the emotional subscale only ($t(20)=2.62$, $p=.016$, $d=0.36$). Repeated measures ANOVA results indicated no significant main effect of time or interaction of time x group for the GHABP subscale having a conversation in a group.

Participant Feedback

Post-Training Questionnaire: Statements

Responses to the closed statements from both groups for the post-training feedback questionnaire are reported in Supplementary Information 3.

Participant Training Experience. Both groups demonstrated similar experiences with the training programs and a comparable percentage of participants in each group agreed that they enjoyed the live-voice training (experimental=66.7%, active-control=71.4%). More participants in the experimental group reported that the program held their interest (experimental=88.9%, active-control=71.4%), while the active-control group were more likely to report that their attention wandered (experimental=22.2%, active-control=42.8%). Participants in both groups reported that the training made them more aware of their hearing, with a higher percentage of participants in the experimental group agreeing with this statement (experimental=77.7%, active-control=62%).

Program Design. Both groups ranked program design statements similarly. Almost all participants understood how to use the training program (experimental=94.4%, active-control=100%). Within the experimental group the majority of participants found it easy to decide which volume to play the CD (66.7%). The active-control group reported finding it more difficult to fit the training sessions into their day (experimental=50%, active-control=66.7%). Neither group indicated that the training program duration was too long based upon their responses to questionnaire statements (experimental=22.2%, active-control=14.3%), however this differs from the open responses.

Post-Training Questionnaire: Open-Ended Questions

Themes identified from responses to the open-ended questions are shown in Supplementary Information 4, together with example quotes from specific participants in each group. For all questions, most themes were the same across both experimental and active-control groups, reflecting the similarity of experiences with the two training protocols. These included themes relating to the training design (e.g., session duration), perceived improvements in listening skills and increased self-awareness of hearing problems. Participants in the active-control group suggested that the addition of background noise during training sessions would have been useful, whilst participants in the experimental group who had trained with a single-talker distractor proposed more specific changes such as having multiple distractor voices.

Training Diaries

Training Adherence. Adherence data were obtained from the participants' training diaries. Adherence was 100% for all participants. All participants from both groups completed the required number of training sessions, although there was some variability in the timeframe that these sessions were completed. Around two-thirds of the participants in the experimental group and active-control group reported that they followed the planned training schedule of five times a week over four weeks (61.1% and 66.6% respectively), whereas the remainder of participants completed all 20 sessions but over a longer timeframe (experimental group range=19-64 days, median=27.5 days; active-control group range=22-120 days, median=27 days).

Open-ended Comments. The open-ended comments sections of the participants' training diaries were thematically analysed and showed identical themes for participants in the experimental and active-control groups. A total of 154 comments were given by the experimental group and 141 by the control group. Four main themes of *training activity*, *training experience, improved communication* and *increased* a*wareness of concentration* were identified, and example quotes are given below.

Training Activity (experimental=106, active-control=68). Some participants focused on the challenges faced during the training sessions. Many of these comments, particularly within the active-control group, related to difficulty identifying the compliance letter presented at the end of each training session and technical faults with the CDs. Experimental group participants also commented on the difficulty of holding a conversation in the presence of the distractor not just for the participant but for their training partner also:

> *"Much harder than normal home conversation. Temptation to switch it off to hear conversation better"* (Participant 18 - Experimental)

One participant (Participant 18 - Experimental) devised a rating scale of "0=extremely difficult" to "10=becoming easier" on which to base his diary. Scores ranged from 6 to 6.5 across the training period suggesting a consistent level of difficulty throughout. Another participant (Participant 50 - Experimental) chose to note the volume setting on his CD player for the training each day. Volume settings increased gradually from 18 to 27/28 at the end of the training program. The active-control group, however, did not always feel that their training was challenging enough:

> *"Silent CD not presenting a challenging situation"* (Participant 49 – Active-Control)

Although they were instructed to have a conversation with one person during the training sessions, three participants reported variation such as conversing with more than one person:

> *"Three of us did a huge crossword – lots of discussion"* (Participant 18 - Experimental)

> "*Wife and family member for this session*" (Participant 8 – Active-Control)

One participant from the active-control group (Participant 16) noted how their seating was positioned during each session. Participants were not given specific guidance on how to set up their rooms and for this participant their location varied day-to-day. Data from these participants was not excluded from the quantitative analysis as it is unknown whether other participants had made similar protocol deviations but had not volunteered this information in their diaries.

