Original Article

Deductive Development and Validation of a Questionnaire to Assess Sensitivity to Very Low and Very High Frequency Sounds: SISUS-Q (Sensitivity to Infra-Sound and Ultra-Sound Questionnaire)

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Abstract

Auditory research and complaints about environmental noise indicate that there exists a significant, small subgroup within the population which is sensitive towards infra- and low-frequency or ultra- and high-frequency sounds (ILF/UHF). This paper reports on the development, factorization and validation of a measures of sensitivity towards frequencies outside the common hearing range. Principal component and exploratory factor analyses in a sample of 267 Europeans (from the UK, Slovenia, and Germany) suggested that ILF versus UHF sensitivity constitute different factors, each characterized by sensory perception, stress-responsivity, and behavioral avoidance. A third factor comprising beliefs of dangerousness of ILF and UHF emerged. The factors explained 72% of the variance. The factor-solution was replicated separately for the English ($n = 98$) and German ($n = 169$) versions of the questionnaire (Slovenians and UK residents filled out the English version). Acceptable to excellent reliability was found. ILF and UHF sensitivity were moderately related to noise sensitivity in the normal hearing range, suggesting the new measures are not redundant. Correlations with psychiatric and somatic symptoms were small to moderate. ILF sensitivity correlated with neuroticism (small effect) and daytime sleepiness (moderate effect). ILF and UHF sensitivity were related to agreeableness (small effects). Overall, the novel ILF and UHF sensitivity scales seems to provide a solid tool for conducting further research on the role of sensitivity concerning adverse effects of ILF and UHF sound (e.g. health outcomes, annoyance ratings). The questionnaire consortium recommends using the new scales in combination with established measures of normal hearing range sensitivity.

Keywords: Extreme frequencies, infrasound, questionnaire validation, sound perception, ultrasound

INTRODUCTION

Infrasound is defined as sound below the average human hearing threshold of 20 Hz, although this definition is no longer sustainable given that sound at even lower frequencies can be perceived when presented at sufficiently high sound pressure levels (SPL).[1,2] What is referred to as low frequency noise (LFN) in the literature includes frequencies of up to 200 Hz[3] and often also comprises infrasound components. The two are therefore frequently mixed up in research and referred to as ILFN (infrasound and low frequency

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noise). Sound sources emitting ILFN are ubiquitous in modern human environments. Examples are road traffic, wind farms, large ventilation systems, and heat pumps; natural sources include earthquakes, ocean waves, wind, or thunderstorms.

More than twenty years ago the scientific consensus was that '(. . .) there is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects'.[4] Another, more recent review however summarized adverse effects of infrasound in three domains: *psychological* (mainly annoyance, but also depression and anxiety), *biological/somatic* (e.g. vertigo, disorientation, nausea, sleep disturbance, blood pressure and skin conductance changes, resonance in inner organs such as heart and abdomen) and *cognitive/ attention* (e.g. lack of concentration, decreased alertness).[3] Another, more recent non-exhaustive overview paper hypothesized that because body cells emit sound at very low frequencies between 6 and 12 Hz (muscle and organic tonus) and each body, including different parts or organs, have different resonance properties, differential interactions of individuals with ILF sound in the environment are likely.[5] It is also known that interindividual differences in the perception of sound get more strongly pronounced below 20 Hz: exactly the same stimulus can be loud and annoying to one individual, while it may be inaudible for another person.[2] Similarly stressing the notion of inter-individually divergent effects of ILFN, Michaud and colleagues[6] reported that only about 7% of residents living in the vicinity of wind turbines were significantly annoyed about noise emitted by the machines, with the majority of complaints coming from the age group on individuals between 40 and 46 years. An experimental study that investigated annoyance caused by LFN combined with infrasonic sound components revealed that individuals with high vs. low 'reactivity' (this is the term used – not further specified by the authors) reported more symptoms, such as bodily sensations, discomfort, fatigue, headache, and general discomfort.[7] Similar results were obtained concerning individuals classified as highly sensitive to LFN based on two questions that the authors derived at the level of face validity[8](i.e. "Are you sensitive to low frequency noise", "I am sensitive to rumbling noise from ventilation systems"). In that study, highly sensitive individuals had a larger decline in task performance and a stronger increase in annoyance relative to non-sensitive subjects that were tested under LFN (vs. reference noise) (i.e. ventilation noise with vs. without infrasonic components). The same authors found that after being exposed to LFN for two hours, the normal circadian decline in cortisol concentration was altered only in subjects who were highly sensitive to noise in general (normal hearing sound range), but not in non-sensitive subjects.[9] From psycho-acoustic experiments it has been concluded that there are individuals with *'extraordinary sensitivity in the low and infrasonic frequency range'*, as some individuals had a much lower sound detection threshold than others.[2] In another study, individuals who complained about ILF sound have been shown to have similar hearing thresholds in the ILF range to controls, but unpleasantness ratings were higher, and tolerance levels in terms of sound pressure were lower for the same frequencies below 20 Hz.[10]

