Improving methods for tinnitus-matching in patients with noise-like tinnitus - STSM Report

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1 Purpose of mission

Tinnitus matching in patients with noise-like tinnitus is a complex endeavor to conceptualize, parametrize and realize - especially compared to the rather straight-forward approach of matching a pure tone tinnitus to an external pure tone pendant (Henry et al., 2013). Concretely, neither (overall) loudness nor (central) pitch can be clearly defined in noise (tinnitus) sounds, especially in broad-band noise tinnitus where frequency distribution is equal over the audible spectrum (taking hearing loss into account where applicable). Yet narrow-band noise (NBN) tinnitus with a dominant centre frequency (e.g. through bandpass filtering) have also been reported. Given these two subcategories of noise-like tinnitus, we planned to invite participants with indicated noise-like tinnitus (i.e. both BBN and NBN) from the host's study pool for further evaluation.

On the software side, a method of adjustment (MOA) matching procedure has been already developed for pure tone tinnitus within the last STSM and successfully deployed in the study conducted afterwards (in review). Experiences gathered in both piloting and the actual study with the pure tone matching procedure built confidence (with a mean rating of the quality of match = 4.0 (range = 1-5, SD = 0.48, n = 30, all scores above 3). Given the manifold of parameters and an intrinsic sequence of synthesis steps (i.e. choice the noise type first, then application of filters and/or modulations (Roberts et al., 2008)) much effort was be spend in properly designing an accessible matching tool. Furthermore, given the ongoing discussion and recent insights (Basile et al., 2013; Hoare et al., 2014; Norena et al., 2002; Roberts et al., 2008; Henry et al., 2013, 2004; Henry and Meikle, 2000; Penner and Saran, 1994) contrasting self-reliant user driven tinnitus matching, tinnitus spectrum matching via likeliness methods, and forced-choice procedures, the pros and cons of the planned MOA tinnitus matching method had to be considered. The primary goal of the planned STSM was therefore to establish an intuitively controllable environment for tinnitus matching in patient with noise-like tinnitus. Digital synthesis (MAX software, https://cycling74.com/products/max/) was coupled with an external hardware controller to enable the patients to shape their noise-like tinnitus on their own. The established tinnitus matching procedure will then be used in future auditory stimulation studies on site. Generated noise-like tinnitus matching sounds will hopefully form the basis of noise stimuli of one future study.

2 Methods and Procedure

In a first phase the applicant installed and programmed both hard and software as well as testing the usability by himself (using the MAX software suite and a modular external controller, namely Palette Fear Expert Kit with 2 buttons, 3 dials and 2 sliders (https://palettegear.com/index, see Figure 1). Akin to previous work (Henry et al., 2013) and own considerations, we opted to implement bandpass filtering of white noise for NBN especially. This resulted in matching tool where 1) noise type (i.e. unfiltered BBN and bandpass-filtered NBN), 2) tinnitus side, 3) centre frequency of the filter (i.e. via coarse and fine tuning), 4) bandwidth of noise (i.e. continuously from 3db/octave up to 96 db/octave) and finally 5) loudness could be matched and compared with the tinnitus percept via 6) on/off switch. The design was reduced to an easily instructable set of steps or possibilities while distractions (screens, instructions) were minimized to ensure self-reliant matching with this MOA approach. Participants had no time limit and were instructed match until they were satisfied with the result. We furthermore interleaved a vocalization task before the MOA matching with the controller where participants were instructed to mimic their noise-like tinnitus by mouth. In contrast to pure tone tinnitus, these approach was deemed feasible as through whistling and sizzling it may be possible to more or less accurately simulate the phantom percept. Imitated sounds were then recorded and may serve for further evaluation of the MOA-matched sounds. Yet, exact statistical analysis methods have still to be considered at this point.

Concretely, participants took part in a single session retest experiment:
-First, the filled in a small form with items from the Tinnitus Sample Case History Questionnaire (TSCHQ, (Langguth et al., 2007)) focusing on descriptions of the tinnitus percept (item 13)
-Second, vocalization task with a recording duration of 5 seconds
-Third, the first round of self-reliant MOA matching
-Fourth, a break of about 15 minutes with distraction of participants and resetting of matching parameters
-Fifth, the retest of the vocalization
-Sixth, the retest of self-reliant MOA matching

To evaluate the quality of the matching, besides actual matching parameters, participants filled in a form rating their satisfaction with a) the matching result (i.e. the agreement between matched sound and perceived tinnitus sound) and b) the matching procedure (i.e. the handling and accessibility of the device). Furthermore duration was measured as well as possible changes to the tinnitus percept.

