Good Vibrations: A Proof-of-Concept Study of the Preferred Temporal Characteristics in Surf-Like Sounds for Tinnitus Therapy

Les bonnes vibrations : une étude de démonstration de faisabilité des caractéristiques temporelles des sons ressemblant à ceux du surf à privilégier pour le traitement des acouphènes

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Abstract

A common audiological method of tinnitus management is to reduce tinnitus audibility by masking. To be effective, masking sounds need to be comfortable for long periods of time. Nature sounds, such as ocean waves or surf sounds, have been suggested to be effective for this reason. Natural or simulated surf sounds are typified by rhythmic oscillations in intensity. There are established asymmetric behavioural and physiological responses to oscillatory sounds that are ramped (gradually increase in intensity then decrease rapidly) versus damped (increase rapidly then decrease gradually over time). Ramped sounds engage attention while damped sounds are more comfortable. The aim of this study was to determine if such asymmetries in response are also translated to tinnitus masking. Two experiments were undertaken with groups of 10 tinnitus sufferers. In Part 1, an experimental round-robin tournament method was used along with rating scales to compare preferences among four recordings of natural surf sounds. In Part 2, a round-robin tournament comparing nine simulated surf sounds was used. Results indicated a preference for damped sounds over ramped sounds. Slower oscillations (rise and decay times of 5–8 seconds) were preferred to faster oscillations (rise and decay times of 2 seconds). The asymmetry in short-term tinnitus masking response to ramped and damped sounds is consistent with existing psychoacoustic research. The potential clinical use of oscillatory sounds and mechanisms underpinning observations are discussed.

Abrégé

Une approche fréquemment utilisée en audiologie pour le traitement des acouphènes est le masquage par un son, ce qui réduit la sensation de l'acouphène. Pour être efficaces, les sons masquants doivent pouvoir être écoutés confortablement sur de longues périodes. C'est pour cette raison que les sons de la nature, comme les sons de vague ou de surf, ont été suggérés comme étant efficaces. Les sons de surf, naturels ou simulés, sont caractérisés par des oscillations rythmiques variant en intensité. Il y a des réponses comportementales et physiologiques asymétriques connues aux sons dont l'intensité augmente graduellement puis diminue rapidement et ceux dont l'intensité augmente rapidement puis diminue graduellement dans le temps. Les premiers attirent l'attention tandis que les deuxièmes sont plus confortables à écouter. L'objectif de cette étude était de déterminer si ces réponses asymétriques se traduisaient également par une diminution de la sensation des acouphènes. Deux expériences ont été réalisées auprès de groupes composés de 10 personnes ayant des acouphènes. Dans la première expérience (*Part 1*), une méthode expérimentale d'essais circulaires et des échelles de cotation ont été utilisées pour comparer les préférences des participants entre quatre enregistrements de sons de surf naturels. Dans la deuxième expérience (*Part 2*), un essai circulaire comparant neuf sons de surf simulés a été utilisé. Les résultats indiquent que les participants ont une préférence pour les sons dont l'intensité augmente rapidement puis diminue graduellement dans le temps. Les résultats indiquent également que les participants préfèrent les oscillations plus lentes (temps de montée et de descente entre 5 et 8 secondes) aux oscillations plus rapides (temps de montée et de descente de 2 secondes). Les réponses asymétriques observées lors de courts masquages des acouphènes par des sons dont l'intensité augmente graduellement puis diminue rapidement et des sons dont l'intensité augmente rapidement puis diminue graduellement dans le temps sont consistantes avec les résultats d'autres recherches en psychoacoustique. L'utilisation clinique potentielle des sons oscillatoires et les mécanismes qui sous-tendent les observations ayant été effectuées sont discutés.

Tinnitus is a common audiological complaint that is often managed by a combination of instruction, counselling, and sound therapy (Hoare, Searchfield, El Refaie, & Henry, 2014; Searchfield, Durai, & Linford, 2017). Tinnitus "sound therapy" is a catch-all name for therapies using sound to reduce tinnitus. Sound therapies include total and partial masking (Tyler, Noble, Coelho, & Ji, 2012), relaxation (Davis, Paki, & Hanley, 2007), desynchronization (Eggermont & Tass, 2015), tonotopic reorganisation (De Ridder, Vanneste, Engineer, & Kilgard, 2014), and other putative mechanisms (Searchfield et al., 2017). Although masking has its roots in observations of the effects of natural sounds on tinnitus (Stephens, 2000), its recent history began with the psychoacoustical observations of Feldmann (1971, 1981) and the development of wearable maskers by Vernon (1981). Forty years after its emergence as a clinical method for managing tinnitus, there is still debate as to the most appropriate level (Jastreboff, 1999; Tyler et al., 2012) and type of sound to treat tinnitus (Hoare et al., 2014; Searchfield et al., 2017), and mechanisms of tinnitus masking are still uncertain (Hoare, Adjamian, Sereda, & Hall, 2013).

Masking sound preferences are likely to vary from person to person and may be due to personality, memories, and context (Searchfield, 2014). Traditional masking sounds have tended to be steady state broadband noise. Broadband noise tends to be well tolerated, void of meaning, and stimulates a wide bandwidth of hearing—all factors thought to assist in habituation to sound (Jastreboff, 1999). Tone-based therapies have been developed as attempts to desynchronize or remap frequencies putatively involved in tinnitus perception (Eggermont & Tass, 2015). Natural environmental sounds, and synthesized copies, have recently re-emerged as sound therapy as digital signal processing, digital memory in ear level devices, and wireless streaming have become widespread (Barozzi et al., 2016). Although clinical trials do not demonstrate superiority of natural sounds over broadband noise in the medium term (Barozzi et al., 2016), there is some evidence of patient preference for temporal variation in sounds in the short term (e.g., Henry, Rheinsburg, & Zaugg, 2004), and it has been suggested that the mode of effect for natural sounds may be different from broadband noise over time (Durai & Searchfield, 2017). The effect of noise may be primarily due to a "presence of sound effect" masking tinnitus, while the effects of natural sounds may be a result of their influence on emotion (Durai & Searchfield, 2017).