The term 'ultrasound' refers to frequencies above the average human hearing range limit of 20 kHz however as for ILF sound, given higher SPL, evidence is accumulating that individuals can perceive sounds at even higher frequencies.[11] High-frequency noise (HFN) includes sounds within the high audible frequency range (8–20 kHz).[4] Concerning ultrasound and high frequency noise (UHFN), similar adverse effects have been summarized as for infrasound, such as dizziness, irritation, fatigue, tinnitus, pressure in the ears, headache, fearfulness, annoyance, discomfort, nausea, hearing impairment, and problems concerning speech intelligibility.[12] UHFN emitting devices are common in modern environments: ultrasonic door sensors, movement sensors, hand dryers, pest control systems, and electrical transformers for instance can emit UHFN. More recently, first well-controlled laboratory studies on UHFN seem to confirm discomforting effects of ultrasound. In a randomized-controlled study, participants were exposed to very high frequency/ultrasound (13.5–20 kHz), which elicited significant increases in self-reported annoyance and difficulties in concentration as compared to a reference stimulus. Yet, these results were restricted to a group of particularly sensitive individuals, who already complained about being bothered by ultrasonic noise before participating.[13] In another study, sensitive individuals (i.e. individuals who complained about symptoms in response to suspected ultrasonic sources in public areas) were tested in a controlled design exposing them to ultrasound (a 20 kHz tone presented continuously for 20 minutes at 15 dB below the participants' detection threshold) vs. a sham condition. They were unable to discriminate between the two conditions and exposure to ultrasound had no impact on reported symptoms. However, there was evidence for small nocebo effects concerning subjective adverse symptoms such as pressure on the ears, fatigue, headache, nausea, or anxiety, which were associated with the expectation of ultrasound being present.[14] Differences in sensitivity are apparent concerning hearing thresholds. About 5% of people (40–49 years of age) have been found to have hearing thresholds in the ultrasonic frequency range that were at least 20 dB more sensitive at 20 kHz than that of a younger age group (30–39 years of age).[9]

As may have become apparent from this brief literature overview, both research and industry would benefit from being able to determine ILF or UHF sensitivity in a psychometrically appropriate manner to account for interindividual differences in responsivity towards these types of sounds in experimental, epidemiological or survey-based studies. Although some studies also found evidence for nocebo effects (i.e. negative expectations favoring symptoms, even in sham conditions),[14,15] a significant number of studies, as reviewed here, still confirms interindividual differences in symptoms, annoyance and hearing thresholds for ILF and UHF sound. So far, measures of normal sound sensitivity, such as the Weinstein Noise Sensitivity Scale,[16] or self-developed, single questions have been used to assess ILF sensitivity,[8] or researchers included individuals who explicitly stated that they were particularly sensitive to airborne ultrasound for experimental purposes. This paper argues that a theoretically derived and validated instrument to measure sensitivity for ILF or UHF needs to be developed. The aim of this study was hence to create a questionnaire that can assess ILF and UHF sensitivity that is economic (brief) and psychometrically valid. This issue was addressed using deductive item generation rules based on a facet-approach. The questionnaire development and hence consortium was part of EARS II (https://www.ears-project.eu) an international European Union-funded project. Online survey data across England, Slovenia and Germany was collected. This data was factor analyzed in order to investigate whether low- and high frequency sensitivity clustered largely together, or whether these constituted rather independent factors (constructs). Furthermore, correlation coefficients were calculated to derive associations between self-reports of psychiatric and somatic symptoms, personality, somatic, and normal sound/ noise sensitivity with the new scales in order to investigate construct validity and overlap (i.e. redundancy of the new questionnaire) with already established measures of sound sensitivity.

METHODS

The ILF and UHF frequencies sensitivity questionnaire: questionnaire conceptualization

An expert meeting was held with members of the EARS II project team, including physicists with expertise in acoustics and neuroscience, as well as a psychologist, to elaborate on an ILF and UHF sensitivity working definition, and on a model based on literature review and expert opinion. Our working definition of ILF or UHF sensitivity was as follows:

ILF or UHF sensitivity are moderately stable traits that, in part independent from other sound features (such as loudness), account for the interindividual differences in reactions towards a given ILF or UHF acoustic stimulus. This sensitivity can be furthermore understood as a dispositional reactivity (or reaction potential) towards noise/sounds in the ILF or UHF range. The dispositional reactivity can be observed on four dimensions: a *perceptual* (i.e. lower perception threshold/ altered senses), an *emotional* (i.e. heightened arousability or stress reactivity in response to ILF or UHF sound), a *cognitive* (i.e. automated negative evaluation/ beliefs of or about ILF/ UHF sound) and a *behavioral* (i.e. automated reaction tendencies induced by ILF or UHF sound, particularly flight/avoidance responses) dimension.

