Vision-Induced Reweighting of Binaural Localization Cues in Electric Hearing

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VISION-INDUCED REWEIGHTING OF BINAURAL LOCALIZATION CUES IN ELECTRIC HEARING

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ABSTRACT

Normal-hearing (NH) listeners rely on two binaural cues, the interaural time (ITD) and level difference (ILD), for azimuthal sound localization. Cochlear-implant (CI) listeners, however, rely almost entirely on ILDs. This is mainly due to 1) current clinical CI stimulation strategies not conveying salient ITDs, and 2) lower ITD sensitivity in CI compared to NH listeners even when salient ITDs are presented via a research interface. Since NH listeners change their ITD/ILD weighting when one of the cues is more informative or reinforced through visual feedback, such reweighting might contribute to CI listeners' low ITD sensitivity, given their daily exposure to reliable ILDs but unreliable ITDs.

Six bilateral CI listeners completed a multi-day lateralization training using visual feedback to reinforce ITD cues, flanked by a pre and post measurement of ITD/ILD weights without feedback. Using a research interface, we presented 100-pps and 300-pps pulse trains at a single interaurally place-matched electrode pair, containing individually derived ILDs combined with ITDs in various spatially inconsistent combinations. Participants' task was to lateralize the stimuli in a virtual audio-visual environment. Additionally, ITD and ILD thresholds were measured before and after training.

Listeners significantly increased their ITD weighting for 100-pps but not 300-pps stimuli. However, 100-pps ITD thresholds were not related to binaural cue weights at 100 pps. Consistent with the well-known decline in ITD sensitivity with increasing pulse rate, ITD weights were lower for 300 pps.

We propose a mechanism potentially contributing to CI listeners' low ITD sensitivity. If training can increase ITD weights in CI listeners, this could make ITDs better usable with future CI-systems conveying salient ITD information.

1. INTRODUCTION

Binaural hearing allows listeners to localize sound sources and facilitates understanding speech in noise. Consequently, bilateral cochlear implantation is becoming the standard treatment for bilateral severe to profound deafness and has proven to be advantageous over unilateral cochlear-implant (CI) use [1]. However, even when using both implants, CI listeners generally perform worse than normal-hearing (NH) listeners in the above-mentioned tasks.

While NH listeners rely on two binaural cues for azimuthal sound localization, the interaural time difference (ITD) and the interaural level difference (ILD), CI listeners rely almost entirely on ILDs with little to no contribution of ITDs [2-3]. This is partly due to current envelope-based stimulation strategies that do not encode fine-structure ITDs while available envelope ITDs are not sufficiently salient for real-life stimuli [4-5]. Furthermore, these stimulation strategies typically use high-rate pulse carriers whereas CI listeners' fine-structure (i.e., pulse) ITD sensitivity deteriorates for pulse rates above 200-300 pps [6]. In other words, CI listeners who use such envelope-based stimulation strategies do not have access to reliable and salient ITD cues in their everyday life. Consequently, strategies to better transmit fine-structure information are being developed (e.g., FSP [7], PDT [8], and PP [9]). However, even though using a fine-structure processing strategy improved the ITD detection threshold for tonal stimuli of a subset of CI listeners [10], these benefits do not or only weakly translate to real-life situations such as sound localization [8,11] or speech understanding in noise [8,10-13]. Finally, even when fine-structure ITDs are presented under the most optimal conditions (i.e., at a single interaurally place-matched electrode pair, directly stimulated via a research interface using the most sensitive pulse rate), CI listeners' ITD sensitivity is lower and much more variable across listeners compared to NH listeners [14-16].

Several explanations have been proposed for this perceptual deficit in electric hearing [see 6 for a review]. For instance, deprivation of binaural experience due to long periods before or between implantation on both ears results in cortical anomalies [17] as well as degraded neural ITD coding, such as fewer ITD sensitive neurons as well as broader ITD tuning curves and an ill adapted distribution of tuning parameters for the remaining ITD sensitive cells [18]. A lacking match between auditory-nerve patterns in electric stimulation and binaural cell properties, possibly causing the above-mentioned rate limitation [19], may also contribute. This rate limitation is not only observed in discrimination thresholds, but also affects lateralization ranges (i.e., how far to the left or right stimuli containing ITDs are lateralized) for both NH and CI listeners, but particularly strongly for CI listeners [20].