Temporally varying noise with oscillations resembling ocean waves or surf sounds have become common options within hearing aid manufacturers' tinnitus treatment devices (Sereda, Davies, & Hall, 2017). The sounds may aid relaxation; however, the benefit and mechanism of effect is unclear. The rationale underpinning the selection of waveform and oscillation characteristics is very subjective. The importance of oscillation characteristics on normal audition is far from trivial (Bach, Neuhoff, Perrig, & Seifritz, 2009; Tajadura-Jiménez, Väljamäe, Asutay, & Västfjäll, 2010), yet little effort appears to have been made to investigate established psychoacoustical and emotional consequences of varying sound oscillation patterns on tinnitus (Reavis et al., 2012).

In the context of this study, oscillating sound refers to periodic changes in amplitude of the temporal envelope of natural or synthesized broadband noise. We deliberately exclude modulations in tones that are unlikely to be effective tinnitus maskers, but may disrupt tinnitus through other mechanisms (Reavis et al., 2012). We focus on sounds that oscillate in such a way as to be perceived to sound like ocean wave "surf" sounds. These sounds contain a wide frequency range and oscillate over time with an initial increase in intensity, a steady state (plateau) at maximum intensity, and then a decrease in intensity. A noise that oscillates over time with a rapid increase in intensity followed by a longer duration decrease in intensity over time is defined as *damped*. When a noise increases in intensity incrementally, but decreases are large and abrupt it is defined as *ramped*. Sounds that have equal rise and fall are defined here as *symmetrical*.

Classical examples of the use of variation in oscillation characteristics exist in music (Huron, 1992). In music, increases of stimulus intensity level are more effective than equivalent decreases in gaining listeners' attention (Huron, 1992). It is not possible to do this across an entire piece of music so instead composers have applied ramps where intensity increases are gradual, but stimulus decreases are large and abrupt (Huron, 1992). The temporal envelope of many sounds in nature are asymmetrical (Schlauch, Ries, & DiGiovanni, 2001). There may be an evolutionary reason for our response to ramped sounds, a perceptual bias to looming sounds may have provided a natural selection advantage as these sounds are perceived as approaching the listener and therefore have greater salience (Bach et al., 2009; Neuhoff, 2001; Tajadura-Jiménez et al., 2010). Ramped sounds have been argued to have greater saliency and elicit responses that would be expected to sounds containing warning information (Bach et al., 2009; Tajadura-Jiménez et al., 2010). Attention, and then response, to ramped sounds may have been an important factor in our survival. Such reactions are still observed in our modern environment; for example, we react when we hear a siren signalling the approach of an emergency vehicle. This perceptual bias for ramped sounds is further illustrated by the finding that there is overestimation of the change in loudness of ramped sounds, and is thought to be an important adaptive mechanism, since underestimating the actual distance of a sound source could provide the listener with a selective advantage (Neuhoff, 2001).

Ramped sounds have been shown to elicit greater skin conductance as a measure of alertness, and their perceived loudness is greater and they sound longer in duration (Bach et al., 2009). Ramped sounds have been rated as more unpleasant and arousing than damped sounds that appear to receed from the listener (Bach et al., 2009). This effect appears most clearly expressed in response to unpleasant sounds, but may not exist for pleasant or neutral sounds (Tajadura-Jiménez et al., 2010).

The purpose of this study was to evaluate patient preference for various recorded natural surf sounds and to create and compare simpler synthesized versions with varying temporal characteristics (i.e., different rise and fall time, plateaus, and speed of oscillation). To improve sound therapy effectiveness, we need to explore the various parameters of sounds used and factors leading to success or failure amongst individuals. The terms *proof-of-concept*, *pilot*, and *feasibility* are sometimes used interchangeably when referring to types of studies, but they are different. The use of these terms has been criticized in some publications as a mechanism to explain poor study design, or in particular, small sample size (Arain, Campbell, Cooper, & Lancaster, 2010). The different study designs have important roles in research (Eldridge et al., 2016). There are slightly divergent definitions of what a proof-of-concept study is depending on the field of research. In medical research, feasibility and proof-of-concept are often used interchangeably. In technology development, proof-of-concept is used as a mechanism alongside rapid prototyping to quickly ascertain the relative merits of concepts before development into a form that can be applied in feasibility or pilot studies (Kendig, 2016).

In this study, an engineering definition of proof-of-concept was used: initial data from a small number of tests to validate and inform the continual development of a technology (EPSRC, 2015). Our purpose was to evaluate possible sound therapy stimuli to focus efforts on the most promising temporal characteristic(s). It was hypothesized that there would be a preference between sounds for tinnitus management based on their temporal characteristics. It was proposed that damped sounds would be preferred from ramped sounds as tinnitus maskers.

Method

The University of Auckland Human Participants Ethics Committee approved the methods used in this study (protocol 7928). Participants were recruited from a tinnitus research volunteer database and were required to have continuously present tinnitus. All participants received an information sheet briefly describing the study and provided written informed consent. The research was undertaken in two parts. Part 1 was an experimental round-robin tournament along with rating scales to compare listeners' preference among four recordings of natural surf sounds. Part 2 was the synthesis and round-robin comparison of simulated surf-like sounds that had varying rise and fall times.

Procedures

Prior to the experiments, to enable their tinnitus experience and demographics to be recorded, participants were asked to complete a Tinnitus Case History Questionnaire (Langguth et al., 2007) and the Tinnitus Functional Index (Meikle et al., 2012).

Otoscopy (Welch Allyn 3.5 V Diagnostic Otoscope) was followed by pure-tone audiometry undertaken using the modified Hughson Westlake procedure (Carhart & Jerger, 1959) in a sound booth (ISO 8253-1) with an Otometrics Madsen Itera II or GSI-61 audiometer. Air conduction thresholds were recorded for 250–8000 Hz using insert earphones (ER-3A) or supra-aural (TDH-39P) transducers. Where a hearing loss was found, bone conduction testing at 500, 1000, 2000, and 4000 Hz was performed using a Radioear B-71 bone conductor transducer to ascertain conductive or sensorineural hearing loss.