Some participants in each group chose to note the topics that they spoke about during the training session. These included general subjects such as holiday plans, garden landscaping, diet and exercise. There were also topics which could be considered more emotive such as making a will, letter of complaint, closure of village post office and the EU referendum. For some individuals finding subjects to talk about for the full training duration appeared challenging whereas others found it easier:

> *"Half an hour of talking is very difficult"* (Participant 40 - Experimental)

> *"Time flew – more to talk about"* (Participant 37 - Experimental)

Training Experience (experimental=32, active-control=72). Beyond the practical issues faced by some individuals regarding the use of CDs, particularly in the active-control group, many participants had a positive experience with the training program and found it enjoyable.

> *"Enjoying our half hour chats! Will continue our half hour chats without the background noise!!"* (Participant 37 - Experimental)

> *"All went down well with a nice cup of tea"* (Participant 20 – Active-Control)

Improved Communication (experimental=7, active-control=0). Some participants noted developing improved communication strategies during the training sessions such as use of lipreading.

> *"Getting used to looking directly at person"* (Participant 32 - Experimental)

> *"It encouraged my wife to better understand my hearing problem"* (Participant 24 - Experimental)

Increased Awareness of Concentration (experimental=9, active-control=1). Participants appeared to be aware of the need for attention and concentration to aid communication.

> *"Paid more attention than normal although a little difficult at the beginning"* (Participant 36 - Experimental)

"Concentrating more on wife's speech" (Participant 27 – Active Control)

Finally, some of the comments from the experimental group related to audiological concerns such as noise induced hearing loss and tinnitus.

DISCUSSION

The main aim of this study was to evaluate the benefits of a new home-delivered auditory training approach for experienced adult hearing aid users using live-voice conversations with communication partners, and to assess how beneficial this was for speech-in-noise perception, cognitive performance and self-reported hearing. Importantly, we wanted to explore whether the additional perceptual and cognitive challenge of holding those conversations in the presence of a single-talker distractor had an incremental benefit or not, for the experimental compared to the active-control group.

There were modest statistically significant improvements shown in both groups, but significant between-groups effects of training were only seen on the AB words-in-noise test. Feedback showed that participants in both groups generally enjoyed the training and felt that they benefitted from it in a number of ways. Thematic analysis of participant feedback from post-training questionnaires and training diaries demonstrated almost identical themes across both training groups, which is perhaps not surprising given the degree of overlap between the training paradigms.

Behavioural Outcomes

Speech-in-Noise Perception

For speech-in-noise perception, the experimental group outperformed active-controls pre- to post-training for perception of AB words-in-noise but there were no significant effects of training in either group for the primary speech-in-noise outcome measure (QuickSIN), nor for competing speech (MCRM). While QuickSIN has previously been shown to be sensitive to auditory training effects (Sweetow & Henderson Sabes, 2006), no significant pre- to post-training improvements were shown in the current study. Although there was not a statistically significant difference in improvement between groups for QuickSIN, there was a clinically significant improvement in performance in the intervention group where the change score exceeded the 80% critical difference of 1.5 dB for the test (Etymotic Research Inc., 2006). This suggests that this training intervention has the potential to be used within clinical practice. Improvements were shown for AB words-in-noise perception for participants in the experimental group, over and above the changes seen for the active-control group. This is in line with other auditory training studies using AB words-in-noise as an outcome measure (Burk et al., 2006; Henshaw & Ferguson, 2014). These improvements demonstrated off-task learning as participants were tested using a different type of background noise compared to the trained task (six-talker babble vs single talker distractor), individual words which were devoid of any context (rather than the contextual sentences likely used for training at home), and an unfamiliar voice. This off-task learning suggests that active listening was improved. It may be that the addition of the competing speech noise during the experimental group's training was enough to subtly impact transfer of learning to untrained skills. Ferguson and Henshaw (2015a) hypothesised that competing speech tests using informational masking would show greater effects of training-related transfer than measures with energetic masking. If this were the case, we would expect to see improvements in the competing speech outcome (MCRM) for participants in the experimental group given the degree of overlap with the trained task (both involved informational masking and inhibition of competing speech). However, in the current study participants did not show significant improvements in understanding competing speech following auditory training.

