DESIGNING PERSONALISED SLEEP SONIFICATION

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Abstract

This paper presents a participatory and personalised approach to the sonification of sleep EEG data. While existing sleep technologies primarily rely on visual and abstract representations, this work explores how sound can be used as a meaningful medium for engaging with sleep. An in-depth, single-participant, iterative design study was conducted combining EEG data collection with three one-hour interviews and progressive design refinements. Through this process, the participant actively contributed to shaping how their sleep was represented through sound, influencing both the selection of sound materials and their mapping to sleep features. This exploratory study shows that sound preferences, in this context, are shaped by both acoustic properties and personal associations, and that iterative engagement is important in understanding nuanced expectations around continuity, narrative flow, duration, and uses of the sonification. The resulting sonification was perceived as engaging, reflective, and personally meaningful, though some limitations remained in clarity of sleep stages. These observations point to the effective role of participatory approaches in designing personal sonifications of data and suggest that future personalisation systems for sound-based sleep representations should prioritise user involvement, contextual meaning, and experiential qualities.

Keywords: *sonification, sleep, personalisation, EEG*

1. Introduction

Sleep plays a critical role in health and well-being, leading to a growing interest in tracking and improving sleep. The rise of consumer sleep technologies has made it possible to continuously monitor sleep stages, duration, and disturbances. These systems have made sleep data more accessible to the general public. However, sleep data is usually represented through static visual summaries, such as hypnograms, sleep scores, or aggregated statistics [1]. While informative, these representations can be difficult to interpret, or relate to. Sleep itself is dynamic, which suggests a mismatch between the process originating the data and how it is commonly represented. Sonification, the use of non-speech audio to represent data [2], offers an alternative. As sonification unfolds over time, changes, transitions, rhythms, and interruptions can be perceptible as a temporal experience rather than a static summary. Prior work has explored sleep sonification in artistic contexts [3], clinical tools [4], and exploratory data representations [5]. However, much of this work remains system-driven and non-personalised, with limited user involvement in the design process.

In this paper, we present an iterative, participatory and personalised approach to sleep data sonification, where the user actively shapes how their data is translated into sound. We explore how sonification can be grounded in users' preferences, associations, and experiences of sleep, moving beyond typical visual summaries into something reflective and interpretive. Rather than propose a general model for sleep data representation, the contribution of this paper is methodological and design-oriented. It explores how an iterative, participant-centred process can inform the design of personalised sleep EEG sonification.

2. Background

2.1. Sleep Health and Measurement

Sleep is a multidimensional phenomenon encompassing behavioural, physiological, and experiential aspects [6]. In the context of health, these dimensions are framed through the concept of *sleep health* that promotes physical and mental well-being [7]. Good sleep health is characterised by subjective satisfaction, appropriate timing, adequate duration, high efficiency (or continuity), and sustained alertness during waking hours [7]. Together, these dimensions capture how long and how well a person sleeps, but also how sleep is experienced and integrated into daily life and what associations they make with their sleep. In practice, sleep health is assessed through measurements that

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translate these dimensions into observable subjective and objective data. Clinical sleep research relies on polysomnography (PSG) to capture detailed physiological signals, but such methods are typically limited to controlled laboratory environments.

In response, consumer sleep technologies (CSTs) have become widely adopted, offering continuous and accessible sleep tracking. These non-prescription devices monitor sleep using physiological proxies such as movement, heart rate, or simplified EEG [1], [8]. CSTs are commonly available as wearable or nearable devices, including watches, rings, and sleep mats supporting everyday awareness of sleep behaviours. However, CSTs typically represent sleep through simplified metrics and visual summaries. While these provide an overview of sleep structure, they often reduce sleep to numerical evaluations that are difficult to interpret or relate to lived experience. This creates a disconnect between measured and experienced sleep. In some cases, such representations may even increase anxiety or preoccupation with sleep [9].

2.2. Sleep and Sound

Sound has been explored in relation to sleep both as an intervention to support sleep and as a factor that can disrupt it [10], [11]. A wide range of sounds have been explored to support sleep onset, reduce disturbances, and improve quality [10], [12]. These primarily include broadband noise [13] and natural soundscapes, such as rain, forest sounds, ocean waves, etc [10], [12]. Despite their diversity, these approaches largely treat sound as a passive acoustic stimulus designed to influence sleep. Beyond influencing sleep, sound has also been explored as a medium for representing and analysing sleep data. This shifts the role of sound from acting on sleep to representing and facilitating reflection on sleep, opening up possibilities to engage with sleep health as a multidimensional and experiential process.

