Determining Unilateral or Bilateral Hearing Aid Preference in Adults: A prospective study

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Abstract

Objective: Despite high rates of bilateral hearing aid fitting globally, a number of adults continue to reject one hearing aid. The current study aimed to identify a clinically suitable tool for determining, pre-fitting, which clients might prefer one hearing aid.

Design: Ninety-five new adult hearing aid candidates, aged 49 - 87 years, were assessed prior to a first hearing aid fitting. Performance was assessed on a modified version of the Listening in Spatialized Noise – Sentences test (LiSN-S), the Dichotic Digits difference Test, the Experiential Hearing Aid simulator, and the Grooved Pegboard Test. All participants were fitted bilaterally, but were instructed to alternate between unilateral and bilateral hearing aid use over fourteen weeks post-fitting. Participants' wearing preferences were assessed via a short questionnaire.

Study Sample: Sixty-eight participants adhered to the prescribed protocol for both bilateral and unilateral hearing aid use.

Results: 78% of participants expressed an overall preference for bilateral hearing aid use. Only the LiSN-S bilateral advantage test outcomes significantly correlated with overall wearing preference.

Conclusions: Although the LiSN-S bilateral advantage score related to overall wearing preference, the accuracy of the predictor was too low to warrant implementation of this test prior to hearing aid fitting. The current practice of recommending bilateral hearing aid use continues to be the best option for clinicians.

Key words: binaural interference, wearing preference, hearing aids

Introduction

The rates of bilateral hearing aid fitting have been steadily increasing globally for decades and, in Australia, these rates have now reached approximately 86% in adults (Bisgaard & Ruf, 2017; HSO Production data, 2017). Given that hearing is a binaural sense, and that the auditory system has evolved with the ability to integrate information received at each of the two ears, it is unsurprising that clinicians appear to recommend bilateral hearing aid fitting whenever a candidate presents with an aidable bilateral hearing loss. In fact, there are significant benefits to clients from the use of bilateral hearing aids. These include improved speech intelligibility due to the effects of head diffraction, binaural redundancy, and binaural squelch (see Ross, 1980; Dillon, 2012 for review), better localization ability (Holmes, 2003), and subjective improvements in sound quality (Walden & Walden, 2005).

In addition to these bilateral aiding benefits, there are also potentially negative consequences to a unilateral hearing aid fitting in the presence of a bilateral hearing loss. Specifically, late-onset auditory deprivation can occur, in which the lack of stimulation causes the ability to understand speech presented to the unamplified ear to deteriorate over time (Hurley, 1999; Silman, Gelfand, & Silverman, 1984). For some individuals, fitting a hearing aid to this unaided ear at a later date can stimulate the auditory system sufficiently to allow either the quality of the signals provided by the ear to improve over time, or the person's ability to understand said signals to improve (for review see Munro, 2008). However, this is not the case for every individual and for some there may be a sustained asymmetry in hearing ability because the brain subsequently becomes less able to use information from the ear providing poorer quality signals, even if a hearing aid is subsequently fitted to that ear (Hurley, 1999, Dawes et al, 2014).

Given the overwhelming body of research demonstrating the potential benefits to a client's communication from aiding two ears, it is somewhat surprising that a bilateral fitting is not always the preferred wearing option for some individuals. Studies investigating the wearing patterns of people fitted bilaterally report wide-ranging preference rates for bilateral hearing aid use: 32% (Schreurs & Olsen, 1985); 39% (Vaughan-Jones et al., 1993); 54% (Cox et al., 2011); 55% (Stephens et al., 1991); 66% (Kobler et al., 2001); 70% (Brooks & Bulmer, 1981); 77% (Erdman & Sedge, 1981); 78% (Dillon et al., 1999; Jordan et al., 1967); 81% (Hickson, 2009); 85% (Byrne & Dermody, 1975); 90% (Erdman & Sedge, 1981); and 93% (Boymans et al., 2008). The largest of these studies (Dillon et al., 1999 and Jordan et al., 1967) both reported a rate of 78%.

There are a number of reasons why people with bilateral loss might prefer a single hearing aid, such as the effect that wearing two hearing aids may have on a patient's self-image, cost, or difficulty manipulating two hearing aids. These reasons are, however, reasonably amenable to discovery prior to hearing aid fitting and presumably help explain why not everyone with a bilateral hearing loss is fitted with two hearing aids in the first place.

One of the potential reasons for rejection of the second aid after fitting is the presence of binaural interference, in which the input from a "poorer" ear is detrimental to that of the "better" ear (Jerger et al., 1983; Ahonniska et al., 1993; Carter et al., 2001; Chmiel et al., 1997; Walden, 2006). For a person who experiences binaural interference, fitting only the "better" ear with a hearing aid would be expected to result in superior outcomes than fitting both ears. A number of case studies demonstrating the presence of binaural interference in hearing-impaired adults have been reported in the literature (Carter et al., 2001; Jerger et al., 1993). Jerger et al (1993) presented a series of examples in which patients performed more poorly on speech reception in noise tasks with bilateral amplification than they did with unilateral amplification, attributing this to the presence of binaural interference.