Here, we investigate another potentially contributing factor, namely, that the lack of reliable and salient ITD cues CI listeners experience in their everyday lives might lead to reweighting of the binaural cues. Specifically, we hypothesize that CI listeners learn over time to increase the perceptual weight given to ILDs, which correctly indicate the location of many sound sources in daily life, and decrease the weighting for ITDs, which arise at random or are not perceived at all. This seems likely given that NH listeners reweight available sound localization cues when some of the cues are altered. Several studies report a stronger weighting of monaural spectral compared to binaural localization cues for azimuthal sound localization after wearing unilateral earplugs [21-23]. Furthermore, NH listeners were observed to increase their weighting for ILDs when ITDs were randomized, even though the auditory stimuli were irrelevant to the task [24]. Finally, a study in our lab showed that the relative weight of either ITD or ILD can be increased in NH listeners, depending on which cue is visually reinforced during a lateralization training in a virtual audio-visual environment [25]. Therefore, we now investigate, if the same paradigm can induce an increase in ITD weighting in CI listeners. We are further interested in how the perceptual weight given to each binaural cue relates to the binaural cue sensitivity and whether reweighting of the cues will also be reflected in a change in sensitivity. Note that binaural cue weight may not necessarily be predictable from binaural cue sensitivity, because the perceptual effects of the two cues may interact in a complex way as a function of cue size.

2. METHODS

2.1 Participants

Six CI listeners, bilaterally implanted with MED-EL devices, completed the experiment. The listener information is summarized in Table 1. We intentionally kept the group heterogeneous concerning age, etiology and binaural experience as we had no *a priori* hypothesis regarding the reweighting potential (e.g., good ITD perception could be beneficial, but might also leave less room for improvement). All participants gave informed consent and received monetary compensation for their participation.

2.2 Apparatus and Stimuli

The setup was based on our NH experiment [25]. During the lateralization task in a virtual audio-visual environment, visual stimuli were presented binocularly via a head-mounted display (Oculus Rift DK1). The visual environment consisted of a reference position straight ahead, a crosshair in the direction the head is oriented, a single horizontal line at 0° elevation, and vertical lines every 15° in azimuth for guidance. If present, a rotating cube was used as visual feedback. Participants were seated on a desk chair that was allowed to rotate. Their head position and orientation were tracked with a head-mounted tracking sensor (Flock of Birds, Ascension) and the visual environment was rendered accordingly in real-time. Auditory stimuli were generated on a personal computer and were directly presented to the two CIs via a research interface (RIB2) developed at the Institute of Ion Physics and Applied Physics, Leopold-Franzens University of Innsbruck, Austria, allowing precisely controlled interaurally coordinated stimulation. Listeners were thus isolated from any audio-visual signals besides the experimental stimuli.

Auditory stimuli were unmodulated pulse trains with a pulse rate of either 100 or 300 pps and a duration of 500 ms, presented at a single interaurally place-matched electrode pair (see procedure for details). Various combinations of ITDs and ILDs were imposed on these source stimuli. Naturally occurring ITDs were used that ranged from -654 µs (left leading) to +654 µs (right leading), corresponding to an azimuth range from -69° (left) to +69° (right), as determined by [26] using broadband cross-correlation of the head-related impulse responses of the KEMAR head with DB-61 small pinna at a source distance of 1.4 m. If the participant's left/right discrimination threshold for ITDs was larger than the ITD corresponding to 69° azimuth (i.e., > 654 µs), these ITDs were doubled to ensure that ITDs could potentially be used for lateralization. As in [27], ILDs are defined in % of the dynamic range (DR) between the threshold (THR), comfortable level (CL) and maximum comfortable level (MCL) of each participant. The range of ILDs (%DR) used was set individually for each participant (see procedure for details), with the goal to elicit a set of perceived azimuths equally spaced between -69° and +69°.