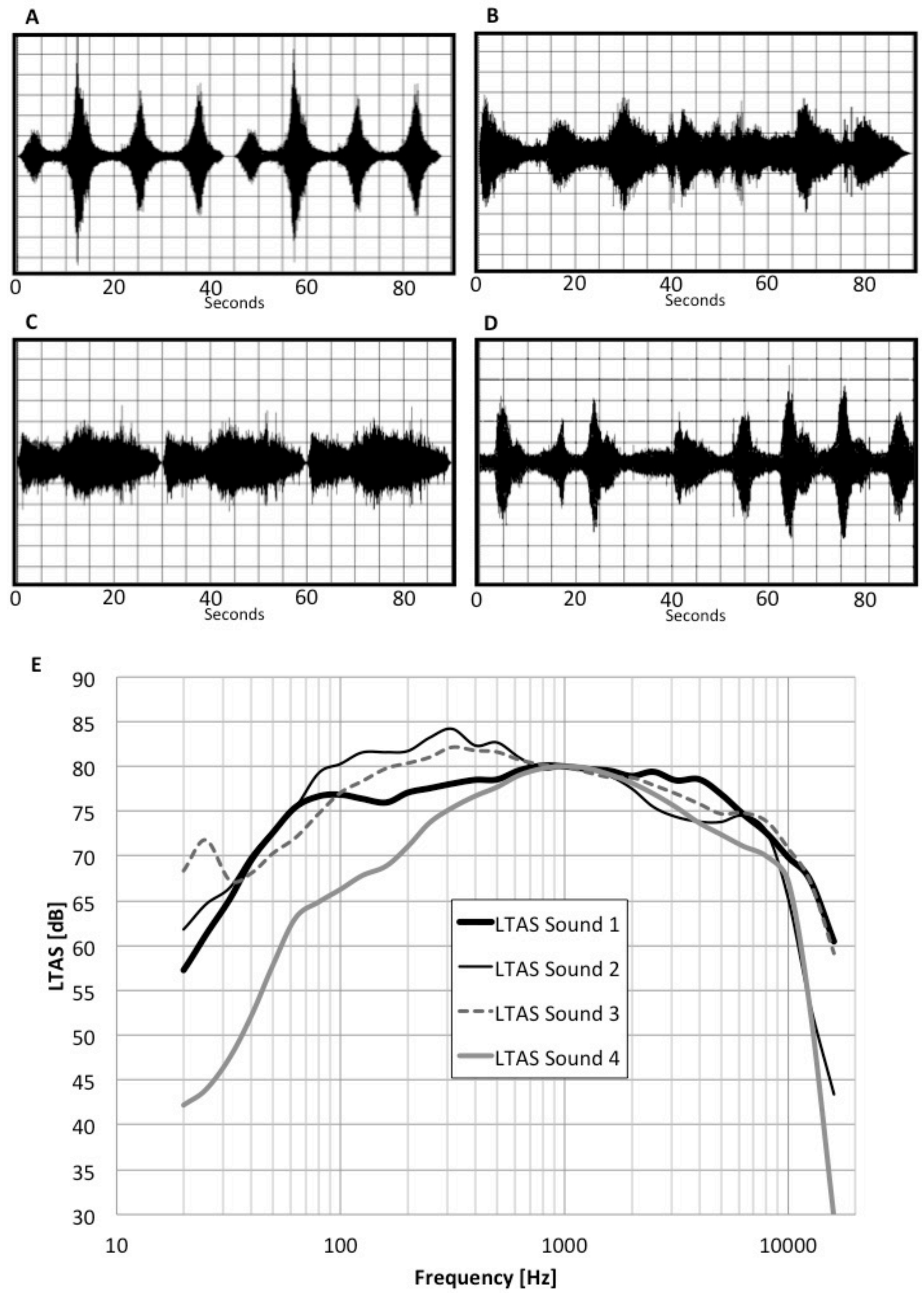
Custom Labview-based tinnitus testing software was used to determine tinnitus pitch of tinnitus with the participant responding to a 2-alternative, forced-choice method of pitch matching using tones at 15 dB SL (Sensation Level). To ensure there was no octave confusion, the matched pitch was re-presented to the participant and compared to tones that were one octave above and one octave below the estimated pitch.

Part 1: Natural Surf Sounds

Participants. Ten participants (5 men and 5 women) aged 37 to 68 years (*M* = 57 years) took part in this study. Participant characteristics are summarized in Appendix A.

Preparation of stimuli. Four audio recordings of ocean surf sounds, each 1.5 minutes in duration, were downloaded from the Internet (https://freesound.org/). The recordings

Figure 1



Temporal waveforms (envelopes, normalized scale); and E. Spectra of each nature sound recording (A–D). Visual analysis of the temporal waveforms of the four sound stimuli show that the various waves making up Sounds B and C had a quick rise and relatively slow decay (described as damped). Sounds A and D, on the other hand, had a combination of damped and ramped (gradual rise and relatively quick decay) waves. The waves of Sound A were also more symmetrical in shape. The length of each wave varied between sounds, with Sounds A and D having waves approximately 10 seconds in length, and Sound C having waves ranging between 10 and 20 seconds. The length of the waves in Sound B varied. Sounds B and D both had irregular patterns in comparison to Sounds A and C, with the distance between peaks varying throughout the two recordings. The interval between waves in each sound stimulus also differed, with Sound A having the longest intervals, and Sounds B and C having fewer and comparatively shorter intervals. Sounds A, B, and C have similar spectra. Sound D had less energy than the other three sounds, especially at low (< 1000 Hz) and high (> 10000 Hz) frequencies.

were selected based on their subjective sound quality and differing oscillation patterns. The recordings were normalized to a consistent root mean square using Audition audio editing software (Adobe) to equalize the sound energy of all four sounds. Individual attenuation parameters obtained from the participants' audiograms (Appendix A), at all frequencies, were applied to the four nature sound recordings to compensate for any hearing loss. To see whether there were any large differences in the long-term average spectrum of the four sound stimuli, each sound stimulus was measured by analysis of the average sound energy in each 1/3 octave band (**Figure 1B**).