Cognition

Participants in the experimental group showed a significant improvement in dual-task performance from T1 to T2 but there were no significant between-group effects of training. The AB words-in-noise element of the dual-task compared to the AB words-in-noise test delivered in isolation showed better scores and this was reflected in the overall dual-task pre- to post-training improvement. This suggests that following training, participants were able to more effectively allocate their cognitive resources between the speech and memory tasks. This is also consistent with open-ended questionnaire responses from both groups whereby participants reported that concentration and attention (i.e., cognitive abilities) were notably better following training. The same dual-task paradigm was also used as an outcome measure by Henshaw and Ferguson (2014) who demonstrated significant effects of phoneme discrimination auditory training indicating that this measure can be sensitive to the effects of auditory training. Although an auditory training study, the 3-interval, 3-alternate forced choice paradigm used by Henshaw and Ferguson (2014) required the trainee to simultaneously hold information in memory while constantly updating that information in order to make same/different comparisons. As such, transfer of learning shown in the dual-task outcome in their study may have arisen through the enhancement of cognitive control processes inherent within the auditory training task rather than the auditory stimuli *per se*. A meta-analysis of auditory and cognitive training for cognition showed that a combined auditory-cognitive approach provides better auditory and cognitive outcomes for adults with hearing loss (Lawrence et al., 2018) which could in turn improve speech perception in challenging listening environments (Anderson et al., 2013).

Self-Reported Outcomes

Participants in both groups reported a reduction in hearing-related participation restrictions following training. There was a mean 8.9% pre- to post-training improvement on the HHIE for participants in the experimental group with a small effect size, compared to an average improvement of 5.2% for active-controls. Test-retest reliability for the HHIE is high, ranging from r=0.84 (pencil and paper) to r=0.96 (face-to-face; Weinstein et al., 1986) so it is unlikely that the improvement in both the experimental and active-control groups in the present study is solely due to repeated assessment alone. However, despite the statistically significant improvements seen for both groups, these did not exceed the required clinically significant improvement of 19.2% (Weinstein et al., 1986).

Neither training approach resulted in significant changes to the pre- to post-intervention scores for the single GHABP question “having a conversation with several people in a group”, in contrast to a previous auditory training study showing pre- to post-training improvement (Ferguson et al., 2014). It is possible that the improvement reported by Ferguson et al. (2014) was driven by cognitive (executive control) improvements arising from the specific training task used as it required participants to actively engage and challenge working memory. The effects of this training were confirmed by improvements in a measure of working memory updating for trained participants, but not for controls. The specific training paradigm could therefore have resulted in the improvements seen in the cognitively challenging group conversation listening situation in that study, while our less cognitively demanding training task did not have the same effect.

During the study, participants in both groups noticed greater awareness of their hearing difficulties for themselves and their communication partner. As participants in both groups had the opportunity to benefit from increased listening practice with their communication partner (either in the presence or absence of background noise), this active listening and the inclusion of the communication partner in the training paradigm allowing opportunities to try new listening strategies may have driven the subjective benefits reported by participants in both groups. The subjective reports are consistent with the results of Tye-Murray et al. (2016) who reported improvement on the COSI following their training program with frequent communication partners.