The adoption of these four dimensions was based on a behavioral analysis as commonly performed in cognitive behavioral therapy (CBT), as the expert consortium thought this would be best suited to understand the processes underlying adverse outcomes often described by individuals who refer to themselves as sensitives. Loosely drawing upon Guttman's facet theory,[17] the consortium relied on a systematic scheme for item generation. Hence, first a dimensional matrix of contents that needed to be addressed given the pre-definition of the construct was established. Every cell (= facet) of the matrix was then to be filled with an equal number of items (i.e. questions to assess the facet), and these items needed to be constructed in a symmetrical manner in terms of phrasing. The result was a symmetrical and balanced questionnaire [see Table 1]. The advantage of our or similar approaches is that one avoids to unwantedly overemphasize certain aspects of a construct. All questions were discussed until a consensus was reached, and all of them were developed simultaneously for an English and a German version by the multi-national team with the aid of native speakers from both sides. The English version was constructed so that it could also be used in other countries by participants with sufficient English language knowledge, and hence the English questionnaire was also used in Slovenia.

Table 1: Result of the item generation process based on several pre-defined facets of infra-/ low frequency (ILF) or ultra-/ high frequency (UHF) sensitivity.

Domain	ILF sensitivity	UHF sensitivity
Self-appraisal	I am more sensitive to low-pitched noises/sounds than other people.	I am more sensitive to high-pitched noises/sounds than other people.
Perceptual	I can hear or otherwise perceive (e.g. via bodily sensations) low-pitched noises/sounds more often than other people/I perceive them more intensely than others.	I can hear or otherwise perceive (e.g. via bodily sensations) high-pitched noises/sounds more often than other people/I perceive them more intensely than others.
Emotional	Low-pitched noises/sounds particularly bother me.	High-pitched noises/sounds particularly bother me.
Cognitive (attitudinal)	Low-pitched noises/sounds, that people may not even hear, can be dangerous or have a negative effect on people.	High-pitched noises/sounds, that people may not even hear, can be dangerous or have a negative effect on people.
Behavioral	I try to avoid low-pitched noises/sounds or leave situations in which these types of noises/sounds occur.	I try to avoid high-pitched noises/sounds or leave situations in which these noises/sounds occur.

The word 'bother' for the emotional facet of sound sensitivity was chosen in order to differentiate this from 'annoyance', as often reported in the literature. The expert consortium agreed that 'bothered' would better approximate an immediate 'excitability' or 'irritation', whereas annoyance more strongly relies upon a strong cognitive component, such as a negative appraisal/evaluation of the sound.

Measures for construct validation

The majority of measures for construct validation were taken only in the German validation sample at the UKE (Universitätsklinikum Hamburg-Eppendorf, Germany), with the exception of the Weinstein Noise Sensitivity Scale (WNSS),[16] which was assessed in all other samples (please refer to the *Participant Recruitment and Procedure* subsection for further explanations and details). All measures will be briefly described in the following.

Somatic symptoms, stress and global severity of psychiatric symptoms

The Patient Health Questionnaire-15 (PHQ-15)[18]measures the severity of somatic symptoms, summarizing the top 15 physical health complaints (e.g. headache, nausea, dizziness) of patients seeking ambulant treatment. Items were rated for the past two weeks on a 3-point Likert scale (0 = *not bothered at all*; 1 = *bothered a little*; 2 = *bothered a lot*). Cronbach's alpha for the scale was .80 in the original study and was acceptable in the present sample (0.77). The brief symptom inventory (BSI) assesses 53 symptoms frequently reported in psychiatric settings, including mental health and somatic symptoms.[19] The total severity index was used, which includes all items from the entire questionnaire (subscales are: somatization, 7 items; social anxiety, 4 items; depression, 6 items; anxiety, 6 items; aggression/ hostility, 6 items; phobic anxiety, 5 items; paranoia, 5 items; psychoticism, 5 items) to explore which type of sensitivity, that is ILF, UHF or normal sound sensitivity, was most strongly related to symptoms. Participants responded how strongly each of the symptoms was affecting them, on average across the past two weeks, on a 5-point Likert scale (0 = *not at all*, . . . , 4 = *very strong*). Evidence for validity and good reliabilities (Cronbach's alpha ranging between 0.82 and 0.95) has been provided.[20] For the present sample, internal consistency was excellent (0.93).

