Adaptation to hearing-aid microphone modes in a dynamic localisation task

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New technology can foster new ways of listening. A new hearing-aid programme can alter how we hear not only sources of sound but also their locations. While previous research has established how different hearing aid types and microphone modes affect static localisation ability, the current study explored the effects of introducing unfamiliar devices and microphone modes on dynamic localisation ability. Twelve experienced users of bilateral behind-the-ear (BTE) hearing aids oriented themselves to a target sound. Each trial consisted of 5-s segments of a target talker in a continuous background of far-field babble at the same overall level as the target. Targets were presented at either ±30, ±75 or ±120°. Head-orientation trajectories were measured with infra-red cameras. Participants first wore their own hearing aids for one block of 60 trials, then wore a new hearing aid and completed five more blocks in three different directional-microphone modes. In general, results showed trajectory differences between modes, and a modest influence of the preceding mode (i.e., adaptation). Three additional participants experienced with in-the-ear hearing aids oriented poorly with the new BTE device for the first two blocks, then returned to their baseline performance. This suggests that such a form-factor change requires additional time for spatial adaptation.

INTRODUCTION

For the sake of comfortable audibility, hearing aids can alter the spatial information of an acoustic environment. In previous studies of aided localisation, however, the ability to locate static sounds along the azimuth has been only modestly affected by wearing hearing aids in their basic setting, an average increase in error of 1° (Akeroyd and Whitmer, 2016). For directional microphones in hearing aids, which attenuate off-axis sounds to varying extent, the ability to locate a desired sound is only a precursor to the primary task of re-orienting to it. Brimijoin *et al.* (2014) demonstrated in a small group of bilateral hearing-aid users that while orienting accuracy was not affected by conventional cardioid directionality, the duration of and delay to start orientation to the talker was affected by directional microphones. While the effect on static localisation has been shown to be generally negligible, traditional hearing-aid directionality altered the dynamic behaviours that depend on the maintenance of cues

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over time.

Directional technology has seen a recent step change with the proliferation of bilateral beamforming (BiBF), linking the microphones across the ears to create a highly directive "lobar" pattern. In its basic form, BiBF eliminates interaural cues, but continuing advances have improved localisation with BiBF (Neher *et al.*, 2017), though errors are still greater than with traditional unlinked directionality (Picou *et al.*, 2019). With its highly directive pattern in the on-axis "look" direction, the ability to orient to a new desired source is vital to BiBF benefit in the real world. Further, the ways in which BiBFs affect spatial perception may induce orientation behaviours that are not globally beneficial. As part of an adaptive directional scheme, it is important to know how the varying levels of directionality within a scheme affect the behaviours in another scheme. The current study explores these questions by looking at orientation behaviour and its adaptation across BiBF and other directional modes in a realistic conversation-monitoring task.

METHODS

Participants

Twelve adults (7 female) with a median age of 69 years (range 52-72 years) participated. Better-ear four-frequency pure-tone threshold averages ranged from 11-54 dB HL with across-ear asymmetries of 0-14 dB HL (see Figure 1a). All participants were experienced (> 2 years) bilateral behind-the-ear (BTE) hearing-aid users. Three additional participants (2 female; age range 56-70 years) also took part who were experienced (> 3 years) users of completely-in-the-canal (CIC) custom hearing-aid users. Their data is treated separately.