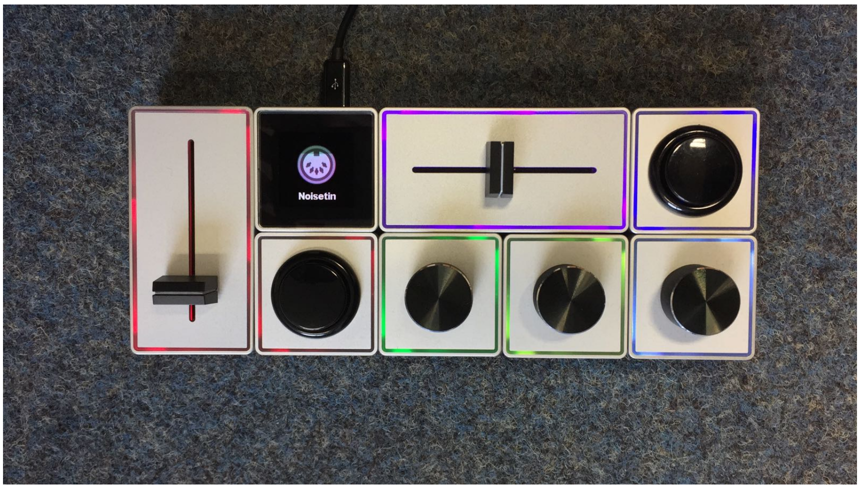

Figure 1: **Palette Gear hardware controller customized for noise-type tinnitus matching:** loudness fader (red), on/off switch (red), frequency tune dial (green), frequency fine tune dial (light green), (filter) bandwidth dial (light blue), filter switch (i.e., unfiltered BBN to bandpass-filtered NBN), panning slider for localization in stereo space (purple). Manipulated parameters are indicated on the mini screen in the upper left. Notably no screen is needed for the matching procedure.

3 Results and Discussion

Results of the two main dimensions, namely actual acoustic parameters of the matching as well as subjective rating of the matched sound and procedure, are reported in the following. First, matching resulting matching parameters and ratings are listed in Table 1 (n=4). Second, retest reliability elicited by correlation analysis for the main parameters of interest were observable except for filter bandwidth (loudness: r=0.997, p=0.003; panning: r=0.977, p=0.023; centre frequency: r=0.985, p=0.015; bandwidth: r=0.748, p=0.462).

Table 1: Results of matching procedure and retest

Loudness (dB)	Panning (0=left, 127= right)	Centre frequency (Hz)	Bandwidth	Rating matching (1-10)	Rating procedure (1-10)	
20	42	707	0.69	8	9	
50	56	2466	3.4	8	9	
80	64	6608	12.6	4	9	
38	90	1393	0.57	8	8	
Loudness t2	Panning t2	Centre frequency t2	Bandwidth t2	Rating matching t2	Rating procedure t2	C
23	50	934	0.83	8	9	
49	53	2355	7.3	8	9	
80	65	4771	14.4	4	10	
37	88	881	5	8	8	

For the exploratory comparison between vocalized noise-like tinnitus and MOA matchings are exemplarily illustrated in Figure 2.

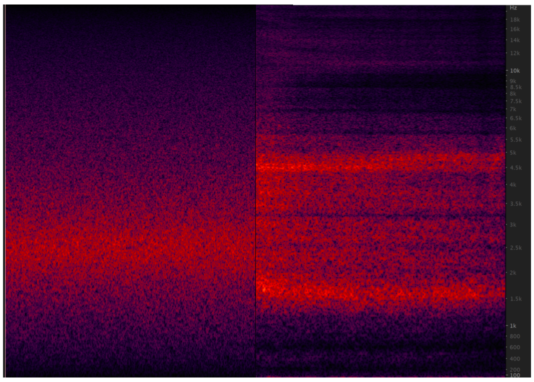

Figure 2: **Spectrogram of exploratory comparison between MOA matching sound (left panel) and vocalization (right panel) in subject 2:** Notably bandwidth and loudness (around 50 dB) are tentatively comparable. Yet, centre frequency could not be vocalized while inherent formant properties of the human articulatory organs are discernible (dual peak frequency, sharp bands).