Walden and Walden (2005) conducted a laboratory-based study and found that out of a sample of 28 adults with a hearing impairment, 23 participants showed superior performance on a speech-in-noise test when using one hearing aid than they did when using two, which may indicate the presence of binaural interference. However, McArdle et al. (2012) attempted to replicate the study of Walden and Walden and found that only 20% of their sample exhibited superior performance with unilateral aiding. Regardless of which of these figures proves to be replicable, these results suggest that a sizeable number of hearing-impaired adults could be achieving better outcomes if binaural interference was able to be identified prior to fitting, and unilateral hearing aid fitting implemented for these people. It is worth noting however, that in the experimental set-up used in both the Walden and Walden (2005) study and the McArdle et al. (2012) paper, speech and noise were presented to the participants from the same location which reduces the potential benefits bilateral aiding could provide, and therefore makes the result less relevant to “real world” performance.

While it might be thought that the audiometric profile could be used to predict who would prefer to wear two versus one hearing aids, many attempts to make such predictions have been unsuccessful (Boymans et al., 2009; Cox et al., 2011; Erdman & Sedge, 1981; Kobler et al, 2010; Swan, 1989). The best that can be said is that, on average, those wearing two hearing aids tend to have more loss than those wearing one (Dillon et al., 1999; Stephens et al., 1991).

A retrospective study by Kobler et al. (2010) examined the similarities and differences between a group of successful bilateral hearing aid users and a group originally fit bilaterally who subsequently chose to wear only one hearing aid. They found a significant difference in group performance on dichotic tasks and speech in noise measurements which is consistent with the earlier work of Walden and Walden (2005) and Jerger et al. (1993). However, the use of a retrospective design leaves open the question of whether auditory deprivation or acclimatization may have been the mechanism that affected performance for the unilateral group. It is also unclear whether difference between the performance of each ear was the consequence of wearing only one hearing aid, or the reason for preferring this configuration. To determine whether asymmetric dichotic perception leads to a preference for unilateral hearing aid use, or whether sustained unilateral hearing aid use leads to asymmetrical dichotic perception, prospective research is required.

A single prospective study has been conducted by Cox et al. (2011) to examine whether a clinical test could be used to predict patient preference for - and performance with - one or two hearing aids. Their participant sample of 94 new and experienced hearing aid users were assessed on a battery of potential predictors prior to hearing aid fitting. This was followed by a structured trial of unilateral and bilateral hearing aid use for three weeks, and unstructured use for the following nine weeks. At the conclusion of the study preference for one or two hearing aids could be predicted with 66% accuracy, based on a backwards step-wise regression, with the implementation of a short test battery including a questionnaire and two binaural measures, one concerning binaural summation and the second dichotic listening. However, Cox and colleagues acknowledge that given the battery would only allow accurate prediction of preference for two thirds of people it does not have sufficient predictive power to be useful. Additionally it may not be clinically practical for clinicians to add a battery of tests to their pre-fitting protocol. As such, further research is required to determine whether a single test, that is practical for clinical use, can predict binaural interference with sufficient accuracy.

The need for further research into patient preference for, and benefit from, bilateral aiding has also been highlighted by a recent Cochrane Review. In this review Schilder, Chong, Ftouh, and Burton (2017) identified only four studies examining the use of one versus two hearing aids that met their criteria for a suitable research design. These studies (Cox et al., 2011;

Erdman & Sedge, 1981; Stephens et al., 1991; Vaughan-Jones et al., 1993) concluded that 54%, 77%, 55% and 39%, respectively, of people fitted bilaterally chose to wear both hearing aids. If these proportions, averaging 56%, reflect real-life choices, then approximately half of the hearing aids fitted are not used. Schilder et al. considered only one of the four studies to be relevant to modern hearing aid technology, and that was the study of Cox et al. (2011) discussed above, but that result alone leads to the same conclusion. Given the scarcity of research in this area, and the potential to improve the efficiency of hearing aid provision, it is clear that more investigation is required.

The current study aimed to identify a clinically suitable tool for determining, prior to hearing aid fitting, which clients will prefer unilateral amplification for reasons potentially linked to binaural interference. If such a tool could be identified it would have the potential to result in improved outcomes for clients. It could also result in significant financial savings for governments who fund hearing aid fitting for their citizens and private clients who self-fund hearing aid purchase. Based on the findings of earlier work, tests of speech intelligibility, dichotic hearing, and subjective preferences were all hypothesised to be potential predictors. Despite the lack of research support for predicting candidacy from the audiogram, we have included measures of the audiogram among the potential predictors, because the information is so readily available to clinicians.

Material & Methods

Participants

Ninety-five adults (44 women, 51 men), aged 49 to 87 years, with sensorineural hearing loss commenced the study. The average audiometric thresholds for the participant group are shown in Table 1. Participants were recruited from Australian Hearing centres prior to being fit with their first set of hearing aids. Inclusion criteria included: 1) no greater than a moderate-to-severe sensorineural hearing loss [[1]4 frequency average hearing loss (4FAHL) < 65 dB HL]; 2) English adequate to allow completion of speech-based tests without an interpreter; and 3) no previous hearing aid use. Because the purpose of the study was to identify clinical measures that were predictive of patient hearing aid preference, no exclusion criteria existed around native language, or symmetry of hearing thresholds. This decision was taken to ensure that the group was as representative of a clinical population as possible. Rather, these additional factors were noted in the participant's case history and used for analysis purposes. As this was a clinical sample, details of the duration of the participants' hearing loss or the etiology was not known. Only 68 participants completed the study, adhering to all protocols. This subset of participants and the reason for withdrawal are discussed further in the results section.