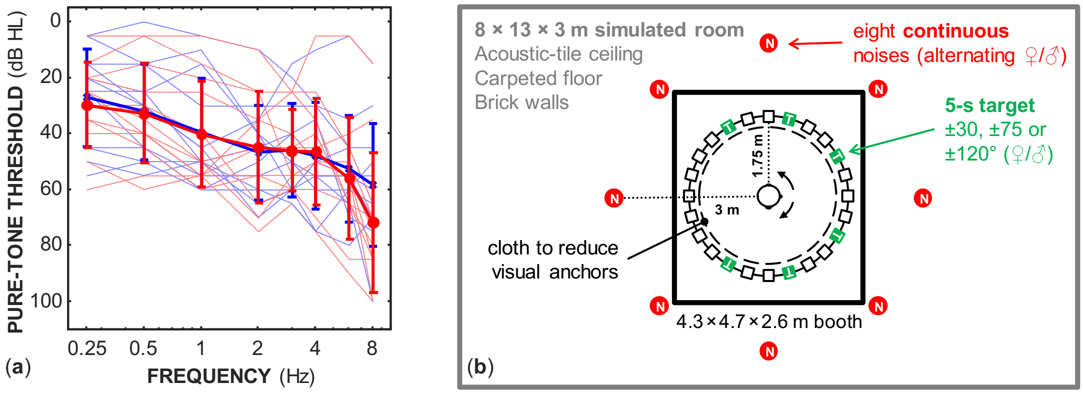

Fig. 1: Panel (a) shows left (blue) and right ear (red) pure-tone thresholds as a function of frequency, both individually (shaded) and means (solid). Error bars show ±1 standard deviation. Panel (b) shows the simulated noise/room configuration, stimuli and actual test apparatus used.

Apparatus

Participants were seated in a freely rotatable chair in the centre of a circular 1.75-m radius 24-loudspeaker array in a sound-attenuated 4.3 × 4.7 × 2.6-m chamber (see Figure 1b). Head yaw was tracked at the plane of the ears and nose at a sampling rate of 100 Hz using infra-red cameras and reflective crown. The visual location of the loudspeakers was obscured by a black cloth; all stimuli were equalised to offset the frequency dependent 0-2 dB attenuation of the cloth.

Stimuli

Continuous babble noise consisted of eight talkers (alternating male/female) placed in a simulated 8 × 13 × 3-m reverberant room at a distance of 3 m and 45° spacing from the centre (see Figure 1b). The 24-channel impulse response for each noise source was generated using ODEON with nearest-loudspeaker rendering. Noise level (all talkers simultaneous) was calibrated to be 66 dB A at the centre of the participant's head.

Target signals were consecutive five-second segments (25-ms onset and 100-ms linear offset gating) from a Sherlock Holmes story (44.1 kHz sampling rate) spoken by either a man or woman, gender randomised across trials (Macpherson and Akeroyd, 2013). Target signals were presented from the loudspeaker nearest to ±30, ±75 or ±120° from the participant's midsagittal plane on each trial. This created a punctate signal for participants to locate, and due to participants' error distributions, a normal distribution of sources up to ±7.5° from each target location to avoid learning of excursions.

Hearing aids

For the first block of sixty trials, participants wore their own hearing aids. All 12 BTE and 3 CIC wearers were wearing digital hearing aids that were tested in their basic omnidirectional programme. Participants then switched to two Signia 7Nx M hearing aids with receivers in the ear coupled with double domes that were fit to each participant's audiogram using Connexx fitting software. The real-ear insertion gains for their own and the newly fitted devices were measured. The new devices were fit with three customised, non-commercial programmes that were set and monitored during the experiment by the tester: (i) a pseudo-omnidirectional mode (OMNI) that mimics generic pinna directivity; (ii) a fixed unlinked hypercardioid directional mode (DIR); and (iii) a bilaterally linked directional beamformer (BiBF).

Procedure

Participants first performed standard audiometry to establish pure-tone air and bone-conduction thresholds. They were then instructed to imagine an ongoing story being told in a lively room by a series of conversation partners. When they heard a new talker, they were to turn as quickly and comfortably to the new talker, and remain oriented directly towards them until the next talker. Participants then completed 12 practice trials (with their own hearing aids). All participants completed six blocks of sixty trials.

Each block consisted of each target angle repeated ten times in randomised order that was fixated after the first block. That is, to compare trials across blocks, the target angle order for each individual was repeated across all blocks. The first block was always with subjects' own hearing aids to allow familiarisation and procedural learning. For the subsequent blocks, participants were randomly allocated into one of two hearing-aid programme orders shown in Table 1. The between-group block design was chosen to examine how exposure to one programme affected behaviour in another while adhering to a naturally occurring sequence in a commercial device.

	Block					
Group	**1** (*change of HA*)	**2**	**3**	**4**	**5**	**6**
1	Own Has	DIR	BiBF	DIR	OMNI	DIR
2	Own Has	DIR	OMNI	DIR	BiBF	DIR

Table 1: Block order design.

Each block started with 10 s of babble to stabilise the hearing-aid programmes. A 600-ms pause was inserted between target presentations in every block, but the babble was continuous throughout the block.