To summarise, both groups showed improved self-reported hearing abilities pre- to post-training but only the experimental group showed improved cognitive performance. The AB words-in-noise test was the only speech-in-noise measure on which the experimental group showed significant improvement relative to the active-control group. This may be due to the added challenge presented by the background noise during their trained task and additional listening effort required to overcome the lack of contextual cues during the AB words-in-noise test compared to the sentences used for QuickSIN.

Participant Feedback

Feedback questionnaire responses from participants in both groups showed an overall positive experience with their training intervention including comments on improved social interactions, the benefits of improved concentration and listening skills and increased awareness of their hearing loss. Regardless of the presence of the distractor in the experimental group, participants in both groups felt that the training had improved their concentration and listening skills, including lip-reading, which may also have helped improve communication and participation during the conversations. Similar results have been reported elsewhere (Henshaw et al, 2015). This increased awareness of themselves and others could help to reduce participation restrictions through aligned coping strategies, such as improved adaptation and understanding, which can lead to better effects (Barker et al., 2017).

Comments from both the feedback questionnaires and training diaries suggested that the active-control group did not think their training was challenging enough as it took place in quiet, so they suggested to have other sounds in the background. The experimental group commented that they would have preferred the distractor to have contained multiple voices rather than a single talker. These comments are in line with recommendations from Barcroft et al. (2011) that the training should be relevant to the individual as both groups wanted the trained condition to reflect the challenges that they face day-to-day listening in noise. The authors suggest that individuals whose primary goal is to improve understanding of a particular communication partner should train with a single talker while people aiming to improve communication with the general community should train with multiple voices as the primary stimulus.

The key themes from the training diaries were the same for the experimental and active-control groups, which is not surprising given the similarity in interventions. The experimental group was more likely to comment on improved communication and concentration. The duration of the training program (30 minutes) was considered by many participants in both groups to be too long. Participant focus groups within auditory training research have identified that daily sessions of 15 minutes were preferable to 30-minute sessions every other day (Ferguson et al., 2014).

Clinical Relevance

Both groups showed behavioural and self-reported benefits after participating in live-voice auditory training. This may be due to the increased opportunity to participate in listening practice along with the involvement of the communication partner. Involvement of the communication partner was a key aspect in the design of this intervention and helped to embed partners within the rehabilitation process, which has shown to improve outcomes for adults with hearing loss (Ferguson et al., 2019; Ferguson, 2020; Hickson et al., 2014; Manchaiah et al., 2012). Participants in the present study reflected positively on their partner's involvement. Audiologists often encourage a family-centred approach to aural rehabilitation and this training intervention has joint-communication at its heart. Involving the family in this way may have benefits over other training methods that are more singular or software-focused as it better reflects real-world situations and includes frequent communication partners. It gives people with hearing loss and their communication partners structured opportunity to practice communication tactics and align their coping strategies (Barker et al., 2017). The benefits shown here may also be enhanced by improving social isolation and loneliness more generally.

When delivering auditory interventions as part of a rehabilitation program, adherence to the training program is paramount. Adherence for both groups in this study was very high at 100%. High adherence is often seen in training studies but does not always translate into clinical practice. Sweetow and Henderson Sabes (2010) had an adherence rate of 30% in their clinical population which was much lower than the compliance rate of 73% reported in their earlier 2006 study. Factors such as clinician-patient interactions and patient motivation can impact adherence (Sweetow & Henderson Sabes, 2010). In the current study, the participant's communication partner was actively involved in the training which may have provided additional motivation to complete the sessions. From a future implementation perspective, this type of auditory training approach can be delivered to a large patient group within a public health setting with very little financial cost, making it a practical and easy to use intervention.