Participants were asked to listen to the initial four 1.5-minute segments of ocean surf sound recordings played via Labview software (National Instruments, Austin, TX) on a computer connected to Sennheiser HD-280 pro circumaural headphones (Sennheiser, Germany) to determine their desired level for tinnitus masking. A method of adjustment was used with the researcher presenting the sound in 2 dB steps. Participants were instructed to select their desired level of sound masking based on comfort and reduced audibility of tinnitus at the time of testing. The desired level was described as "the lowest level that provided tinnitus relief and was comfortable to listen to for 5 minutes." The desired level did not vary greatly between sounds (standard deviation 1.6 dB). The test level was the average sensation level across the four sounds (Appendix A). Participants then listened to each sound at their chosen level for 5 minutes without making judgements. The stimuli were presented in counterbalanced order.

Rating scales. Following the 5-minute presentation of each sound, participants were asked to complete three rating scales while continuing to listen to the sound. A tinnitus loudness scale and tinnitus annoyance scale were used to evaluate the participants' subjective ratings of tinnitus loudness and tinnitus annoyance, respectively, in response to each sound. The tinnitus loudness scale and tinnitus annoyance scale ranged from the extremes of *not annoying at all* (1) to *very annoying* (10) and *not loud at all* (1) to *very loud* (10). The stimulus annoyance scale was used to evaluate participants' subjective ratings of stimulus annoyance and ranged from *very annoying* (1) to *pleasant* (10).

Round-robin tournament. A round-robin tournament (balanced paired-comparison method) of 6 trials was then used in which each of the four sounds were compared against every other sound to determine which sound was the most preferred across the comparisons (sound A vs. B, A vs. C, A vs. D, B vs. C, etc.). Each sound was played for as long as participants needed to make their judgement. Preferences between sounds were recorded and the standard ranking ("1, 2, 2, 4") method was used to order the sounds according to individual preference and account for ties.

Part 2: Simulated Sounds

Participants. A total of 10 participants (7 men and 3 women) aged 22 to 68 years (M = 54.2 years) took part. Five participants from Part 1 also participated in Part 2. Participant characteristics are summarized in Appendix A.

Preparation of stimuli. A pink noise track was generated using the Audition software. The pink noise was presented to the participants and the threshold level was obtained using an ascending method in 2 dB steps. Participants were instructed to select their preferred level of sound masking based on comfort and reduced audibility of tinnitus as described in Part 1. This level was used to test all temporal varieties of the noise (Appendix B). Labview software was used to generate nine simulated surf sound tinnitus maskers from the pink noise. The duration of each of the rise and decay (gain) components of the nine simulated surf sounds was varied (**Table 1, Figure 2**). All sounds included a 2-second period of maximum intensity (plateau) and a 2-second interval between waveforms.

Round-robin tournament. A round-robin tournament of 36 trials in which each sound stimulus was compared against every other sound stimulus (paired comparison) was used to determine which sound was the most preferred. The standard ranking method was used to order the sounds according to individual preference and account for ties.

Analysis. Nonparametric analysis of results was undertaken using GraphPad Prism version 5 for MacOSX. Continuous data were evaluated using Friedman's test with post hoc analysis using Dunn's multiple comparison test. Spearman rank correlations were calculated to evaluate the relationship between individuals' selections of sounds.

Results

Part 1

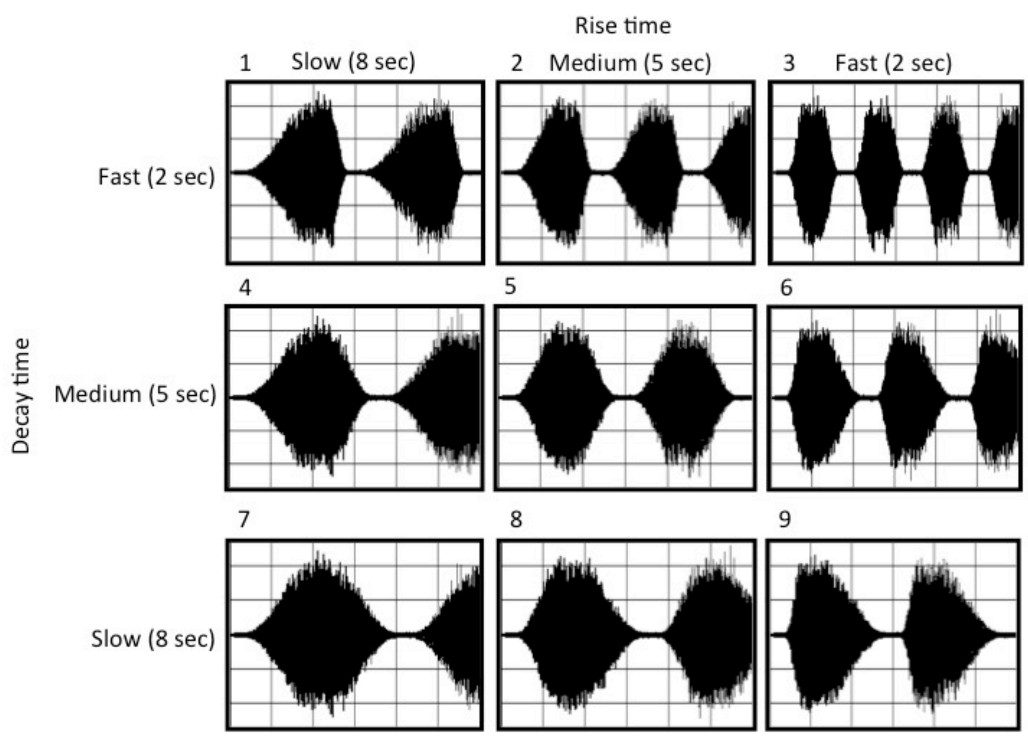
There was a statistically significant difference in tinnitus loudness depending on condition (**Figure 3A**), $\chi^2(5) = 15.1$, $p < .005$. Post hoc analysis using Dunn's multiple comparison test did not identify any statistically significant differences between pairs of conditions. There was a statistically significant difference in tinnitus annoyance depending on condition (**Figure 3B**), $\chi^2(5) = 29.7$, $p < .001$. Post hoc analysis using Dunn's multiple comparison test found all