2.3. Sonification of Sleep

Sonification has been explored across domains as a way to communicate temporal and complex information. In sleep, prior approaches typically map features such as frequency, amplitude, or sleep stages to auditory parameters including pitch, rhythm, or timbre. For instance, Brain's Night Symphony (BraiNSy) translates EEG signals into musical structures, where different sleep stages are expressed through variations in harmony, tempo, and texture [5]. Similarly, work by Fernandez and colleagues [14] explores how sleep dynamics can be rendered as sequences of tones and pauses to convey temporal patterns across the night. More recent work has investigated the use of sound to support interpretation and analysis, such as improving sleep stage classification through auditory display [4], or transforming EEG signals into sound-based features for computational models [15]. Other work has explored sound within more experiential contexts, such as installations to represent and invite reflection on sleep [3]. In contrast to these works, this study uses EEG-derived sleep stages, along with participant's preferences and associations to represent and reflect on sleep.

2.4. Participatory and Personalised Sonification

Current sonification approaches point to the need to move beyond designer-defined mappings towards involving users to create representations that are meaningful to the user whose data is being represented. This is particularly important in sleep, where both the experience of sleep and responses to sound are highly subjective and context-dependent [16], [17], [18]. Participatory Design (PD) addresses this by involving users as active contributors in the design process [19], [20], embracing the "many-voiced nature of design" [21]. Instead of relying solely on mappings defined by designers or researchers, PD allows different forms of expertise, experiences, and interpretations to shape how, in this case, sonifications are constructed. Applying PD to sleep sonification shifts the process towards representations shaped by the user, for example through the selection of sounds or the mapping of data to auditory parameters.

3. Methodology

This exploratory study is aimed at identifying some of the key factors that should be investigated in the development of a personalised sonification of sleep EEG data. It is structured as an in-depth single-participant design exploration, combining physiological data collection with three, 1-hour-long interviews roughly one week apart followed by design iterations to explore how individuals may wish to shape the auditory representation of their own sleep. This funneling process, where the participant's ideas and the designer's interpretations become increasingly aligned, explores how personal preferences, associations, and expectations shape sleep sonification design.

3.1. Participant and Data Collection

The participant, and intended listener of the sonification, was a 49-year-old woman living in Sweden, employed in the technology sector, with no formal expertise in sound. Data were recorded across three 90-minute nap sessions conducted in a controlled indoor environment. A 90-minute nap duration was selected because it typically allows most adults to complete one full sleep cycle, progressing through wakefulness, non-rapid eye movement (NREM) sleep stages N1, N2, and N3, and rapid eye movement (REM) sleep [22]. EEG data was collected using an 8-channel Mentalab Explore Pro system which is a research grade device designed for sleep studies [23]. Each session followed a structured protocol consisting of equipment setup, completion of sleep-related questionnaires, a vigilance test, and a 90-minute nap opportunity. Each session produced a separate dataset for sonification. The participant expressed a strong interest in understanding and listening to their sleep, and was already familiar with the concept of sonification.

3.2. Sonification System and Design

The data collected using the Mentalab Explore Pro was analyzed using MNE [24], an open-source Python package for processing neurophysiological data, and YASA [25] for automatic sleep staging. The resulting sleep stage data were transmitted via OSC to Pure Data [26], which was used as the sound engine for the sonification. The sonification was based on EEG-derived sleep stages rather than continuous EEG signal, the stages and their durations controlled the ordering, timing, and transitions of stage-specific sound layers in Pure Data. The soundscape was designed iteratively by the researchers, drawing on the participant's preferences, associations, and feedback from the three interview sessions. Different sound elements were assigned to each sleep stage (see Table 1), with mappings shaped by how the participant interpreted and related to different sounds. The choice of sounds across sleep stages was structured around water as a unifying element, reflecting the participant's strong preference for water-based soundscapes. This provided perceptual continuity along the sleep stages. Across NREM stages (N1–N3), sounds were designed to become progressively deeper and lower in frequency aligning with slower and deeper sleep dynamics. In contrast, REM was represented using more abstract and "fanciful" textures, reflecting the participant's association of REM with dream-like experiences. For wake after sleep onset (WASO), which refers to periods of wakefulness after sleep onset, additional textural and abrupt sounds were introduced on top of the three base sounds to reflect the disruptive and unpleasant experience of awakening during sleep. Water-based sounds became an important anchor and served as a starting point for exploring the participant's specific associations with places, bodily sensations, textures, and memories. The iterative design process however introduced additional, sometimes less conventionally relaxing sounds (see Table 1).