	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
Minimum threshold Left ear (dB SPL)	0	5	10	15	25	20
Average threshold Left ear (dB SPL)	21	26	30	41	56	67
Maximum threshold Left ear (dB SPL)	60	60	60	65	85	105
Minimum threshold Right ear (dB SPL)	0	5	10	15	20	15
Average threshold Right ear (dB SPL)	21	26	32	42	56	66

[1] The 4-frequency average hearing loss refers to the average of thresholds at 500, 1000, 2000 and 4000 Hz.

Maximum threshold Right ear (dB SPL)	60	60	60	70	90	105

Table 1: Audiometric information for the participant population (n = 95).

The audiometric evaluation and hearing aid fitting were completed by the Australian Hearing audiologist according to Australian Hearing protocols. Briefly, the hearing aids were fit to the NAL-NL2 target for a bilateral fitting plus 2 dB. The additional 2 dB was added at all frequencies to provide a compromise between unilateral and bilateral targets as the participants alternated between these wearing configurations during the study. Fittings were verified using real ear insertion gain (REIG) measures. The clinical audiologists ensured all fittings were within 5 dB of targets. Adjustments were then allowed to accommodate the participant's listening preferences. Participants were fit with either custom in-the-ear or behind-the-ear hearing aids. The style and model of the hearing aids were selected by the participant in consultation with their clinical audiologist. Participants had the option of fully subsidized hearing aids, funded by the Australian government Office of Hearing Services program, or partially funded hearing aids which gave them access to higher level technology or a receiver-in-the-canal style of aid. All hearing aids, with the exception of the fully subsidized in-the-canal devices included adaptive directional microphone technology. Partially self-funded devices did include additional functionality regarding ear-to-ear connectivity. The clinical audiologists were asked not to promote either bilateral or unilateral fitting as being preferable but instead to encourage the participant to use the study as an opportunity to reach their own choice.

Approval to conduct this study was obtained from the Australian Hearing Ethics Committee. The study complied in all aspects with the National Statement on Ethical Conduct of Human

Research (National Health and Medical Research Council, 2018). Participants received a small gratuity to cover travel costs associated with their participation.

Procedures

Pre-fitting appointment

The first research appointment was conducted in the two weeks prior to the participant's hearing aid fitting. At the beginning of the appointment the participants were asked if they had a preference for one or two hearing aids and why. If they expressed a preference for one hearing aid, they were asked which ear they thought they would prefer and why. The participants were then assessed by the research audiologist on the Grooved Pegboard Test, Dichotic Digits difference Test, the Different Voices 90° condition of the Listening in Spatialized Noise – Sentences Test, and the Experiential Hearing Aid Simulation. These are described in detail below. The stimuli for the DDdT, LiSN-S and Experiential Hearing Aid Simulation were presented via a laptop computer and Sennheiser HD215 headphones. The presentation of the auditory measures was counterbalanced across participants.

The Grooved Pegboard Test: The Grooved Pegboard Test (Lafayette Instrument Company, Inc, 2003) is a well-established measure of finger dexterity. This test includes a 25-hole board with slots at random angles and corresponding metal pegs with a key down one side.

The Grooved Pegboard Test was administered according to the guidelines set out by the test developer (Lafayette Instrument Company, 2003). The pegboard was placed on the table directly in front of the participant. The participant was instructed to fill the pegboard, using their dominant hand, starting with the top row and working from the non-dominant to dominant side. The time taken was recorded by the researcher as well as any drops of the pegs. This procedure was then repeated with their non-dominant hand but working in the opposite direction.

Dichotic Digits difference Test: Dichotic digit recognition was measured using the National Acoustic Laboratories (NAL) Dichotic Digit difference Test (DDdT; Cameron et al., 2013). The digit stimuli, monosyllabic numbers one through 10 (excluding the bisyllabic seven), were recorded at NAL using a male speaker with an Australian English accent. Based on data from the development of the DDdT (Cameron et al. 2016), the six easiest and five hardest digit pairings were eliminated from the total digit-pair options. The exclusion of the easiest and hardest pairings ensured that the remaining pairings were of equal difficulty. A graphical user interface and signal processing application programmed in Matlab was used to present randomized lists of 25 2-pair digits to each participant. Specifically, four digits were presented on every trial, two to the right ear and two to the left ear. The first five trials of each list were practice items and not included in the scoring. Within each trial, the digit pairs were separated by half a second of silence.

The DDdT stimuli were calibrated using a spondee word task presented unilaterally. The researcher entered the 4FAHL for each ear into the MATLAB interface. Participants were then asked to repeat the word heard in either ear and to guess if they were unsure. The level of the spondee words was then adjusted using an adaptive technique to find the SRT and this was used, in combination with the participant’s 4FAHL, to adjust the dichotic digits test material to a sensation level of 40 – 0.5*4FAHL dB above the spondee SRT as an approximation of typical most comfortable levels.