Table 1

Temporal Characteristics of the Nine Simulated Surf Sounds Generated

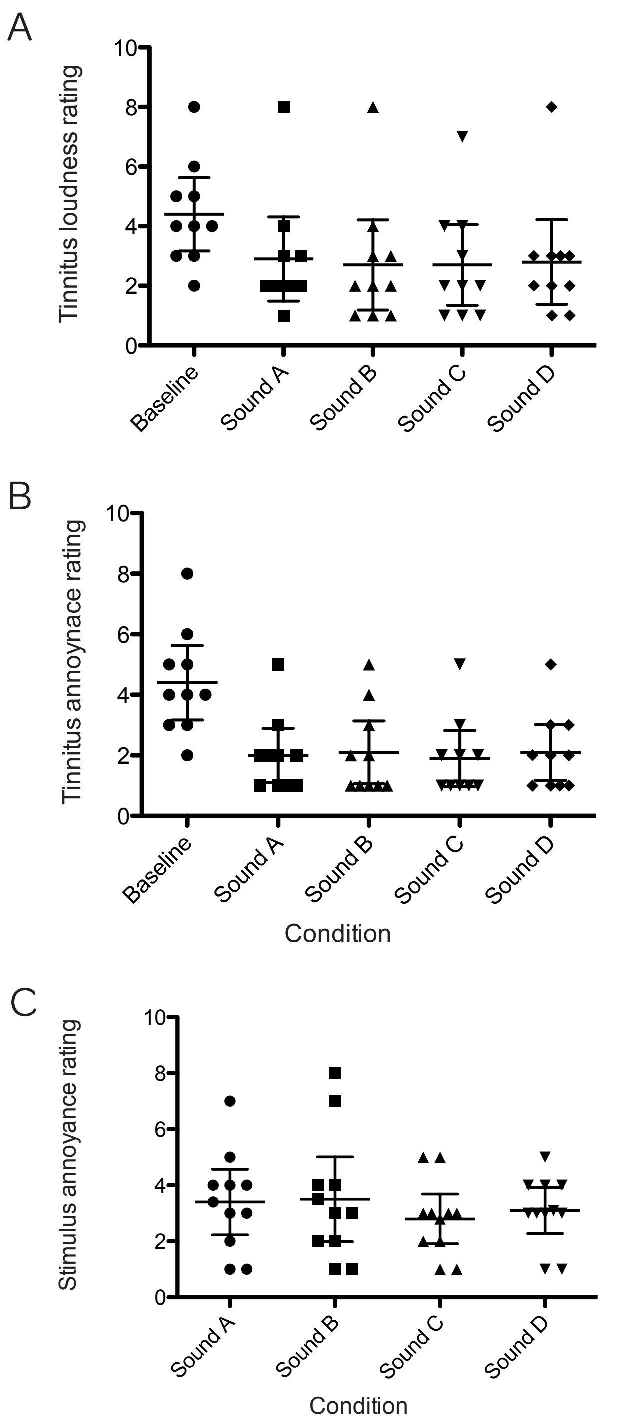
	Rise (sec)	Plateau (sec)	Fall (sec)	Interval (sec)
Sound 1	8	2	2	2
Sound 2	5	2	2	2
Sound 3	2	2	2	2
Sound 4	8	2	5	2
Sound 5	5	2	5	2
Sound 6	2	2	5	2
Sound 7	8	2	8	2
Sound 8	5	2	8	2
Sound 9	2	2	8	2

Figure 2



Waveform view of the first 30 seconds of each of the nine simulated sounds. The sounds are arranged into a matrix according to rise and decay times. The changes in intensity as a function of time of each of the nine sound stimuli are shown. Sounds 3, 5, and 7 are symmetrical with identical rise and decay times. The temporal envelope of Sounds 1, 2, and 4, on the other hand, are asymmetrical with a gradual rise and comparatively quick decay. These sounds are referred to as "ramped." Sounds 9, 6, and 8 have a rapid onset and gradual decay so are "damped."

Figure 3



Individual ratings of A. Tinnitus loudness. B. Tinnitus annoyance. C. Stimulus annoyance during presentation of each sound stimulus. Baseline, no sound, ratings are shown for A and B.

sounds had lower median annoyance ratings compared to baseline (baseline median = 4.0; Sound A median = 2.0, $p < .05$; Sound B median = 1.5, $p < .05$; Sound C median = 1.5, $p < .01$; Sound D median = 2.0, $p < .05$). However, there was no statistically significant difference in stimulus annoyance between the sound conditions (**Figure 3C**).