Results implicate both feasibility (as seen in the high ratings of both matching (except subject 3) and procedure) and retest-reliability for most of the central parameters. Panning and loudness seemed to be reliably matched in both runs. Centre frequency exhibits considerable differences between runs in subjects 3 (6608 vs. 4771 Hz) and 4 (1393 vs 881 Hz) with both frequencies situated at least within the same octave. Bandwidth posed serious problems as visible in Table 1 (bandwidth q value of 0.5 refers to a filter slope of 3dB/Octave and 25 to a slope of 96dB/Octave). This comes as no surprise given the rather abstract or technical nature of this parameter: While (tinnitus) pitch, loudness, and laterality seem to be easy accessible to name, memorize and imitate, band noise seems to be challenging presumably also for musicians and audio engineers. Furthermore, the continuum from rather broad and noisy sounding matches (e.g. with bandwidth Q values of 0.5) to sharp, ringing and ‘resonating’ steep filter sounds may be further confusing, as many participants indicating difficulties to disentangle exclusive NBN tinnitus from a mixture of a pure tone tinnitus in a mixture with (often less loud) BBN. Future studies or approaches could therefore further test these inconsistencies. Of further note, the tonal quality of steep NBN may not be directly comparable to the tonal quality of the described mixture as filter properties (resonance quality) are highly determinant for the psychoacoustic percept and are not necessarily directly comparable to simple pure tones: they often may have a crude and instable tonal sound at the centre frequency. Hearing loss, which seems to be more widely distributed over all audible frequencies in noise-type tinnitus patients (Langguth et al., 2017), combined with the broad frequency distribution of the BBN and NBN tinnitus percepts (and consequently matchings) furthermore massively complicates all matching efforts. All in all, subtypization of and within the noise-like tinnitus should be promoted to tackle these issues. Matching and descriptions should be optimized for both better tinnitus characteristics assessment as well as, and more importantly, better sound therapies for tinnitus relief.

4 Future Directions

The matching procedure could ease the tinnitus matching in the specific subtype of noise-like tinnitus and will certainly be applied in respective future studies with audio stimulation in tinnitus at the host's institute. Yet the approach has to be further evaluated as noise-type tinnitus matching is a tricky subject compared to the omnipresent and conceptually rather straightforward (single) pure tone tinnitus matching. It comes as no surprise that only one article has tackled this issue (Henry et al., 2013) with mixed results and impressions. As in the previous work, technological limitations, especially with the low acoustic energy of (narrow-band) noise led to complications, which could be resolved. But with the hardware at hand, we could hardly reach the 80dB safety limit at the phones output when filtering maximally steep (96 db/Octave) at high frequencies. This poses some serious problems in matching especially in patients with severe hearing loss in relevant frequencies. Hardware upgrades like amplifiers and (hardware) limiters have to be considered to ensure both feasibility and safety, especially in self-reliant MOA approaches.

Future Collaboration As indicated above, future studies will try to optimize and deploy this matching approach at the host institute. Beyond that, the author was invited for postdoctoral fellowship at the host institute starting this autumn. A respective grant proposal is under review.

Output The planned study with noise-like tinnitus is envisioned to be published in a fitting peer-reviewed scientific journal.

Comments Not always, certainly also not in science, everything works out as planned. Specifically for this short-term scientific mission, it was difficult to recruit the specific subtype of patients with noise-like tinnitus from the host's study pool. In fact, many interested participants had to be disqualified due to tonal, pulsating or otherwise unsuitable tinnitus percepts. This opens the fundamental question, how research and clinical intervention can rely on subjective descriptions as well as diagnosed forms of different phantom percept sounds, outside the predominant tonal tinnitus. Yet, given the overall highly successful former STSMs at the host institute and the follow-up studies started within the STSM period are comforting in face of the tedious and challenging recruitment for this STSM resulting in the considerably low sample size.

All in all, from the three main goals set, namely 1) establishment of the procedure including soft- and hardware, 2) testing period with patients, and 3) preparation of a study for this specific tinnitus subtype, certainly 1) and 3) could be accomplished within the STSM's grant period to the full satisfaction of both host and guest.

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