Participants were assessed on all four conditions of the DDdT as described in Cameron et al (2016). These are dichotic free recall, dichotic directed left recall, dichotic directed right recall, and diotic. In the free recall response condition, listeners were required to repeat all stimuli heard from both ears, regardless of order. In the directed conditions, the listeners were required to repeat the stimulus from the directed ear only. For example, in the directed right condition listeners repeated the digits from the right ear only while ignoring the stimuli from the left ear. The order of presentation of the dichotic response conditions was counterbalanced across participants. Listeners were instructed on the task and provided with practice items to ensure they understood the task before each condition. Listeners were required to respond verbally and digits were scored as correct or incorrect.

LiSN-S: Auditory segregation was measured using a modified version of the LiSN-S (Cameron & Dillon, 2007; Cameron, Glyde & Dillon, 2012). Specifically, the LiSN-S uses target sentences presented in continuous discourse (children's stories) to determine the listener's speech recognition threshold (SRT) for four conditions. The target sentences spoken by a female speaker are always presented at 0° azimuth (under headphones using head-related transfer functions). For the purposes of this study, only one condition of the LiSN-S was tested. In this condition the background discourse is spoken by two different female speakers, one presented at +90° azimuth and a different female speaker from -90° azimuth. This condition is the most realistic of the LiSN-S conditions and therefore considered the most likely to provide results that may be predictive of real-life performance. The LiSN-S stimuli were presented via an external sound card attached to the laptop computer. An external amplifier was used to add 10 dB to the stimuli as Glyde et al (2015) demonstrated that, given the relatively low level at which the LiSN-S stimuli are normally presented (55 dB SPL for the distractor sounds), audibility may continue to impact performance even after NAL-RP amplification was applied.

The LiSN-S was presented in three amplification conditions using a built-in prescribed gain amplifier using NAL-RP (Glyde et al., 2013): bilateral amplification, left ear amplification, and right ear amplification. The bilateral amplification condition was administered twice to ensure that unilateral amplification and bilateral amplification were undertaken the same number of times. This approach minimizes the bias that otherwise occurs when bilateral advantage is calculated as the bilateral score minus the better of the two unilateral scores

(Byrne & Dillon, 1979). In the unilateral amplification conditions, sounds were presented at the usual unaided level (distractor sounds presented at 55 dB SPL + 10 dB provided by the external amplifier) to the ear that received no amplification. The bilateral amplification condition was always presented first and repeated at the end. The order of the presentation for the right and left ear amplification condition and LiSN-S lists was counterbalanced across listeners.

Listeners heard target sentences that varied in level in the presence of competing continuous discourse at ±90° (DV90° condition). The listeners' task was to repeat as many words as possible in each target sentence. The signal-to-noise ratio (SNR) was adjusted adaptively in order to determine each individual's speech recognition threshold (SRT). The SRT was defined as the SNR at which 50% of the words were recalled correctly. Listeners were required to respond verbally by repeating the entire sentence. The number of words correctly repeated was entered into the LiSN-S software per trial. The SRT was automatically calculated based on completion of either the practice items plus a minimum of 17 sentences and a standard error of less than 1 dB, or 30 sentences, whichever occurred first.

Experiential Hearing Aid Simulation: In order to determine an initial measure of listener amplification preference, a hearing aid simulation program, developed at NAL, was used. The hearing aid simulator presents video and audio of five simulated communication situations: watching television, conversation in quiet, conversation in a cafeteria, conversation on a busy street, and conversation at a playground. The videos were between three and five minutes in length. The audio in each situation was recorded through a KEMAR manikin, thus imparting average head-related transfer functions to each recording. During playback from a personal computer, through headphones, amplification based on the NAL-NL2 prescriptive formula and the individual participant's audiogram was applied. The communication situations can be presented with amplification in the right ear, the left ear or both ears together. Unamplified sound is presented to an ear if amplification is not selected for that ear. Options for simulations are available for omni-directional or directional microphones and three earmold settings (closed, vented, and open). For the present study, the omni-directional setting was used for the quiet communication situations, and the directional microphone setting was used for the noisy communication situations. If the participant's hearing aids did not have directional microphone technology, the omni-directional setting was used. The earmold setting was matched to the patient's hearing aid style.

Participants listened to three communication situations in the Experiential Hearing Aid Simulation program. To determine which three situations were used, the participant was asked to choose which were most representative of their everyday communication needs. In each situation, participants listened to the simulation three times; once with two simulated hearing aids, once with a right simulated hearing aid only, and once with a left simulated hearing aid only. Participants were asked to state which option (i.e., hearing aid configuration) they most preferred and which option they least preferred. Participants were also asked to rate the strength of their preference (most preferred and least preferred) on a scale from 1 to 5 relative to their second or middle choice. For example, if a participant most preferred the bilateral configuration and least preferred the left-only configuration, they were asked to rate the strength of their preference relative to their preferences for the right-only configuration. Each communication situation was played for a minimum of one minute and a maximum of the entire video in each hearing aid configuration. The amount of time each video was viewed in each configuration depended on the amount of time each participant needed to make their decision re: preference. The order of amplification configurations was counterbalanced across participants. Participants ratings were used to derive an overall score for binaural preference averaged across the three simulations, with a possible range of -10 to

+5, and a right preference averaged across the three simulations, with a possible range of -10 to +10.