ITDs and ILDs within this range were then combined to consistent- and inconsistent-cue combinations. In consistent-cue conditions, the ITD and ILD cue of the auditory stimulus corresponded to the same azimuth (red asterisks along the diagonal in Figure 1), while they corresponded to disparate azimuths in inconsistent-cue conditions. In the test phases, ITD and ILD cues were uniformly distributed ±24° around each azimuth on the diagonal of Figure 1, in both the ITD and ILD dimensions (all symbols in Figure 1 in rows and columns, respectively). In the training phase,

Listener	Implant L	Implant R	Age at testing	Etiology	Age at onset of deafness	Age at implantation L	Age at implantation R
CI3	C40+	C40+	35	Meningitis	20	20	20
CI62	C40+	C40+	19	Connexin 26	0	2	0
CI66	Synchrony	Concerto	55	Progressive	Childhood	37	46
CI74	Concerto	Sonata	49	Progressive	Adulthood	43	42
CI100	Pulsar	C40+	22	Unknown	Childhood	8	2
CI117	Synchrony	C40+	38	Progressive	Early adulthood	37	22

Table 1. Participant data.

the range of ITD azimuths (referred to as *targets*) was restricted to ±45° (all asterisks in Figure 1) and were visually reinforced. We restricted the ITD azimuth range in the training phase to ensure that the visual feedback would always be visible when facing the reference position (i.e., ±45° was the field of view of the head mounted display).

For the sensitivity measurements, participants were seated in front of the screen of a personal computer and responded with a gamepad. The auditory stimuli, unmodulated 100-pps or 300-pps pulse trains, were again directly presented to the two CIs via the RIB2.

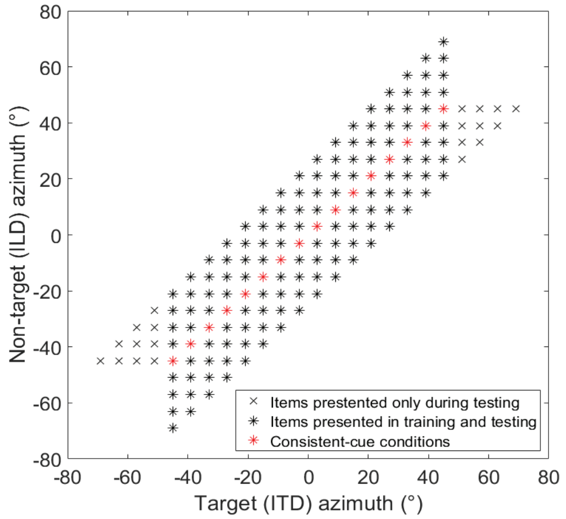

Figure 1. ITD/ILD combinations tested in this study. During training, ILD azimuths were uniformly distributed around each ITD azimuth (columns of asterisks). During testing, ITD/ILD combinations marked with an 'x' were additionally presented to also ensure a uniform distribution of ITD azimuths around each ILD azimuth, which was needed for the binaural cue weight estimation.

2.3 Procedure

The general structure of the experiment is shown in Figure 2. Which of the two pulse rates was trained first was counter-balanced across participants. The data collection per participant took 4-5 days to complete.

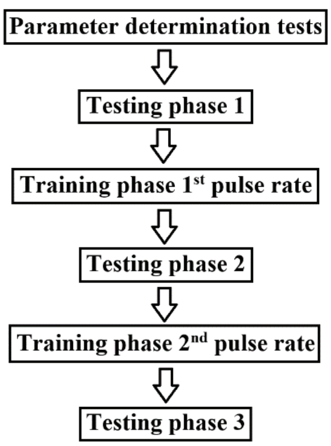

Figure 2. Experimental stages.

2.3.1 Parameter Determination

We determined a place-matched binaural electrode pair as in [15]. If a place-matched electrode pair had already been determined for a participant in a previous study, it was also used in the present study. We then determined the THR, CL and MCL separately for the two pulse rates used (100 and 300 pps) at the place-matched electrode pair members.

To determine the relationship between ILD and perceived azimuth, we presented 6 left and 6 right leading ILDs (10 repetitions per ILD) and asked the participants to lateralize the stimuli in the virtual environment. On each trial, participants listened to the auditory stimulus while facing the reference position and then indicated its perceived azimuth via head turn and button press. After they returned to the reference position, the next auditory stimulus was presented. We then averaged the response azimuths for each ILD and fitted either a linear function or an inverse tangent function, depending on which fitted the data better. Finally, ILDs were read out from the fitted function to obtain ILD azimuths for the main experiment. Due to limited testing time, only the 100-pps stimulus was used, as we did not expect the functions to differ significantly between pulse rates.

To get accustomed with the training task, participants then performed a pre-training including visual feedback (see description of the training task below). In the pre-training we only presented consistent-cue combinations, 4 repetitions per target azimuth (i.e., 64 trials total). This was done separately with 100- and 300-pps stimuli right before the respective test 1.