Sleepiness

As tiredness, dizziness or sleepiness are often reported symptoms associated with ILS and UHF sound, daytime sleepiness was assessed with the Epworth Sleepiness Scale (ESS) (21). The ESS assesses the self-rated likelihood of dozing within eight typical daytime activities (e.g. sitting quietly after a lunch without alcohol – 0 = would never doze, 1 = slight chance of dozing, 2 = moderate chance of dozing, 3 = high chance of dozing). The scale refers to the 'way of life in recent times'. The ESS has been studied extensively in the recent past decades and validity as well as good reliability (Cronbach's alpha of .82 on average across different studies) have been established (see https://epworthsleepinessscale.com/about-the-ess/). Internal consistency was acceptable (0.75) in our study sample.

Personality

To assess personality, an updated, 30-item version of the five factor personality inventory (NEO-FFI-3–Neo Five-Factor personality Inventory)[23] was used. The items measure the five most important personality factors, with 6 items per factor (i.e. personality trait). *Neuroticism* circumscribes a personality trait that is characterized by proneness to 'moodiness' and frequent experience of aversive emotions as well as rumination and worry. Individuals with high *extraversion* usually enjoy human interactions, are enthusiastic and energetic, talkative, assertive, and gregarious. High *conscientiousness* describes individuals with a strong focus on orderliness, self-discipline, dutifulness, competence, achievement striving, and deliberation. Individuals with high *openness* exhibit intellectual curiosity, aesthetic sensitivity, attentiveness to feelings, and a preference for variety. Lastly, the trait of *agreeableness* best describes warm, kind and empathetic individuals. All items are rated on a 5-point Likert-scale, ranging from 0 = *strongly disagree* including the neutral category (2 = *neither agree nor disagree*) to 4 = *strongly agree*. Both factorial validity and good internal consistencies (Cronbach's α) have been reported for this brief version of the original 120 item NEO-FFI, ranging between 0.78 and 0.86.[23] In the present sample, internal consistencies were lower but all acceptable: 0.82 for neuroticism, 0.68 for extraversion, 0.71 for conscientiousness, 0.73 for openness and 0.67 for agreeableness.

Noise sensitivity (for the normal hearing range)

The Weinstein Noise Sensitivity Scale (WNSS)[16,24]and the noise sensitivity questionnaire (NoiSeQ)[25] measure global sound sensitivity (referring to the normal hearing range). The WNSS measures sensitivity as a unidimensional construct. It has been widely used in noise research across the world and can be considered the most popular measure for noise sensitivity. It was based on the following definition by Job[26]: 'noise sensitivity refers to the internal state of any individual which increases their degree of reactivity to noise in general'. Higher sensitivity is regarded as a prerequisite for higher annoyance. The WNSS comprises 21 items that address affective reactions or attitudes towards every day and environmental sounds, which are rated on a 5-point Likert scale which ranges from 0 = *completely disagree* to 5 = *strongly agree*. The original version has good internal consistency of 0.84,[24] and it was excellent in our sample (Cronbach's α = 0.90).

The NoiSeQ[25] is a multidimensional measure of noise sensitivity across different daily life situations: leisure, work, habitation, communication, and sleep. Each context is measured with 7 items. Items are rated on a 4-point Likert scale (3 = *strongly agree*, 2 = *slightly agree*, 1 = *slightly disagree*, and 0 = *strongly disagree*). Although the measurement of noise sensitivity across different situations was implemented because of the notion that it may differ across contexts (e.g. leisure vs. work), a total score can also be used to index noise sensitivity in general. Internal consistency of the total questionnaire has been reported as excellent[25] and was also excellent (Cronbach's α =0.90) in our sample.

Ehics, participant recruitment and procedure

The questionnaire assessment was part of different local or online studies within the EARS-II project. In all countries, informed consent of the participants was obtained before participation. The assessments were completely anonymous for the online assessments, and data from the local recruitment sites were anonymized (i.e. the coding lists were deleted) upon completion of the trials. Adherence to the declaration of Helsinki and local ethical standards was assured at all sites. There was no general explicit ethical approval for the questionnaire validation across all sites, but the assessments were included as part of the local studies, for which positive ethics votes were obtained (Germany – Braunschweig: PTB ethics vote 3/16; Germany – Hamburg: Ethikkommission der Ärztekammer Hamburg – approval number: PV5570; University of Southampton: UoS ethics committee, Ethics ID: 30365.A1).