Listening Trial

At the conclusion of testing, the participants were issued a hearing aid usage diary that outlined a hearing aid usage schedule. The diary specified when they should wear both hearing aids and when they should wear only one hearing aid (right or left) over the course of the first fourteen weeks post-fitting. Each participant cycled through wearing the hearing aids in three configurations in two-week intervals at a time for each configuration. In total they wore bilateral hearing aids for a total of six weeks, right ear only for a total of four weeks, and left ear only for a total of four weeks. The diary also provided space for the participants to record their impressions during each scheduled period. It was necessary to start with the bilateral condition so as not to interfere with Australian Hearing's follow-up appointment (typically two to three weeks after fitting), at which the client's ability to operate both hearing aids is checked. The order in which the participants trialed the remaining three aided conditions (i.e., both hearing aids, left hearing aid, right hearing aid) was counterbalanced.

Telephone follow-up

After the completion of the fourteen week listening period, the participants were contacted by telephone to complete a 6-item questionnaire (see Appendix A) in order to evaluate their perceived real-world benefit of one versus two hearing aids as well as their preferred aided configuration out of bilateral, right aided only, and left aided only. Specifically, the questionnaire asked: wearing preference in noise and quiet, which configuration allowed them to hear most clearly in noise and quiet, as well as how easily they feel they can hear in noise on a scale from zero to ten for each of the three hearing aid configurations. Participants who expressed a preference for bilateral hearing aid use were then counseled to wear their hearing aids in their preferred configuration. Participants who expressed a preference for unilateral hearing aid use were advised that they could wear their hearing aids unilaterally from that point on if they wished but that given there may still be further acclimatization they may wish to continue trialing bilateral use. All participants were reminded that they should contact Australian Hearing if they were experiencing difficulties. They were also asked to post their hearing aid usage diary with their recorded impressions to NAL and these were checked as an additional measure of participant compliance with the wearing schedule.

Results

Pre-fitting descriptive statistics

Of the 95 adults who commenced the study, 66 participants were fitted with fully subsidized hearing aids, funded by the Australian government Office of Hearing Services program. Twenty-nine participants chose to partially fund their own hearing aids. Further details regarding participants' hearing aid choices are provided in Table 2. The mean, range, and standard deviation for each predictor variable is provided in Table 3.

	Behind the ear	In the canal	Receiver in the canal
Number of participants fitted	66	3	26
Partially self-funded	2	1	26
Fit with traditional vented ear mold	6	N/A	0
Number of participants withdrawn	21	1	2

Table 2: Participants hearing aid selections.

Prior to hearing-aid fitting, 48 participants expressed no pre-conceived preference between unilateral and bilateral hearing aid use. Of those participants who did state a preference, sixteen participants thought they would prefer to use only one hearing aid, and 31 indicated they would prefer bilateral use.

Variable	Mean	SD	Min.	Max.
Age (years)	72.2	7.4	49.8	87.5
Audiogram average (dB HL)	38.8	7.9	26.9	60.0
Audiogram asymmetry (dB HL)	-0.8	5.4	-16.2	18.8
Pre-fitting preference	16.8% one, 50.5% no pref., 32.6% two			
Hearing aid technology level	69.5% fully sub., 30.5% higher level			
Grooved pegboard test average (seconds)	115.8	46.3	63.5	300.0
Grooved pegboard test difference (seconds)	18.2	39.4	-26.0	217.0
DDdT free recall average (%)	70.4	16.4	0.0	97.5
DDdT directed average (%)	80.4	22.4	20.0	100.0
DDdT free recall right ear advantage (% points)	1.6	26.4	-92.5	85.0
DDdT directed right ear advantage (% points)	-1.3	19.8	-100.0	52.5
DDdT free recall absolute ear difference (% points)	18.6	18.7	0.0	92.5
LiSN-S bilateral advantage (dB)	1.5	2.4	-2.0	12.5
LiSN-S right ear advantage (dB)	0.3	2.0	-5.8	4.4
Experiential Hearing Aid Simulation binaural preference score	-0.2	2.8	-8.3	5.0
Experiential Hearing Aid Simulation right ear preference score	0.2	2.4	-7.7	5.3

Table 3: Descriptive statistics for all participants. Mean, standard deviation, minimum, and maximum scores.

Post-trial preferences

Of the original 95 participants who commenced the study, 23 participants either withdrew from the study or lost contact during the 14 week listening trial. Most of these were due to health reasons or deciding not to proceed with fitting at all. Four of the remaining 72 participants were excluded from analysis as they did not adhere to the listening schedule outlined in the usage diary.

At the post-trial interview, participants were asked about their wearing preferences overall, in noisy environments, and in quiet environments. As shown in Table 4, six participants had no overall preference for either bilateral and unilateral fitting. Only the remaining 62 participants, who expressed a preference for unilateral or bilateral hearing aid use, were included in the statistical analysis.