2.3.2 Testing Phase

In each testing phase we measured binaural cue weights as well as binaural cue thresholds for both pulse rates.

Binaural cue weights were measured with a lateralization task in a virtual audio-visual environment without visual feedback, based on the methods used in [25,28]. On each trial, participants listened to the auditory stimulus while facing the reference position and then indicated its perceived azimuth via head turn and button press. When they returned to the reference position, the next item was presented. After each 124 trials, participants took a short break.. Each ITD/ILD combination was presented 3 times. In addition, a centered item was presented at the beginning as well as after each break to help participants to orient themselves, resulting in 496 trials in total. This measurement was done in separate blocks for the 100- and 300-pps stimuli.

For measuring binaural cue thresholds, we used a constant-stimuli, two-interval left/right discrimination paradigm. The first interval consisted of a centered stimulus. The second interval consisted of the same stimulus with, depending on which cue was tested, either a nonzero ITD or a nonzero ILD (100-pps ITD, 300-pps ITD and ILD thresholds were measured in separate blocks). The participants had to indicate on which side (left or right) the second stimulus was perceived compared to the first stimulus by pressing the corresponding button on a gamepad. They received feedback (correct/incorrect) after each response. We tested 100, 200, 400, 800, and 1600 µs ITDs and individually chosen ILDs with 100 repetitions per cue size. If it was known from previous tests that the 100-pps ITD threshold of a participant was outside of this range, the range of ITDs tested was adjusted accordingly (smallest ITD tested: 25 µs). ITD thresholds were measured separately for 100 and 300 pps in testing phase 1 and after the training phase with the respective pulse rate. ILD thresholds were measured using 100-pps stimuli during all three testing phases.

2.3.3 Training Phase

Participants were trained with a lateralization task in a virtual audio-visual environment including visual feedback consistent with the ITD azimuth. A training trial started with the participants listening to the auditory stimulus while at the reference position and indicating the perceived azimuth via head turn and button press, identical to the testing trials described above. It proceeded with visual feedback appearing at the target (ITD) azimuth. Participants were instructed to perform a head turn to the target azimuth and confirm it with a button press. When they returned to the reference position and pressed the button, the auditory stimulus was presented again, now simultaneously with the visual feedback. Then, the target azimuth had to be confirmed again via another head turn and button press. Finally, participants returned to the reference position and a new trial was initiated. After each 73 trials, participants took a short break. One training block consisted of 146 trials, namely each target azimuth combined with each non-target azimuth ±24° around that target azimuth (columns of asterisks in Figure 1) plus a centered item at the beginning and after each break to help participants to orient themselves. Participants completed 5 training blocks per pulse rate.

2.4 Analysis

The data was analyzed using MATLAB R2018b (The MathWorks, Natick, MA). Analogous to [25], we estimated binaural cue weights individually for each participant based on a regression analysis fitted separately for each azimuth α (between 3° and 45° with a 6° spacing between azimuths) after averaging repetitions and mirroring the data across the midline (assuming left/right symmetry). The regression model equation is as follows:

$$R(\alpha, \Delta_{ITD}, \Delta_{ILD}, Q) = k_{ITD}(\alpha) * \Delta_{ITD} + k_{ILD}(\alpha) * \Delta_{ILD} + Q(\alpha)$$

$$w_{ILD} = \frac{atan\left(\frac{k_{ILD}(\alpha)}{k_{ITD}(\alpha)}\right)}{\frac{\pi}{2}} \quad (1)$$

where R is the participant's mean response azimuth in a trial with ITD and ILD corresponding to the azimuths α + ΔITD and α + ΔILD, respectively, $kITD$ and $kILD$ are the estimated linear regression slopes (determining the individual binaural cue weight contributions), and Q is the estimated overall bias at azimuth α. Thus, $kITD$ and $kILD$ quantify, for each azimuth up to 45°, the response shift induced by the various azimuthal offsets of the respective cues (from -24° to +24°) while setting the offset of the "other" cue to zero. These estimates of $kITD$ and $kILD$, representing orthogonal vectors, are then combined to derive the ILD weight, w_{ILD} (note that $w_{ITD} = 1 - w_{ILD}$). To compare pre and post training weights across participants, we averaged the estimated weights obtained before or after the training, depending on which pulse rate was trained first (i.e., for determining 100-pps weights, if the participant started with 100-pps training, test 1 constitutes the pretest and the estimated weights from testing phases 2 and 3 were averaged to constitute the posttest. If the participant started with 300-pps training, 100-pps weights from testing phases 1 and 2 were averaged to constitute the pretest and test 3 constitutes the posttest).