Study Limitations

Other studies focusing on training with familiar voices have used formal recorded speech as their stimuli (Tye-Murray et al., 2016). Our study is unique in its use of informal live-voice stimuli, but the informal nature of this protocol has its limitations. First, many of the fundamental aspects of formal training paradigms that have been linked to successful auditory perceptual learning are missing in our live-voice approach e.g., performance feedback, adaptive adjustment of the training stimuli based on performance and gamification (Bieber & Gordon-Salant, 2021). As such, further research that directly compares the mechanisms and magnitude of training and transfer effects across informal and formal training approaches is warranted. Second, participants were advised to complete the training at a "challenging level" but interpretation of "challenging" could vary from person-to-person and day-to-day. The lack of researcher control over the trained task, such as the position of the speaker or the volume of the distractor, may have affected findings however this limitation was accepted in the present study in order to best represent real-world training experiences. Future studies should be designed with greater control over the training activities to reduce this variability and therefore assess the effect of the trained task more specifically.

Only off-task measures and not on-task learning effects were obtained. While participant feedback indicated that they did notice improvements in hearing their communication partners, this change was not formally assessed. The inclusion criteria of this study relating to severity and type of hearing loss was deliberately broad to be representative of our local patient group. This heterogeneity likely increased performance variability on outcome measures but maybe we should accept this as an inherent limitation of realistic real-world interventions. There was high performance variability on outcome measures, particularly the QuickSIN and MCRM. It has been shown previously that as task complexity increases (e.g., competing speech) test-retest reliability decreases which can limit robust results (Ferguson & Henshaw, 2015a). Furthermore, the power calculation for the study was based on the QuickSIN and due to participant withdrawals, the study was underpowered by 28% (experimental) and 16% (active-control) which will affect generalisability of the findings.

The final limitations of this study relate to the lack of blinding and poor validation of hearing aid functionality. Although participants were not directly told which group was the experimental condition, they knew that the study aimed to improve speech perception in background noise. It is reasonable to assume that participants may have guessed which group they were in and so were not truly blinded. The impact of the researcher not being blinded to group allocation was controlled through strict criteria for scoring a response as correct or incorrect. It could also be argued that performing objective measurements on the participant's hearing aid prior to testing, rather than a subjective listening check, would be a more suitable method of assessing whether they were functioning correctly.

Conclusion

Live-voice home-delivered auditory training with a communication partner is an intervention designed to improve listening skills that requires no specialist software. Importantly, we sought to understand whether the additional perceptual and cognitive challenge of holding conversations in the presence of a single-talker distractor (experimental group) was necessary to induce improvement in outcomes, or whether live-voice training in quiet (active-control group) would be sufficient. The intervention was well-received and adult hearing aid users in both groups reported benefits. Specifically, participants reported being more aware of their hearing abilities and felt that they had improved their concentration and listening skills post-training. However, behavioural outcome improvements were subtle and observed across both groups. A small statistically significant improvement was seen in the AB word-in-noise perception for experimental participants compared to active-controls, but this between-group improvement was not reflected in any of the other speech-in-noise, cognitive or self-reported outcome measures. As improvements were shown for participants in both groups, it is argued that the implementation of the distractor in the experimental group may have not been sufficiently controlled to enable group differences and that the improvements shown were primarily driven by listening practice and the involvement of the communication partner in both groups. This suggests that active listening with a communication partner has benefits not recognised previously, and may also help reduce the debilitating downstream effects of social isolation and loneliness. Further research is required to specifically compare the beneficial effects of this training with formal auditory training methods. Finally, a carefully controlled study of distractor effects in a larger number of participants will enable investigation of the mechanisms of training-related benefit to speech-in-noise perception.

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DECLARATION OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

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SUPPLEMENTARY INFORMATION

1. CONSORT 2010 checklist

2. CONSORT 2010 flow diagram demonstrating the flow of participants through the trial.

3. Number and percentage of total participants responding to statements about their experiences with the training program. Statements are grouped by participant training experience and program design and ranked for each training group by number of responses relating to a positive experience.

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