Wearing preference	Quiet	Noise	Overall
Bilateral	50 (74%)	54 (79%)	53 (78%)
Unilateral	15 (22%)	13 (19%)	9 (13%)
No preference	3 (4%)	1 (2%)	6 (9%)

Table 4. Number of participants with each wearing preference at 14 weeks post-fitting.

The probability of an overall preference for two hearing aids was modeled using univariate logistic regression models, with one model for each of the potential predictor variables. With these models, if the predicted probability exceeds a particular cut-off value then preference for two aids is predicted, otherwise preference for one aid is predicted.

Predictive accuracy was measured as the maximum average of sensitivity and specificity (AvSS). "Maximum" refers to the maximum over all possible cut-off values. The measure can take values between 0 and 1, with higher values indicating greater accuracy. Sensitivity was estimated from participants who preferred two aids and the specificity was estimated from participants who preferred one aid, and an unweighted average was calculated.

To avoid the bias that can be caused by estimating the accuracy of a model using the same data that was used to fit the model, a "leave one out" approach was employed. This involved fitting the model leaving out one participant and using the fitted model to predict the probability of preferring two aids for the participant who was left out, then repeating that process for every participant, and using those predicted probabilities to estimate the AvSS.

Table 5 gives the AvSS values for each model, together with the p-value for the test of the null hypothesis of no association between the preference and the predictor variable.

Variable	**Definition**	**p-value**	**AvSS**
Age		p = 0.25	0.544
Audiogram average threshold	Average of left and right 4FAHL	p = 0.76	0.500
Audiogram asymmetry	Left 4FAHL minus right 4FAHL	p = 0.21	0.582
Pre-fitting preference	Preference for bilateral fittings expressed prior to hearing aid fitting	p = 0.94	0.500
Hearing aid technology level§	Level of hearing aid technology fitted. Fully subsidized or higher level	p = 0.39	0.575
Grooved pegboard test average score	Average of dominant hand and non-dominant hand score	p = 0.81	0.500
Grooved pegboard test difference	Non-dominant hand score minus dominant hand score.	p = 0.75	0.500
DDdT free recall average	Average of free recall left and right percentage scores.	p = 0.69	0.500
DDdT directed average	Average of directed left and right percentage scores.	p = 0.27	0.588
DDdT free recall right ear advantage	Free recall right percentage score minus free recall left score.	p = 0.18	0.594
DDdT directed right ear advantage	Directed right percentage score minus directed left percentage score.	p = 0.78	0.500

DDdT free recall absolute ear difference	Absolute value of free recall right percentage score minus left percentage score.	p = 0.46	0.535
LiSN-S bilateral advantage	Better monaurally amplified SNR minus better binaurally amplified SNR.	p = 0.04*	0.712
LiSN-S right ear advantage	Left ear amplified SNR minus right ear amplified SNR.	p = 0.65	0.500
Experiential Hearing Aid Simulation binaural preference score	A measure of how strongly the binaural condition was preferred, averaged over the three situations.	p = 0.20	0.670
Experiential Hearing Aid Simulation right ear preference score	A measure of how strongly the right-aided condition was preferred over the left-aided condition, averaged over the three situations.	p = 0.29	0.585

Table 4: Results of univariate logistic regression models for overall wearing preference, for each potential predictor variable. Predictive accuracy was measured using the maximum average of sensitivity and specificity (AvSS). * indicates significance to a level of $p < 0.05$. [§] Regarding hearing aid technology, participants fitted with fully subsidized ITC devices were excluded from the analysis due to the lack of directional microphone technology.

Of the potential predictors of preference, only LiSN-S bilateral advantage reached statistical significance ($p = 0.04$). Were it considered appropriate to make a correction to the p values for the number of potential predictors however, even the LiSN-S bilateral advantage score predictor would not be significantly related to the final preference. In terms of the accuracy of the LiSN-S bilateral advantage as a predictor, the model was able to achieve a maximum average of sensitivity and specificity (AvSS) of 0.712. This is the best accuracy achieved by any of the predictor variables..

Figure 1 shows the distribution of participants' LiSN-S scores broken down into overall wearing preference post-trial. All eight participants with LiSN-S bilateral advantage scores of 4 dB or greater preferred binaural hearing aid use.