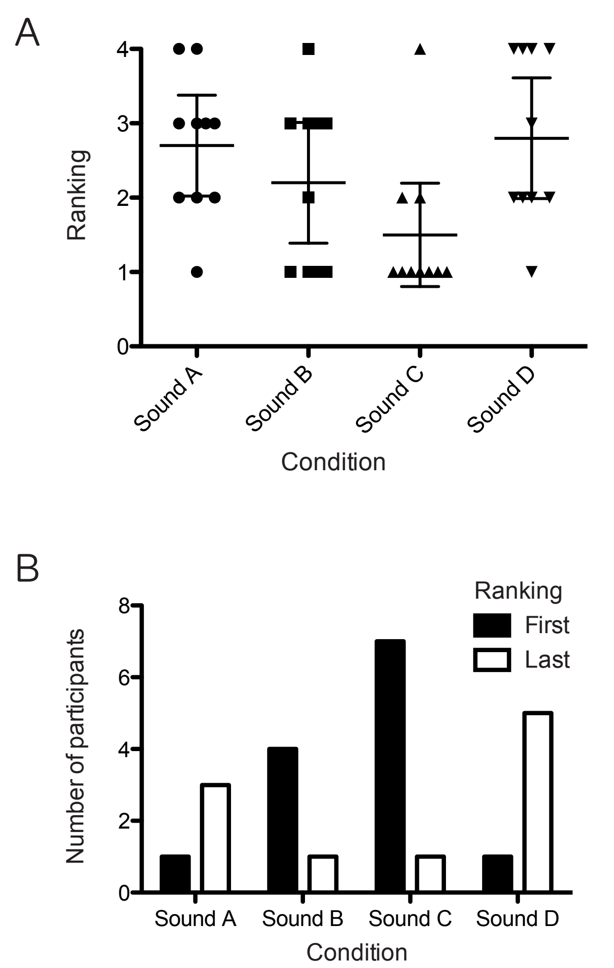
Standard rankings for the round-robin tournament (**Figure 4A**) showed that Sound C had the lowest (best) ranking (median = 1.0) compared to Sound B and Sound D (median ranking = 2.5) and Sound A (median ranking = 3.0). A Spearman's rank-order correlation was run to determine the relationship between the sound rankings (matrix shown in Appendix B). There was a strong, negative correlation between Sound A and D, which was statistically significant, $r_s(2) = -0.68$, $p < .05$ (matrix shown in Appendix C). Sound C was most frequently ranked as the best sound, while Sound D was most often ranked last (**Figure 4B**).

Part 2

Standard rankings for the round-robin tournament (**Figure 5**) showed that Sound 5 had the lowest (best) ranking (median = 2.5) compared to Sound 3 that had the highest (worst) ranking (7.5). A Spearman's rank-order correlation was run to determine the relationship between the sound rankings (Appendix C). There was a strong, negative correlation between Sound 1 and 3, $r_s(7) = -0.65$, $p < .05$; Sound 1 and 6, $r_s(7) = -0.67$, $p < .05$; and Sound 1 and 9 $r_s(7) = -0.77$, $p < .05$, which were statistically significant. There was a strong, statistically significant positive correlation between Sound 1 and 4, $r_s(7) = 0.65$, $p < .05$. There was a strong, statistically significant, negative correlation between Sound 2 and 6, $r_s(7) = -0.7$, $p < .05$. There was a very strong, negative correlation between Sound 3 and 4, $r_s(7) = -0.86$, $p < .01$, and Sound 3 and 7, $r_s(7) = -0.86$, $p < .05$. Sound 3 had a strong positive correlation with Sound 9, $r_s(7) = 0.78$, $p < .05$. Sound 4 had a strong positive correlation with Sound 7, $r_s(7) = 0.76$, $p < .05$, and a very strong, negative correlation with Sound 9, $r_s(7) = -0.86$, $p < .01$. There was a strong, negative correlation between Sound 5 and 8, $r_s(7) = -0.68$, $p < .05$, and a very strong, negative correlation between Sound 7 and 9, $r_s(7) = -0.82$, $p < .01$.

The nine sounds were collapsed into three categories of symmetrical, ramped, and damped (**Figure 5B**). Damped sounds were slightly more frequently ranked as best (7 times) compared to symmetrical sounds (5 times) with ramped sound favoured by only two participants. The symmetrical sounds were most frequently rated last (11 times).

Figure 4



A. Individual rankings (1–4) for each surf sound by participants. B. Summary of the number of first and last rankings for each of the four sounds.

Discussion

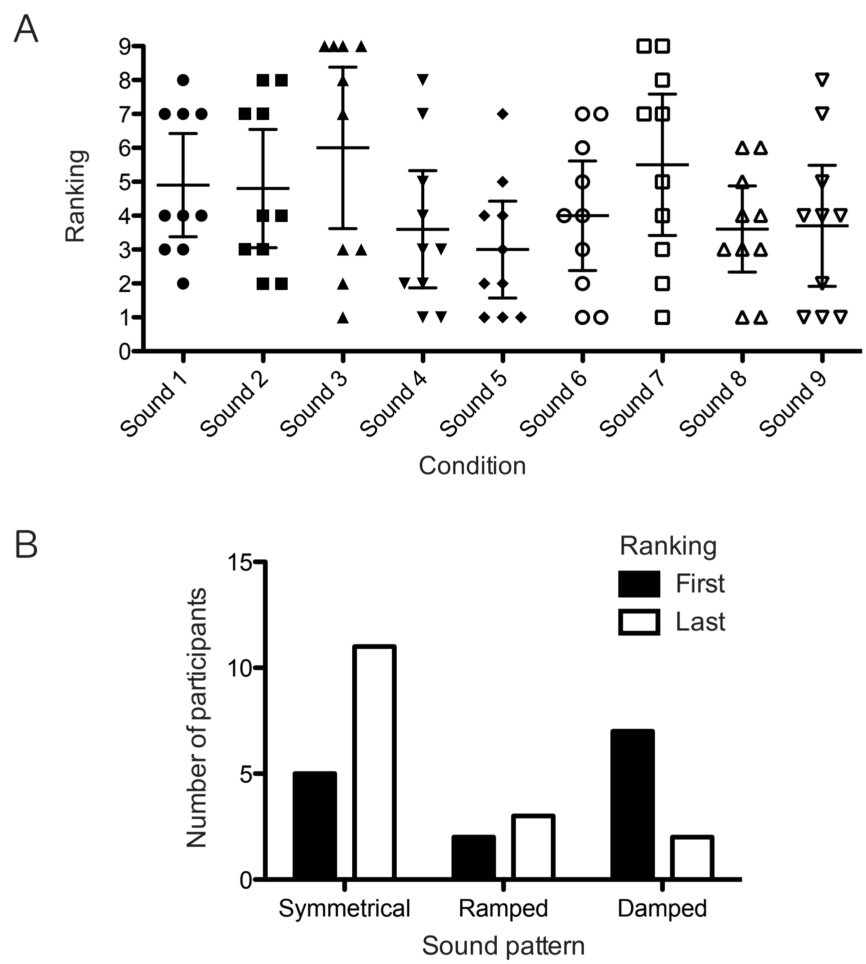
In two experiments, we attempted to evaluate the components of oscillating sounds that led to user preference as maskers. The selection of sounds was based on existing psychoacoustical and musicology evidence indicating that ramped sounds should engage attention more than damped sounds, whereas damped sounds should be more comfortable than ramped sounds. We hypothesized that there would be a preference between sounds for tinnitus management based on their temporal characteristics. It was proposed that damped sounds would be preferred from ramped sounds as tinnitus maskers.