RESULTS

Analysis

Head yaw trajectories were recorded for each trial; trajectories for trials where the participant did not move were discarded. From each trajectory, eight measures were calculated (cf. Brimijoin *et al.*, 2014). *Error* is the absolute difference between the end angle and the actual target angle. The *start time* of each orientation was defined as the earliest time point at which the angle exceeded ±5° from that trial's starting position. The *end time* of each orientation was when the angle last exceeded ±5° from the end position. The *duration* is the difference between start and end times. *Orientation velocity* was the derivative of angular position. Kinematic studies have shown that the *peak velocity* and *peak velocity time* are indicators of motor-control decisions (Maurer *et al.*, 2017). *Complexity* was calculated as the minimum polynomial fit to the velocity-time function minus two, as any simple movement should have a ballistic velocity fit with a 2nd order polynomial. *Misorientations* were counted when the sign of the initial movement greated than 5° was not equal to the sign of the target (e.g., initially moved to the left for a right hemifield target). *Reversals* were how many changes in direction occurred over each orientation (after 10-sample smoothing).

General results

Mean results (across all 12 BTE participants) for each orientation measure as a function of target angle, device and microphone mode are shown in Figure 2. Results for the DIR mode were averaged across all three DIR blocks. Repeated-measures analyses of variance revealed clear main effects of angle: increased duration, peak velocity and complexity with larger angles, and increased number of reversals with decreasing angle due to overshoot (all $p < 0.001$). There was, however, no main effect of microphone mode, nor significant interactions across measures.

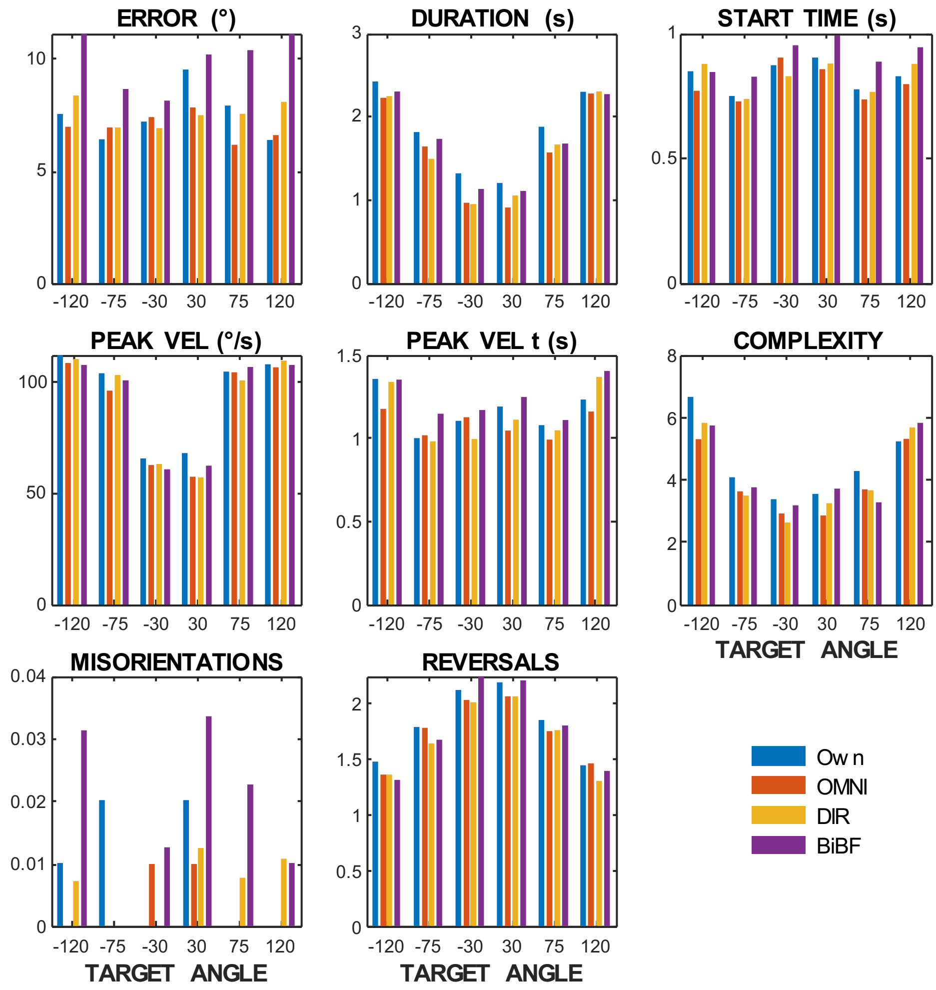

Fig. 2: Mean orientation measures (see text) as a function of angle for own device (blue), omnidirectional mode (OMNI; red), directional (DIR; yellow) and bilateral beamformer (BiBF; purple).