Binaural cue thresholds were determined with the MATLAB toolbox psignifit 4 [29]. ITDs were logarithmized before fitting the psychometric function. To determine ILD thresholds, the difference between the reference and target stimulus in current units (cu) was evaluated.

Statistical analyses of results were performed using SPSS Statistics 20 (IBM, Armonk, NY).

3. RESULTS

3.1 Binaural Cue Weights

The results are shown in Figures 3 and 4. ILD weights were subjected to a 2 *(pulse rate)* x 2 *(time)* x 8 *(azimuth)* repeated-measures ANOVA. The ANOVA yielded a significant main effect of *pulse rate* ($F(1,5) = 10.26$, $p = .024$, $\eta_p^2 = .672$) with larger ILD weights in the 300-pps ($M = .966$, $SD = .064$) compared to the 100-pps condition ($M = .809$, $SD = .167$). There was also a significant main effect of *azimuth* ($F(7,35) = 7.28$, $p < .001$, $\eta_p^2 = .593$) with larger ILD weights at more lateral azimuths as well as a significant *pulse rate* x *time* interaction ($F(1,5) = 8.76$, $p = .032$, $\eta_p^2 = .637$). All other main effects and interactions were non-significant ($p > .050$). Follow-up partial ANOVAs (separately for the pulse rates) showed that the *time* x *pulse rate* interaction was driven by a significant reduction of ILD weights from pre- to posttest in the 100-pps condition ($F(1,5) = 6.93$, $p = .046$, $\eta_p^2 = .581$), but no effect of *time* in the 300-pps condition ($F(1,5) = 0.69$, $p = .443$, $\eta_p^2 = .122$).

We additionally tested wheter ILD weights averaged across azimuths were significantly different from 1 using a one-sample *t*-test. This was the case for 100-pps ILD weights in the pre- ($T(5) = -2.52$, $p = .027$, $d_z = -1.03$) as well as the posttest ($T(5) = -3.11$, $p = .014$, $d_z = -1.27$). For the 300-pps stimuli, neither the pre- ($T(5) = -1.51$, $p = .096$, $d_z = -0.62$) nor the posttest ($T(5)= -1.04$, $p = .173$, $d_z = -0.42$) ILD weights were significantly different from 1.

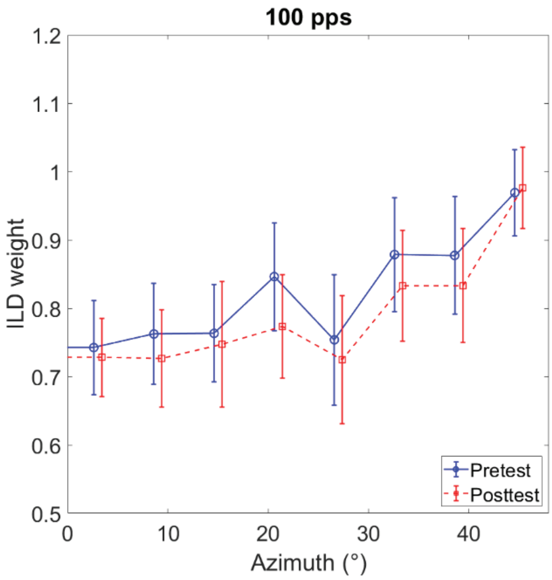

Figure 3. Mean ILD weights as a function of azimuth for the 100-pps condition. Error bars show the standard error of the mean.