Consistent with the known heterogeneity of tinnitus, the participants varied in their preference for masking sound. The results showed a general positive effect of surf-like sounds on tinnitus loudness and annoyance compared to a no sound baseline. Sound C had a lower, but not statistically significant, rating on annoyance. A strong negative correlation between Sound A and D suggested opposite ratings for individuals (i.e., those rating one highly tended to rate the other lowly). Both Sounds A and D had a combination of damped and ramped waves. The waves of Sound A were also more symmetrical in shape. The length of Sounds A and D were similar, approximately 10 seconds in length. The waves differed slightly in that Wave D appeared to contain more damped waves, and Wave A was more regular in rhythm. Sound A and D did not rank highly compared to Sound A. More participants ranked Sound C highly; this surf sound had a damped characteristic with relatively small differences between minimum and maximum energy peaks.

In an attempt to simplify the aspects of sound being compared, a base sound of pink noise was modified in the temporal domain to create nine sounds with different temporal characteristics. Although this resulted in many comparisons for a small number of participants, some interesting trends were evident. The results suggest a preference for sound stimuli with a decay time of 5 to 8 seconds and with a medium to slow modulation rate (14–17 seconds). The standard sound (with a symmetrical temporal pattern) that was most preferred was Sound 5 with a length of 14 seconds. The asymmetrical sound that appeared to be most preferred was Sound 9 that had waves with a damped shape. The sounds that were ranked highly most often (i.e., Sounds 4, 5, 6, 8, 9) all had medium to slow decay times, resembling a receding sound. Sound 7 also had this characteristic but was symmetrical in profile. At face value, these findings correspond with those of the nature sound experiment, in which the winning sound stimulus (Sound C) had waves with a damped shape and length ranging from 10–20 seconds.

When rankings were correlated, several factors appear to have contributed to the final rankings. There were positive correlations between sounds with a slow rise time; persons who liked or disliked the ramped sounds had ramped sounds ranked similarly. For persons for whom damped sounds were ranked highly, ramped sounds ranked low. This is most clearly a factor for Sound 9 versus Sound 1 and Sound 6 versus Sound 2. These sounds were negatively correlated but differed only in being damped versus

Figure 5



A. Individual rankings (1–9) for each simulated surf sound by participants. B. Summary of the number of first and last rankings for each category of sound.

ramped. Although symmetrical and damped sounds were most frequently preferred, some persons preferred the ramped sounds. The correlations provide some preliminary evidence that the timing of sounds may be contributing to preference, but it is possible that there were other characteristics contributing to preferences.

The trend for damped sound over ramped sound seen in this experiment could be due to the comparatively reduced arousal evoked by damped sounds as these sounds may be perceived as moving away from the listener. Although not directly assessed here, it is possible that ramped sounds did capture attention more than damped sounds, but most, although not all, participants chose comfort over attention diversion. As the sounds elicit different activity in particular neutral networks and specific cell types they may also act directly on neural assemblies that contribute to tinnitus perception (Olsen & Stevens, 2013; Wang, Qin, Chimoto, Tazunoki, & Sato, 2014).

Conclusion

This is a proof-of-concept study that evaluated participant preferences to natural and simulated surf sounds of varying oscillatory patterns. The study did not intend to evaluate all potential combinations of oscillations nor did it purport to determine the long-term effects of preferences. The results suggest the temporal pattern of sounds be considered alongside frequency content and overall intensity as the basis for sound selection for tinnitus sound therapy. As hypothesized, there was an asymmetric response to ramped and damped sounds in reference to tinnitus perception. A slow oscillation rate also appears to be an important factor in participant preferences.

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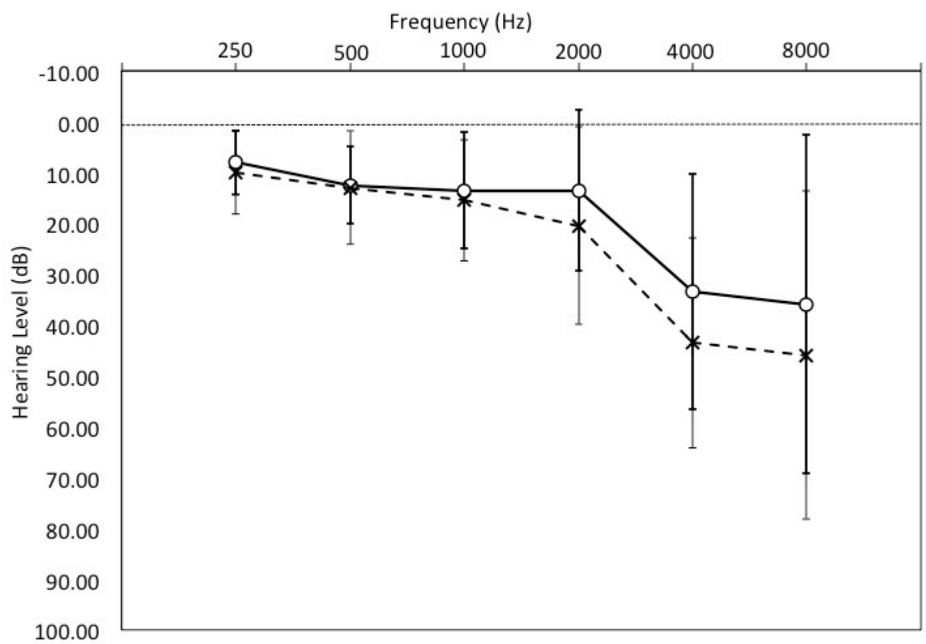
Appendix A
Participant Characteristics Part 1

Figure A1



Average hearing thresholds of participants in Part 1, error bars represent +/- 1 standard deviation (o right ear, x left ear).