Adaptation results

The block design beginning with participants' own devices (Table 1) allows an examination of adaptation in orientation behaviour during and after exposure to different directional processing. For a simple analysis, measure means were calculated for each block as a function of angle for each participant in each of the block-order groups; the group mean results are shown in Figure 3. In addition, the same means are shown for the three CIC users. What is visually apparent is the dramatic increase in error, duration, start time, misorientations and peak velocity time (coupled with a decrease in peak velocity) for the CIC users, especially for orientations to ±120° targets for the first two blocks after the switch from their CIC devices to the new BTE devices (i.e., block numbers 2-3). As performance in the remaining blocks returns to that of the BTE groups, the CIC data shows clear signs of feedback-based learning: cautious, contemplative movement, accepting high errors as an adaptation process. Relative to these differences, changes across blocks in any measure between BTE groups 1 and 2 are much smaller.

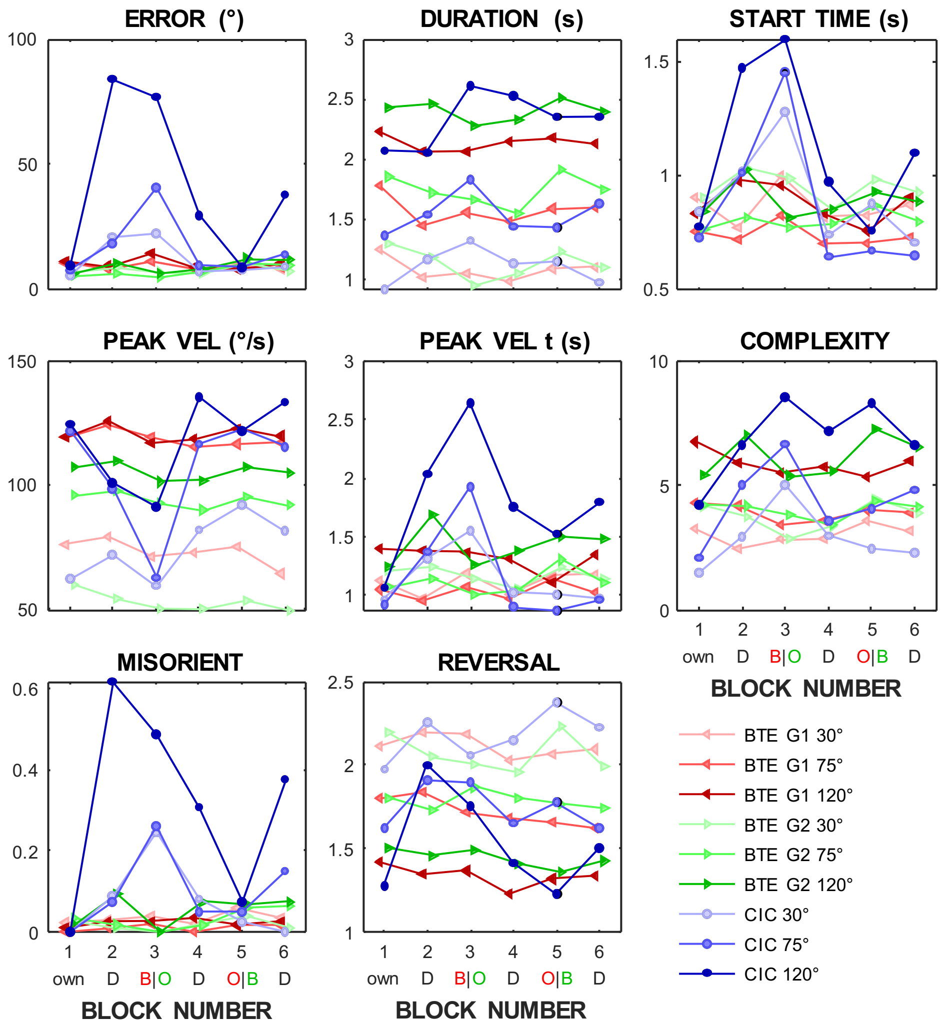

Fig. 3: Mean orientation measures as a function of experimental block (own device; D = directional; B = BiBF; O = pseudo-omnidirectional) for each group (colour/symbol) and target angle (shading; see legend).