The novel questionnaire was launched as an anonymous online survey on the 'one klick survey' online platform, available in German and English. It was explicitly advertised in Germany, the UK, and Slovenia—mainly via University platforms. A small subset of questionnaires was attained from on-site research (from Braunschweig and Hamburg, Germany, and from Southampton, England) using paper (or local digital but non-online) versions of the questionnaire.

The entire survey took about 45 minutes. There were no formal inclusion criteria, except for age above 18 years (or having a parent's consent). First, demographic assessments were taken, including age, nation of residence (i.e. Germany, Slovenia, UK, other), sex, living environment (e.g. living in a city, village, or small town; living arrangement such as single detached house, apartment block with five or more storeys, etc.), and self-reported hearing status (normal hearing yes vs. no). This was followed by presenting a list that included 30 sound sources/ sounds, 10 of which were restricted to the normal hearing range with no considerable infra- or ultrasonic frequencies (e.g. background music at a shopping mall), 10 typical ILFN sound sources/ sounds (e.g. traffic noise), and 10 typical UHFN sound sources/sounds (e.g. stopping trains with squeaking brakes). Participants were instructed to indicate whether they encountered any of these sources/ sounds in the past 12 months (yes vs. no). Afterwards, for all affirmed sources, exposure frequency and duration were assessed (frequency: *never*; *every few months*; *monthly*; *weekly*; *daily*, duration: *8 hours or more*; *4-8 hours*; *1-4 hours*; *< 1 hour*; usage of hearing protection/ headphones when exposed: *never*; *sometimes*; *always*). Hereafter, we asked the subjects to indicate their annoyance concerning each of the sounds produced by the sources on a 11-point Likert scale, as recommended by ICBEN (27), (0 = *does not bother/ annoy me at all*; 10 = *extremely bothers/ annoys me*), also providing an option of indicating that the sound was never perceived before (*never heard that sound*). This was directly followed up by the ILF and UHF sound sensitivity questionnaire (SISUS-Q). Finally, Weinstein's noise sensitivity questionnaire was assessed.

The subsample that was used for construct validation purposes was recruited on-site at one of our research labs in Hamburg, Germany. These participants also filled out the questions described above, but in addition subsequently answered the other questionnaires that were intended for constructing validation purposes: PHQ-15, BSI, ESS, PSS, NEO-FFI-3, and NoiSeQ. This data was baseline data from a longitudinal, single-blind, randomized-controlled study of the effect of night-time sound exposure by infra- vs. ultrasound on the brain, mental health, and cognitive performance (for a full description of that study please check the NIH trial registry: https://clinicaltrials.gov/ct2/show/NCT03459183).

Statistical analyses

The factorial structure of the novel questionnaire was assessed using exploratory factor analysis in the total, multinational sample. First, a Principal Component Analysis (PCA) was conducted in order to derive the optimal number of factors to be extracted based on the eigenvalue > 1.0 criterion. Second, we used PCA applying a direct oblimin rotation procedure, with a default Delta = 0, maximum number of iterations for convergence = 25 and a fixed number of factors as determined in step 1. The threshold for acceptable total explained variance through any number of components exceeding an eigenvalue of 1.0 was set to 60% following a general and rather conservative rule of thumb.[28] A minimum acceptable factor loading for an item on a given component was defined as exceeding a threshold of .40 (between a medium and large association of a given item with the factor). All analyses on the total sample were repeated separately for the German and the English versions (the latter including UK- and Slovenian participants) of the questionnaire in order to examine whether the results were replicable for the two versions/languages.

After establishing the scales using factor analysis, internal consistencies for the newly derived scales (Cronbach's α) were calculated. Subsequently (Pearson) correlation analyses were performed with constructs found to be related to normal and hence likely also related to IFS and UHF sound sensitivity (i.e. somatic and psychiatric symptoms, sleepiness, personality, global [hearing sound] sensitivity). For the interpretation of the correlation coefficients Cohen's[29] rule of thumb was applied with $r \geq 0.10$ and $r < 30$ small; $r \geq 0.30$ and $r < 50$ medium; and $r \geq 0.50$ indicating a large effect (correlation).

RESULTS

Sample characteristics

In total, $n = 146$ full datasets (including the entire SISUS-Q) were acquired online, of which $n = 70$ filled out the German- and $n = 81$ filled out the English version (total online sample $n = 151$). This equals to about less than one third (30.5%) of a total of $N = 496$ individuals (German initial $n = 187$–completion rate = 37.4%; English initial $n = 309$–completion rate = 26.2%) who started the questionnaire but quit before the SISUS-Q. A subset of $n = 38$ cases was attained from on-site research (i.e. Southampton, $n = 17$; Braunschweig, $n = 21$). Seventy-eight datasets were acquired as part of an intervention study in Hamburg, Germany.