Table 1: Sounds used for each sleep stage. *Additional sounds included for WASO.

Sleep Stage	Sounds
Wake	Running Water, City Sounds, Bryant Park, Wooden Scratch*, Door Opening*
N1	River splashes, Distant Traffic, Car Cabin
N2	Rain, Fire, Airplane Cabin
N3	Ocean Waves, Tree Bark, Low Bass Rumble
REM	Jacuzzi, Fizz, Seoul Park

After a discussion about desired sonification length with the participant (see Section 4.1), the original 90-minute nap was compressed into an approximately 5-minute representation with each sleep stage scaled proportionally to its duration in the original data. This solution preserved the overall progression and relative distribution of sleep stages. However, short and rapid fluctuations between stages were smoothed by prioritizing the dominant stage within a given segment to create a smoother soundscape and avoid constant abrupt changes. This was a design choice to address the participant's desire for continuity and narrative flow. The sonification can be found here: https://tinyurl.com/2tu4f937.

3.3. The Participatory Design Process

Following the EEG data collection, the design process consisted of three iterative stages: (1) an initial interview to understand the participant's relationship with sleep and expectations, (2) a sound exploration phase to identify preferences and shape the sonification, and (3) an evaluation of the first version of the personalised sonification. Each stage informed the next, allowing the design to progressively incorporate the participant's input. Interviews were audio recorded, transcribed using Otter.ai and then manually corrected. The data was analysed using a thematic analysis to inform each design iteration. Transcripts were read by the researchers to identify recurring topics related to sleep experience, sound preferences, associations, use contexts, and responses to the sonification.

3.3.1. Initial Interview

A semi-structured interview explored the participant's relationship with sleep, their experiences during the recorded naps, their everyday sleep practices, whether and how they use sleep data, and what they expect from it. Their thoughts on representing sleep through sound were also explored, including the kinds of sounds they associate with sleep, how they imagine such a system working, and how they might use it. We also examined whether they envisaged the sonification as something informative, experiential, or a combination of both. The interview was guided by the questions in Table 2.

Table 2: Interview guide questions

No.	Question
1	*What is your current relationship with sleep, and how did you experience these naps?*
2	*What is your interest in learning more about your brain and sleep?*
3	*Are you interested in EEG or other related data? Do you gather any data, and for what purpose do you look at it?*
4	*What is interesting for you about "hearing" your brain sleeping?*
5	*What would you like to get from it?*
6	*What kind of sounds do you imagine for such a representation and why?*
7	*How would you imagine it to work? How long should it be? How would you use such a system? When? Why? Alone or with others?*
8	*Would you prefer it to be more informative about your sleep, or something you could listen to during sleep itself?*

3.3.2. Sound Exploration and Participant Preferences

Building on the first interview, the participant was presented with a set of potential sounds to be used in the sonification, and a visual representation of the sleep stages and early soundscapes mockups. The discussion was less guided than the first, allowing for spontaneous responses and reflections to the material presented. The aim was to identify which sounds they liked or disliked, and to understand how they responded to different sonic qualities and sonic transitions. The discussion focused on their wishes for the overall character of the sonification, for example, whether it should feel reflective, strictly based on the sleep stages, whether it should feel continuous, or have disruptions, rhythmic, or dream-like, and on how specific sounds might represent different parts of the sleep experience, including awakenings. The participant was also asked to reflect on why certain sounds stood out to them, what associations they carried, and what kinds of imagery or feelings they evoked. This helped move the design beyond general preference and toward a more detailed understanding of the participant's listening habits, sensitivities, and personal associations, which in turn shaped the sonification presented at the next stage.

3.3.3. Personalised Sonification and Evaluation

In the third interview, the participant was presented with a full sonification of one nap dataset and asked to reflect on their listening experience. The discussion focused on how the sonification represented their sleep, including the clarity of different sleep stages, the transitions between them, its overall flow and whether it felt personal or meaningful to them. To gather structured feedback, items from the User Experience Questionnaire (UEQ) [27] were used during the discussion in the form of open-ended questions (i.e. no ratings were gathered). These included questions reflecting attractiveness, stimulation, novelty, perspicuity or clarity of communication, and dependability, see [27].

4. Results

The results are structured around the three stages of the iterative design process. It describes how participant's inputs informed the development of the sonification and how it was experienced.