To look for adaptation in the movement itself, the trajectories as opposed to measures derived from them were compared across blocks. For each repeat of each angle, the trajectory in the directional blocks (2, 4 and 6) were compared with the preceding block (1, 3 and 5). To derive a singular measure to analyse across conditions, the structural similarity index (SSI) was used, as it considers each sample in relation to others as opposed to independent error estimation (Wang *et al.*, 2004). Based on average start times and durations, the SSI was calculated for the 1-3 s segment of each

±120° trajectory (see Figure 4a). The mean results are shown in Figure 4b. The SSI for trajectories in the OMNI and subsequent DIR block was significantly greater than the DIR and either participants' own device or BiBF ($p < 0.05$); that is, participants' behaviours on average were more similar between DIR and OMNI modes than other modes. However, this adaptation evidence only applies to the SSI, not other similarity analyses (e.g., coherence).

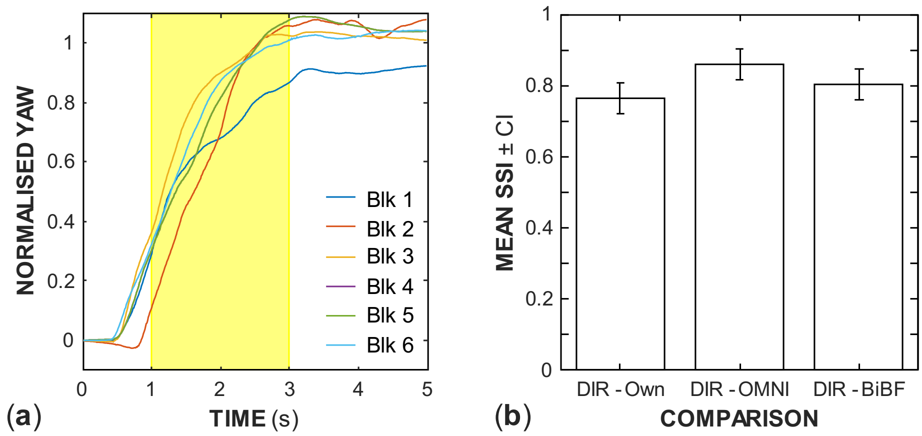

Fig. 4: Panel (a) shows sample trajectories – yaw (normalised to actual target angle) as a function of time – for a given trial in each block, highlighting the section analysed. Panel (b) shows mean SSI as a function of the similarity comparsion between the directional (DIR) blocks and the preceding block [own device, omnidirectional (OMNI) or bilateral beamformer (BiBF)]. Error bars indicate 95% within-subject confidence intervals.

DISCUSSION

Despite known changes to spatial cues, the bilateral beamformer here did not produce substantial changes in orientation behaviour on average. Nor did the fixed directional condition produce changes in behaviour from the omnidirectional condition, which contrasts with the previous orientation differences in Brimijoin *et al.* (2014). The tasks were slightly different in that here the task was timed, whereas the end of each trial was participant controlled in Brimijoin *et al.*, which may have elicited further searching or centring behaviour. The current timed task may have induced a particular global strategy to orient to the source that superseded any particular strategy for a given microphone mode. As the three microphone modes were all directional, it is possible that for an orienting task, they induce the same behaviour, though they produce different static localisation results (cf. Picou and Ricketts, 2019). Another difference is that the previous study used phantom sources between loudspeakers as opposed to single-loudspeaker sources in the current study; this difference could have caused more uncertainty in the precise location of the source, though only minimally. A direct comparison of the participant-controlled and timed methods would be necessary to determine whether it was the differences in method or similarities in microphone that limited the effects in the current study.

Adaptation was not an issue with microphone modes, but it was when the task involved a change in form factor. For the three experienced CIC users, the change to the new BTE device resulted in substantial issues in orienting over the first two blocks with the new devices, then returned to original performance for the remaining three blocks. As each block was 5'36" with a short break, this effect lasted approx. 12 minutes. The effects of this CIC-BTE adaptation (e.g., initially turning in the wrong direction on more than 50% of the trials) were most evident for the further off-axis sources. While there were differences in gain between the two devices, these gain differences were within the same range as the differences in the 12 experienced BTE users, who showed negligible changes when switching devices. Hence the cause of this major disruption in dynamic localisation ability was most likely due to the change in microphone positions. These results highlight the need for accommodating new patients who are changing to a different form factor and tempering their immediate spatial expectations.

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