Hence, in sum a total N = 267 SISUS-Q full data was available for factor analysis, of which 54.3% were male, mean age was 28.7 (SD = 9.8, age range for the total sample: 17–68). For replication of the factor structures the sample sizes were $n = 98$ for the English (51% male, mean age = 30.9, SD = 12.1) and $n = 169$ for the German (56.2% male, mean age = 27.4; SD = 7.9) version of the questionnaire. The English version was filled out by $n = 57$ Slovenians, n = 32 people from the UK and $n = 9$ individuals from other European nations.

For construct validation, a total $N = 187$ cases ($n = 95$ Germans, $n = 56$ Slovenians, $n = 32$ people from the UK) was available for correlation between SISUS-Q and WNSS (59.9% males, mean age = 29.3, SD = 11.0) and a total of 75-78 for correlation with other constructs (i.e. somatic and psychiatric symptoms, sleepiness, personality, NoiSeQ [multi-faceted normal hearing sound sensitivity]), (41% male, mean age = 27.2, SD = 5.9).

Principal component and exploratory factor analysis

First, analyses were run in the total sample ($N = 267$). The Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) was acceptable (=0.754) and the Bartlett's test (testing the assumption that the correlation matrix is an identity matrix – i.e. the variables are unrelated and hence structural analyses are not suited for the data) was significant ($P < .001$). This indicates appropriateness to conduct factor analysis. The PCA revealed that there were three components with an eigenvalue > 1, with an accumulated 72.2% of explained variance, whereby the first component accounted for about 41.4%, the second for about 17.0% and the third component for about 13.8% of explained variance. The rotated 3-factor solution pattern matrix for the EFA revealed that all factor loadings exceeded .60, and that there were no side loadings (exceeding 0.40) for any of the items [see Table 2 for details]. On a content-basis it appears that there was an ILF-sensitivity factor (four items), an UHF-sensitivity factor (four items) and a negative cognitive appraisal of both, ILF and UHF sounds (negative cognitive appraisal of extreme values; NCAEF) factor (two items). Correlations between the three components were small. Between ILF and UHF-sensitivity the correlation was 0.29 between ILF-sensitivity and negative cognitive appraisal the correlation was 0.21 and between UHF-sensitivity and negative cognitive appraisal the correlation was 0.28.

The same three factor-solution was replicated repeating the analyses separately for the English ($n = 98$) and the German ($n = 169$) subsamples, supporting its replicability and robustness. The subsample analyses can be found in Appendix 1A and 1B. For the English version of the questionnaire internal consistencies (Cronbach's α) were good (.83, .81 and .90), and for the German version there were acceptable to good reliabilities (ILFS scale: .85; UHFS scale: .82; NCAEF scale: .69).

Exploratory principal component and exploratory factor analysis by residency

The sample was subdivided into one sample with participants of residency within the UK and one sample of participants with participants of residency within Slovenia (+ 4 individuals from other European nations; combining the

Table 2: Pattern matrix of the three-factorial solution as identified with Principle Component Analysis in the total sample (*N* = 260)

Item	Component		
	1ILF sensitivity	2UHF sensitivity	3NCAEF
Low-pitched noises/sounds particularly bother me.	0.862		
I can hear or otherwise perceive (e.g. via bodily sensations) low-pitched noises/sounds more often than other people/I perceive them more intensely than others.	0.801		
I am more sensitive to low-pitched noises/sounds than other people	0.816		
I try to avoid low-pitched noises/sounds or leave situations in which these types of noises/sounds occur.	0.706		
I am more sensitive to high-pitched noises/sounds than other people.		0.890	
I can hear or otherwise perceive (e.g. via bodily sensations) high-pitched noises/sounds more often than other people/I perceive them more intensely than others.		0.812	
High-pitched noises/sounds particularly bother me.		0.753	
I try to avoid high-pitched noises/sounds or leave situations in which these noises/sounds occur.		0.623	
Low-pitched noises/sounds, that people may not even hear, can be dangerous or have a negative effect on people.			0.868
High-pitched noises/sounds, that people may not even hear, can be dangerous or have a negative effect on people.			0.816

Item factor loadings below 0.40 were suppressed. ILF-s = Infrasound/low frequency sensitivity; ULF-s. = Ultrasound/ high frequency sensitivity; NCAEF = negative cognitive appraisal of extreme frequencies.

two appeared justified due to the fact that both for them as for Slovenians English was not the mother tongue). The corresponding subsample sizes were not entirely appropriate for factor analysis, hence caution in interpreting the results is adverted. Results are only provided on a descriptive basis here, as even the most liberal guidelines suggest a minimum of $n = 4$ observations per variable,[30] but higher numbers such as a sample of a minimum of $N = 100$[31]are widely recommended for PCA. In sum, these subsample analysis also replicated the three-factorial solution, with clear results for the UK only ($n = 32$) subsample and somewhat ambiguous results for the Slovenian/ non-native English European subsample ($n = 61$) with ambiguous loadings > 0.40 of two ILF items that also loaded onto the UHF sensitivity factor).