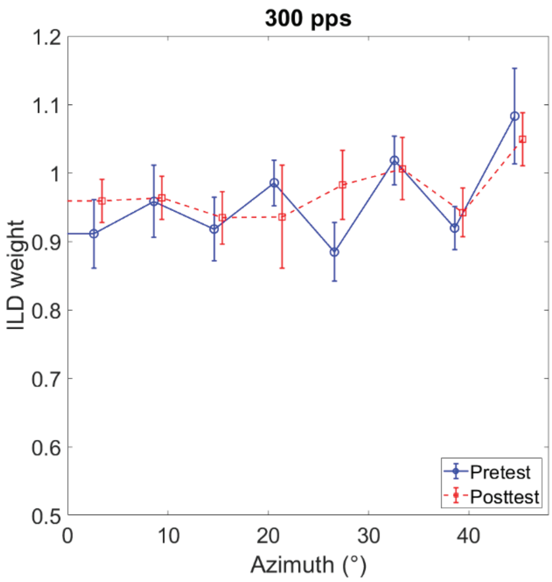

Figure 4. Mean ILD weights as a function of azimuth for the 300-pps condition. Error bars show the standard error of the mean.

3.2 Discrimination Thresholds

We determined discrimination thresholds as the stimulus level at which the fitted psychometric function reached 75% correct responses. For 300-pps pulse trains, four out of the six subjects did not reach this performance level even for the largest ITD tested. For the other two listeners thresholds were determinable, but much higher than at 100 pps. These results are consistent with the typically observed rate limitation in ITD sensitivity. Because of the undeterminable thresholds for the majority of the group, the 300-pps data were excluded from the statistical analysis.

100-pps ITD psychometric functions are shown in Figure 5. The estimated pre- and posttest thresholds were subjected to a paired *t*-test, which did not yield a significant effect ($T(5) = -0.26$, $p = .808$, $d_z = -0.11$), suggesting that the training had no effect on 100-pps ITD thresholds.

ILD thresholds were subjected to a repeated-measures ANOVA with the factor *time* (test 1 vs. test 2 vs. test 3), as they were measured during all 3 test phases but only with 100-pps stimuli. Median thresholds were 2.45 cu ($SD = 0.54$) for test 1, 1.54 cu ($SD = 1.01$) for test 2 and 1.76 cu ($SD = 1.58$) for test 3. The ANOVA did not yield a significant effect of *time* ($F(2,10) = 0.42$, $p = .666$, $\eta_p^2 = .078$), suggesting that the training had no effect on ILD thresholds.

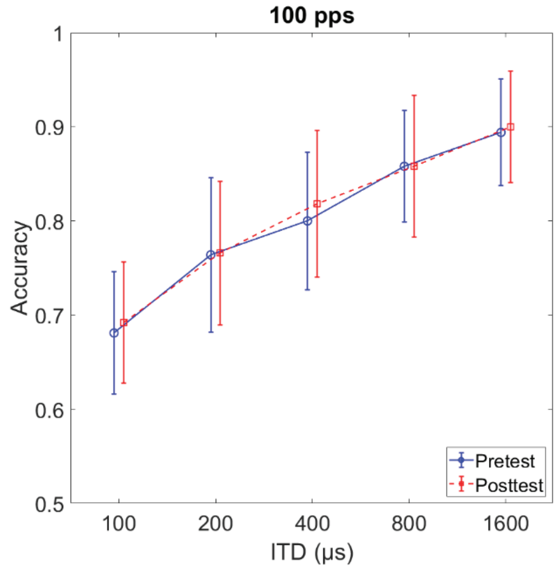

Figure 5. Psychometric functions for left/right discrimination of ITDs with 100-pps stimuli. Error bars show the standard error of the mean.

3.3 Relationship between Cue Weights and Discrimination Thresholds

To determine, if there is a relationship between the estimated cue weights and discrimination thresholds, we ran correlation analyses with the 100-pps ILD weight at ±3° of each participant and the 100-pps ITD thresholds of each participant. We chose the ILD weight at the most central azimuth as the ITD threshold was also estimated close to the perceived center. If the two measures are related, we would expect a positive correlation since lower ITD thresholds indicate better ITD sensitivity and lower ILD weights indicate a stronger contribution of the ITD cue to the azimuthal percept. The correlation of 100-pps pretest ITD thresholds with neither 100-pps pretest ILD weights ($r(4) = .354$, $p = .491$) nor with the pre- vs. posttest differences in 100-pps ILD weights ($r(4) = -.444$, $p = .377$) reached significance. The correlation of pre- vs. posttest differences in 100-pps ITD thresholds with pre- vs. posttest differences in 100-pps ILD weights ($r(4) = .781$, $p = .067$) approached significance.