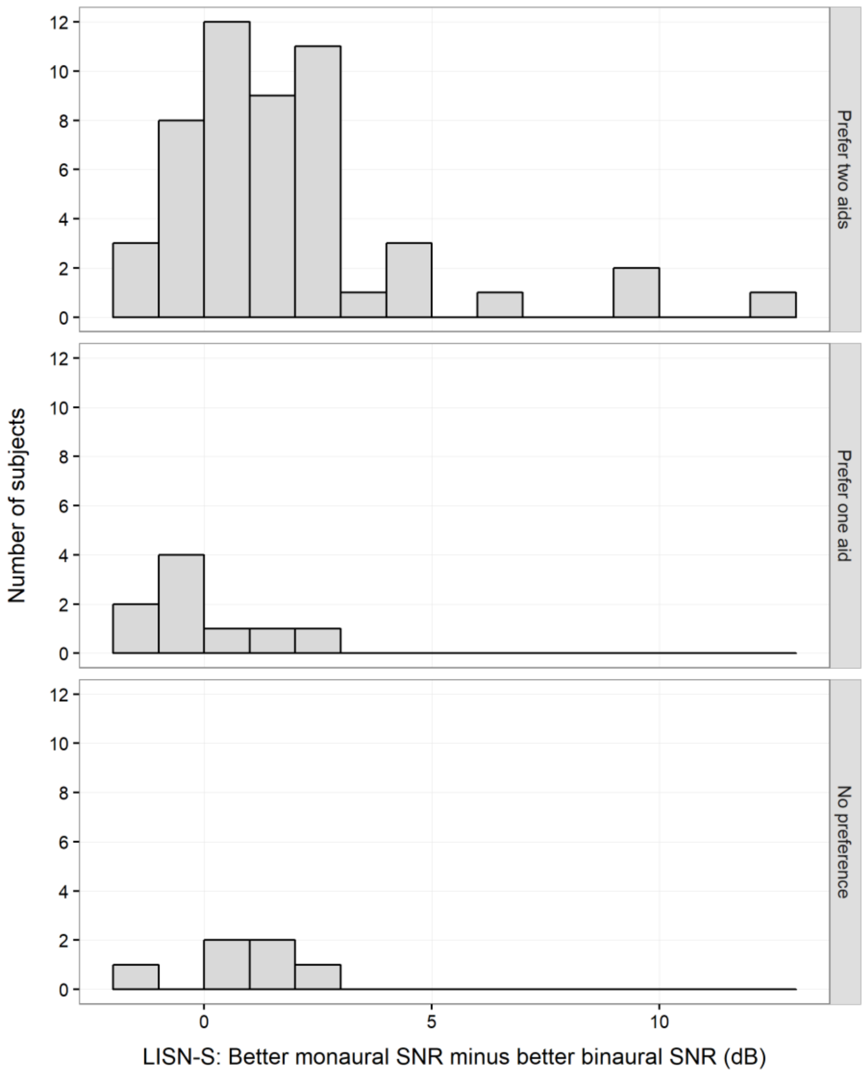

Fig. 1. A histogram of LiSN-S bilateral advantage score broken into wearing preference.

The relationship between wearing preference and each of the other potential predictors is shown in the online Supplemental material.

Discussion

The current study aimed to identify one or more clinically practical variables that might predict preference for unilateral hearing aid use prior to the fitting of hearing aids. The focus was on measures that may indicate the presence of binaural interference, which frequently is not identified until after hearing aid fitting occurs. Identifying and implementing such a tool could potentially reduce the number of unsuccessful bilateral fittings that occur and therefore improve client outcomes and reduce the cost of providing services.

Of the measures considered, only a measure of binaural benefit derived from the LiSN-S proved to be a significant predictor of bilateral wearing preference at fourteen weeks post-fitting. The relationship between a speech reception in noise task and binaural preference is consistent with the findings of Cox et al (2011). As hypothesized, people who achieved the strongest speech perception advantage from having amplification in both ears (relative to in only one ear) at initial assessment were much more likely to prefer bilateral amplification at 14 weeks post hearing aid fitting.

However, the relationship between LiSN-S bilateral advantage scores and subsequent bilateral preference was too weak to be of practical use (and does not survive correction for multiple comparisons). The LiSN-S bilateral advantage could only achieve a maximum average of sensitivity and specificity of 0.712, which is too low for the measure to be considered accurate enough for clinical implementation. As Figure 1 shows, although very positive bilateral benefit inevitably resulted in a preference for two hearing aids, many people with lower amounts of bilateral advantage also preferred two hearing aids, this likely explains why the sensitivity and specificity of the measure was limited.

It is likely that some combination of predictor variables, including those variables measured in this experiment, could drive the eventual preference. For example, for some people, a preference for a unilateral fitting may arise from binaural interference, for others the cause may be difficulty manipulating the second hearing aid, and for others it may be stigma effects (not measured here). In principle, it would be possible to combine measures of each potential variable to make a better prediction than is possible from any one predictor alone. In this experiment, the small number (nine) of people who preferred a unilateral fitting precluded the valid use of such multivariable prediction methods.

It is worth noting that the approximately 78% of participants who expressed an overall preference for bilateral hearing aid use at the end of this study is comparable to the proportion found by McArdle et al (2012) rather than to the far smaller proportion reported by Walden and Walden (2005) or by Cox et al. (2011). This difference may relate to the different inclusion criteria, as Cox and colleagues were more prescriptive in regards to the population tested, whereas this study sought to represent a clinical population. Alternatively, it may relate to the less realistic (i.e. non-spatially separated) listening conditions used in both the Walden & Walden (2005) and Cox et al. (2011). Given the current finding does come from within a clinical population it provides further support to the current clinical approach of recommending bilateral aiding whenever possible, as one might expect that it will be the preferred configuration for close to 80% of clients who wear one or two hearing aids.

Also worth noting is that approximately the same proportion of people preferred unilateral fitting in quiet as preferred it in noise (Table 2). This contrasts starkly with research and accepted wisdom from several decades ago, in which it was reportedly common to wear two hearing aids in quiet places but remove one hearing aid when it was noisy (Brooks, 1980; Brooks, 1984; Byrne 1980; Chung & Stevens, 1986; Dirks & Carhart, 1962; Schreurs & Olsen, 1985). Perhaps the noise reduction capabilities and/or wide dynamic range compression characteristics of modern hearing aids have changed this wearing pattern.