Construct validation of the ILF-UHF sensitivity and negative appraisal questionnaire scales

As two items are considered insufficient to constitute a psychometric scale, it was decided not to interpret associations of other questionnaires with NCAEF, but to report these for descriptive purposes only. All correlations of the ILF, UHF sensitivity and NCAEF scales with other scales can be found in Table 3. The mean scores were used (i.e. sum for each of the subscales divided by the number of items) for all scales entered into correlation analysis (means and standard deviations for the validation sample are included in Table 3). Both ILF and UHF sensitivity were significantly associated with normal hearing sound/ noise sensitivity to a medium extent. The ILF and UHF sensitivity scales were significantly and positively associated with psychiatric symptoms (medium-sized effect), whereas only ILF was significantly associated with somatic symptoms and daytime sleepiness (both medium-sized effects). Similar to the normal noise sensitivity measure (NoiSeQ), which was significantly related to neuroticism ($r = 0.292$; small effect) and extraversion ($r = -0.261$; small effect), ILF sensitivity was associated with neuroticism to a similar, small extent ($r = 0.262$). However, deviating from normal sound sensitivity, both ILF and UHF sensitivity were significantly associated with agreeableness to a small extent ($r = 0.249$ and 0.250, respectively).

DISCUSSION

In this paper a questionnaire development, factorization and validation of a measure that aims at capturing sound sensitivity for ILS and UHF was presented. The need for such as measure was derived from several lines of evidence coming from psycho-acoustic, experimental and epidemiological survey research pointing towards the existence of highly sensitive subgroups within the general population; i.e. individuals who may be particularly affected by infra- and low frequency (ILF) or ultra- and high frequency (UHF) sound.

The analyses revealed that ILF and UHF sensitivity may constitute different types of sensitivity, as corresponding items loaded highly on clearly separable factors. This was evident both in the total and in the separate English and German questionnaire version subsamples. In addition, it was replicated in a UK only sample. Negative cognitive appraisals of extreme sound frequencies (NCAEF; i.e. the belief that ILF or UHF sounds are particularly dangerous or may have a negative effect on people) loaded on a separate factor. This suggests that sensitivity in these frequency ranges may have two aspects; one is rather physiological and characterized by *perception* through the senses, *irritation* elicited by the sound, and *behavioral avoidance* (similar to classical conditioning, where an unpleasant stimulus is associated with an automated avoidance tendency of and object, subject, or place) of these sounds, and the other is a clearly cognitive component. We however refrained from further interpreting NCAEF in the construct validation analysis, as the minimum number of items for a psychological scale is three, and the scale comprised only two. The fact that ILFand UHF sensitivity were separate factors could suggest different mechanisms being involved in the perception of ILF and UHF sounds, but more research is necessary to investigate this. Furthermore, ILF and UHF sensitivity were only moderately related to noise sensitivity in the normal hearing range. This demonstrates convergent validity of the new scales. The moderate size of the associations also speak for ILF and UHF sensitivities being sufficiently distinct from sensitivity to sounds in the common hearing range, suggesting that they are distinctive types of sensitivity. Confirming construct validity, ILF and UHF sensitivity were related to common measures of psychiatric symptoms to a small to moderate extent. However, ILF and UHF sensitivity also showed a divergent pattern of associations: only ILF sensitivity was moderately related to somatic symptoms and daytime sleepiness. Noise sensitivity in the normal hearing range has clearly been associated with virtually all personality dimensions.[32]. In the present study, ILF sensitivity was modestly related to neuroticism and both ILF and UHF sensitivity were related to agreeableness to a small extent. These results slightly deviate from results concerning normal sound sensitivity and suggest an overall weaker relation of these sensitivities with personality.

Limitations

A first important limitation is sample heterogeneity in terms of recruitment sites and sample sizes. There are several problems related to this approach, such as potential confounders, that is residency in a large vs. small town, for the analyses. This should be controlled in future studies, using larger and more balanced, nationwide samples. However, subsample analyses broadly replicated the main findings. The low average age in the present study sample suggests that particularly sensitive age groups (see introduction; 40-49 of age for ILF sound; 30–39 years of age for UHF sound) might not have been sufficiently represented. There also was a high attrition rate in the online samples (nearly all participants quit very early into the survey).