4. DISCUSSION

We investigated a factor potentially contributing to the previous finding that sound localization with clinical CI systems is largely based on ILDs. Specifically, we hypothesized that CI listeners reduce their ITD weighting based on their everyday experience with clinical CI systems, which lacks reliable and salient ITD cues while ILD cues are largely preserved. Consequently, we addressed the question if CI listeners can be trained to weight ITDs more strongly when they are presented reliably and saliently via a research interface and reinforced through visual feedback.

The results suggest that ILD weighting can be decreased (and ITD weighting therefore increased) for 100-pps but not for 300-pps stimuli. Furthermore, ILD weights were consistently higher for 300 pps compared to 100 pps and not significantly different from 1 for the 300-pps condition (note that an ILD weight of 1 equals an ITD weight of 0) both before and after training, suggesting that ITDs did not contribute at all to the azimuthal percept at 300 pps. Together with the observation that ITD thresholds for 300-pps stimuli exceeded the tested range (100-1600 μs) for 4 of our 6 participants both before and after training, this suggests that constraints in peripheral auditory processing of temporal information in high-rate (e.g., 300 pps) electric pulse trains could be the reason for the lack of reweighting at 300 pps. Since the ITD sensitivity of inferior colliculus neurons of rabbits bilaterally implanted with CIs shows a similar pattern to perceptual discrimination thresholds in human CI listeners [30] and auditory nerve responses in cats appear to encode timing cues up to a few hundred Hz of stimulation [31], the loss of temporal information on the way from the auditory nerve to the midbrain appears to cause these constraints for 300-pps pulse trains.

The ITD thresholds we measured are consistent with previous studies. Data pooled across 14 studies with a total of 100 CI listeners using unmodulated pulse trains with ≤ 100 pps yielded a median threshold of 144 μs [6]. In the present study, the median ITD threshold before training for the 100-pps stimuli was 295 μs, which is slightly higher but well within the range of ITD thresholds observed in the included studies. Consistent with the deterioration of ITD sensitivity for rates exceeding 100 pps [6], ITD thresholds in the present study were higher for 300 compared to 100 pps and exceeded 1600 μs for 4 out of 6 participants, providing further evidence for the rate limitation in ITD sensitivity. The finding that at 300-pps ITD thresholds as well as 300-pps ILD weights remained unchanged by the training suggests that this rate limitation is not just due to a current lack of exposure to robust ITD cues.

We additionally measured ILD thresholds to mitigate concerns that training with unreliable ILD cues might reduce CI listeners' ILD sensitivity, potentially worsening their overall localization ability. However, there were no differences in ILD thresholds between the three testing phases, suggesting that the training had no influence on ILD sensitivity.

In the present study, the estimated ILD weights were larger at more lateral azimuths compared to central azimuths. There also was a trend for this pattern in our NH study [25], but it did not reach significance. The current results might be explainable by the relative salience of ITD and ILD cues as a function of azimuth. While we selected the ILD values on an individual basis during the parameter determination to encompass the targeted azimuthal range, we used a fixed range of ITD cues, which was only crudely adapted to the individual listener's sensitivity.

The pre- vs. posttest differences in 100-pps ILD weights were not related to the 100-pps pretest ITD thresholds. Therefore, baseline ITD sensitivity does not seem to be a predictor for reweighting potential. However, the correlation between the pre- vs. post differences in 100-pps ILD weights and ITD thresholds approached significance, suggesting that the amount of training-induced reweighting might be related to corresponding changes in ITD sensitivity, although this result should be interpreted with caution, given the small number of participants.

Interestingly, differences in 100-pps ITD thresholds across participants were not reflected in corresponding differences in 100-pps ILD weights. This could be due to the small number of participants and the overall variability in threshold and weight estimates. However, it might also be due to differences in the two tasks. During ITD threshold estimation, the level at the two ears was kept constant while the estimation of binaural cue weights with the methods used in this study included different ILDs and may thus involve interactions between ITD and ILD cues. Such interactions could also be a reason why better ITD detection thresholds with a clinical fine-structure coding strategy compared to an envelope-based coding strategy was reported to not be reflected in better binaural unmasking of speech [10]. Instead, binaural cue weighting may be a better predictor for such real-life tasks where multiple cues are present at the same time.

In conclusion, the present results are promising in terms of making low-rate fine-structure ITD information better usable with future CI-systems conveying reliable and salient ITD information.

5. ACKNOLEDGEMENTS

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