The lack of significant relationship with pre-fitting wearing preference found in the current study can be considered another reason for clinicians to encourage clients to try bilateral use initially where bilateral amplification is audiologically appropriate. This encouragement should, however, be tempered with a realistic discussion of what benefits may come from bilateral hearing aid use in relation to the client's own listening goals, as suggested by Hickson (2009). It may also be worth clinicians mentioning to clients that they may prefer to use their hearing aids in one configuration (e.g. unilaterally) in quiet but in a different configuration (e.g. bilaterally) in noise, as was the case with a number of participants in the current study (see Table 3).

Although there was no significant relationship between ear asymmetry as measured with the DDdT and eventual wearing preference, it was noteworthy that nine participants had a right-ear advantage of more than 30 percentage points, yet all of these expressed a final preference for a bilateral fitting. This contrasts with the findings of Cox et al (2011) that participants with asymmetrical findings were more likely to prefer a unilateral fitting. Consequently, ear asymmetry, whether based on the audiogram, dichotic speech perception, or speech perception in noise measured one ear at a time, should not be taken as evidence that a bilateral fitting is not suitable.

The inclusion of a hearing aid simulator to allow for subjective evaluations of hearing aid benefit prior to aiding was a novel inclusion in this study. However, participants' preferences in the simulations did not ultimately significantly relate to wearing preference at the end of the study. This may suggest that the situations simulated were not closely enough related to the individual's own listening environments, despite the participants selecting these situations themselves. Other possible explanations include the length of the simulations being too short for the participants to form meaningful impressions; the processing within the simulations not sufficiently matching that of the participants' own hearing aids; the videos using standardized head-related transfer functions which may have differed from those of the individual and the videos not including movement around the environment. Additional research addressing these potential limitations may be warranted.

A limitation of the current study was a relatively high dropout rate of 37%. If a higher percentage of the original sample had been maintained, it is possible that more participants may have preferred a unilateral hearing aid and, as a result, significant predictors of wearing preference may have been identified. However, given the population used were first-time hearing aid wearers it would be unrealistic to expect all participants to be retained, as not all fittings are going to be successful. A larger sample size to begin with may also have resulted in more participants with a unilateral preference but, again, the population of interest makes this difficult to achieve.

A further limitation of the study reported here is the need for the participants to be open to trialing bilateral hearing aids prior to participation. It is plausible that some people who may have experienced binaural interference self-selected out of the research, and this could have led to an overestimation of the percentage of people who prefer bilateral amplification.

It is possible that the first listening period being bilateral for all listeners predisposed them to prefer that condition. However, it is also possible that experiencing this condition when they were least used to the sound of hearing aids had the opposite effect. On balance, and given the number of alternations between conditions, we don’t think it likely that the fixed order, which was necessary for logistical reasons, affected the outcomes.

Finally, one factor that was not considered here was the potential impact of occlusion on wearing preference. Thunberg Jespersen and colleagues (2006) did identify an increased perception of occlusion in participants aided bilaterally versus unilaterally so it is plausible that this may contribute to unilateral wearing preference. However, the high percentage of open fittings in the current study does make this less likely to have been a factor.

Given the current study was not able to identify a clinically practical predictor of binaural interference, further research into this area is still needed. Until a predictor can be found, the current findings suggest that continuing to recommend bilateral amplification, where practical, may be the best option at this point. Clinicians should however be mindful that not every client will get the same binaural benefit and that preference for unilateral or bilateral amplification may differ based on the wearing environment.

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Declaration of Interest Statement

Conflicts of interest and sources of funding: The Listening in Spatialized Noise – Sentences Test and the Experiential Hearing Aid Simulation are both licensed products. Financial returns from the sale of these products previously benefitted the National Acoustic Laboratories. This has in no way influenced the research reported in this article.

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Supplemental Material

Figure S1a displays the distribution of participants by age, in relation to their overall wearing preference at 14 weeks post-fitting. Figure 1b and 1c show the distribution of participants with regards to their pure tone audiograms. Participants had an audiogram average score ranging from 23 dB HL to 60 dB HL and up to a 20 dB asymmetry.

Figure S2 displays the distribution of participants in relation to performance on the Grooved Pegboard Test. Neither higher average scores on the GPT, which indicate poorer finger dexterity, or GPT asymmetry, indicating poorer dexterity in one hand, were more frequent amongst participants who preferred unilateral hearing aid use.

The distribution of DDdT results, in relation to overall wearing preference, are shown in Figure S3 a - e. Figure 3c deals with the free recall difference score. Seven participants had a difference score indicating more than 40% difference in performance between their ears, and all expressed an overall preference for two hearing aids. This non-significant trend for larger interaural differences in DDdT scores to occur within those who preferred binaural use is also reflected in the directed paradigm (see Figure 3d).

The distribution of Experiential Hearing Aid Simulation results, divided into overall wearing preference are shown in Figure S4. There is no obvious differences between overall wearing preference groups for either binaural preference score or right ear preference score in the Experiential Hearing Aid Simulation.