Table 3: Correlations, means and standard deviations between/for the novel scales and measures of pathology, sleep, personality, and global noise sensitivity

Variable		1) ILF	2)	3)	4)	5)	6)	7)	8)	9)	10)	11)	12	13
Descriptives	MSDN	2.7 (2.2)	5.2 (2.6)	5.3 (2.9)	0.3 (0.2)	0.3 (0.2)	1.1 (0.5)	1.1 (0.7)	2.5 (0.5)	2.5(0.7)	0.9 (0.5)	3.1 (0.5)	2.1 (1.0)	1.4 (0.4)
		276	276	267	78	77	78	76	76	76	76	76	187	78
2) UHF-s.	r	$\mathbf{0.394*}^{**}$												
	N	267												
3) NCAEF	r	**0.357*****	**0.340*****											
	N	267	267											
4) PHQ-15	r	**0.384*****	0.152	0.172										
	N	0.78	78	78										
5) GSI	r	**0.363****	**0.291***	0.221	**0.503*****									
	N	77	77	77	77									
6) ESS	r	**0.351****	0.143	0.202	0.156	0.212								
	N	78	78	78	78	77								
7) Neuroticism	r	**0.262***	0.186	0.036	**0.392*****	**0.660*****	0.178							
	N	76	76	76	76	75	76							
8) Extraversion	r	−0.178	−0.129	−0.139	**−0.268***	**−0.283***	−0.052	**−0.243***						
	N	76	76	76	76	75	76	76						
9) Openness	r	−146	−0.028	0.022	**0.256***	0.074	0.101	0.007	0.152					
	N	76	76	76	76	75	76	76	76					
10) Agreeableness	r	**0.249***	**0.250***	**0.236***	0.206	**0.452****	0.011	**0.359****	**−0.338****	**−0.259***				
	N	76	76	76	76	75	76	76	76	76				
11) Conscientiousness	r	−0.081	0.087	0.035	−0.203	**−0.317****	−0.153	**−0.505****	0.030	−0.160	**−0.254***			
	N	76	76	76	76	75	76	76	76	76	76			
12) WNSS	r	−0.130	−0.140	−0.120	-	-	-	-	-	-	-	-		
	N	187	187	187	-	-	-	-	-	-	-	-		
13) NOISEQ	r	**0.321****	**0.329****	−0.015	**0.300****	**0.292****	−0.086	**0.373****	**−0.261***	−0.072	0.035	−0.122		
	N	78	78	78	78	77	78	76	76	76	76		76	

ILF-s. = infrasound/ low-frequency sensitivity; UHF-s. = ultrasound/ high frequency sensitivity; NCAEF = negative cognitive appraisal of extreme frequencies; PHQ-15 = patient health questionnaire (somatic symptoms); GSI = global severity index (for psychiatric symptoms – Brief Symptom Inventory); ESS = Epworth sleepiness scale (daytime sleepiness); WNSS = Weinstein noise sensitivity scale; NoiSeQ = noise sensitivity questionnaire. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Nothing is known about these quitters, and hence it is hard to draw any conclusion about the representativeness of the sample. Future studies should attempt to assess more socio-demographic data, such as on education (including opinions and knowledge about ILF and UHF sound), to control for confounders. In addition, the factor solution within the Slovenian sample was not as clear as in the other subsamples. This likely has been due to language-related problems, as in the UK sample the factorial solution was much clearer. Hence, providing a Slovenian version would have been more appropriate and future studies should consider translating the questionnaire if authors wish to use a non-English or non-German version of the ILF-UHF sensitivity questionnaire.

CONCLUSION

The questionnaire consortium concludes that it is justified to use the constructed English and German ILF- and UHF-sensitivity scales (SISUS-Q) in future experimental, psycho-acoustic, or epidemiological survey studies, and it is recommended using them in addition to established measures of sound sensitivity, such as the NoiSeQ[25]or WNSS.[16,24]This may shed further light on construct validity of the new scales and on the potential moderating role of extreme frequency sensitivity in terms of perception or other types of adverse reactions to ILF and UHF. Possible relationships between extreme frequency sensitivity physiological correlates (i.e. cochlear mechanics, brain activation) and certain personality traits (i.e. neuroticism or agreeableness) should be the topic of further investigation.

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Conflicts of interest

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Data availability statement

We hereby declare that our full data plus code and syntaxes (including a thorough documentation of all analyses that were undertaken) are fully available upon request.

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UNCITED REFERENCES

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