Table A1

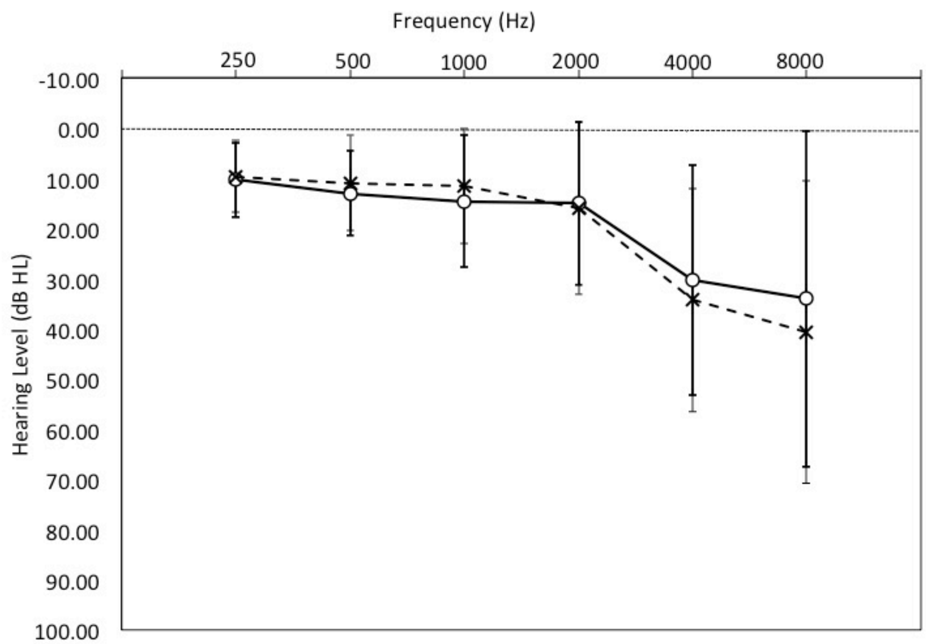
Tinnitus Characteristics of Participants in the Natural Surf Sound Comparison

	Age (years)	TFI score	Pitch (Hz)	Test level (dB SL)
1	37	53.6	12700	22
2	50	21.6	15200	20
3	61	9.6	12700	20
4	60	45.6	7900	20
5	62	6.8	6300	20
6	64	11.2	13700	28
7	68	24.0	10100	20
8	64	22.8	7000	25
9	43	18.4	9000	35
10	61	36.1	11900	28
Mean	57	25.0	10650	23.8
SD	10.2	15.6	3033.2	5.1

Note. The test level is the level at which all the sounds were presented for that individual. TFI = Tinnitus Functional Index, dB SL = decibels sensation level, SD = standard deviation.

Appendix B
Participant Characteristics Part 2

Figure B1



Average hearing thresholds of participants in Part 2 error bars represent +/- 1 standard deviation (o right ear, x left ear).

Table B1

Tinnitus Characteristics of Simulated Sound Participants

	Age (years)	TFI score	Pitch (Hz)	Test level (dB SL)
1	50	21.6	15200	29
2	68	24.0	10100	12
3	62	6.8	6300	30
4	51	24.4	10700	16
5	50	89.2	3800	26
6	58	24.0	11000	18
7	60	45.6	7900	16
8	61	36.1	11900	30
9	60	10.4	10000	33
10	22	24.4	5700	19
Mean	54.2	30.7	9260	22.9
SD	4.0	7.4	1036	7.8

Note. The test level is the level at which all the sounds were presented for that individual. TFI = Tinnitus Functional Index, dB SL = decibels sensation level, SD = standard deviation.

Appendix C
Correlation Matrices

Table C1

Correlation Matrix of Rankings for the Surf Sounds

	Sound A	Sound B	Sound C	Sound D
Sound A	-	0.22	0.45	-0.68*
Sound B	0.22	-	-0.36	-0.31
Sound C	0.45	-0.36	-	-0.30
Sound D	-0.68*	-0.31	-0.30	-

Note. *p < .05.

Table C2

Correlation Matrix of Rankings for the Surf Sounds

	Sound 1	Sound 2	Sound 3	Sound 4	Sound 5	Sound 6	Sound 7	Sound 8	Sound 9
Sound 1	-	0.25	-0.65*	0.76*	-0.03	-0.67*	0.65*	0.28	-0.77*
Sound 2	0.25	-	0.20	0.00	0.20	-0.70*	-0.23	-0.30	-0.23
Sound 3	-0.65*	0.20	-	-0.86**	-0.20	0.13	-0.86**	-0.28	0.78*
Sound 4	0.76*	0.00	-0.86**	-	0.39	-0.46	0.76*	-0.01	-0.86*
Sound 5	-0.03	0.20	-0.20	0.39	-	-0.24	0.34	-0.68*	-0.52
Sound 6	-0.67*	-0.70*	0.13	-0.46	-0.24	-	-0.19	0.05	0.53
Sound 7	0.65*	-0.23	-0.86**	0.76*	0.34	-0.19	-	0.12	-0.82**
Sound 8	0.28	-0.30	-0.28	-0.01	-0.68*	0.05	0.12	-	0.03
Sound 9	-0.77*	-0.23	0.78*	-0.86**	-0.52	0.53	-0.82**	0.03	-

Note. *p < .05, **p < .01.