4.1. Initial Interview: Relationship with Sleep and Sounds

The initial interview explored participant's relationship with sleep and how they positioned data and sound within the context of sleep. They reported dissatisfaction with information from sleep trackers and expressed interest in alternative representations that would support reflection and mindfulness. Auditory representation was described as something that could help them be kind to themselves and provide "grounding or be slightly meditative, because it would feel very much like it's mine, my thing" and something worth revisiting several times. Accordingly, expectations from the sonification were twofold: it should represent their sleep, while also supporting reflection. In terms of sound preferences, there was a clear inclination toward continuous, textured and, due to a strong sensitivity to repetition, non-looping soundscapes. Nature-based and water-related sounds were preferred, often tied to vivid personal associations (the participant mentioned a specific park, Bryant Park in New York, and cities, e.g. Seoul), indicating that sound to them was not purely acoustic but contextual and experiential. Clear dislikes included animal/insect sounds and abrupt or intrusive auditory elements particularly during rest. However, the participant acknowledged that such sounds could be meaningful if used deliberately in the sonification (e.g. to represent disturbance), and were therefore open to using rough textures for WASO segments. Duration was also discussed, and comparisons were drawn to the typical length of a song and longer musical pieces. A range of 2 to 10 minutes was discussed with a final decision for creating something about 5 minutes long, which could allow for reflection but also 'leave the listener wanting more'. This interview helped position the soundscape toward a tool for reflection and meditation on sleep. Overall, the insights guided sound selection and design: stage-based soundscapes, evolving textures, and mappings grounded in participant associations, especially water and nature.

4.2. Second Interview: Sound Exploration and Participant Preferences

Researchers presented the participant with a visual representation of their sleep stages and suggestions of sounds for each stage. The participant emphasised the importance of continuity and narrative flow, responding positively to interconnected soundscapes, noting that "there will be a kind of narrative flow to it". At the same time, sensitivity to looping became more nuanced, they distinguished between acceptable repetition and problematic looping, stating that "repetitive is fine, but just not that I can hear when we're back to the start". Sound preferences also became more nuanced through direct exposure to examples, with strong positive responses to nature-based sounds, particularly rain and thunder in mid-sleep stages ("I can feel my body relaxing"), while deeper stages were associated with low-frequency, slow, "drone-like" textures. Wake was aligned with environmental ambiences such as city parks and distant traffic. These sounds evoked vivid personal associations with specific places. REM was linked to more abstract and "fanciful" sounds, with openness toward imaginative or less literal representations. The preferences of different sounds were shaped through personal and contextual associations rather than purely acoustic properties. The researchers' suggestions of fizzy and bubbly sounds for REM were positively considered. This phase revealed fine-grained distinctions between water textures including urban rivers, jacuzzi bubbles, rain, and "thin" or "wet" water, moving the water motif beyond a generic 'relaxing' category.

Additionally, the participant also confirmed potential use cases of the sonification, describing it as something that could be used both to "ramp down" and "ramp up", supporting transitions between states rather than only relaxation. These insights refined the design into a clearer structure: a defined sleep stage-to-sound mapping, emphasis on continuous transitions, and the integration of contrast between smooth progression and disruptions representing WASO.

4.3. Third Interview: Personalised Sonification and Evaluation

The third interview involved an evaluation of the developed 5-minute sonification, with reflections guided by UEQ-inspired prompts. Overall, the response was positive across dimensions, with the participant describing the experience as "very relaxing" and "very interesting", and expressing motivation to listen again. The sonification was perceived as a continuous "flow" and a "little journey", and described as engaging but not overstimulating and "not boring" or "abrasive". When reflecting on expectations, the participant reported that the experience was "80 to 90% in line with what I was expecting", suggesting a high level of alignment with prior discussions. A strong outcome was the sense of personal connection. The participant described the sonification as "like mine and that it belongs to me" and "homely", suggesting that the personalised design approach contributed to meaningful engagement with the data representation. In terms of structure, the sonification was experienced as coherent but not predictable. The participant noted that it did not feel expected or repetitive, stating that "I wasn't going: 'Oh yeah, and here come the bells'", and reported no noticeable issues with looping. However, clarity of sleep stage representation remained slightly limited. The participant was able to distinguish only "two to three" phases, and REM was not clearly identifiable. Transitions between stages were also described to be sometimes "too abrupt". The 5-minute sonification was perceived as relatively short, with the participant noting that it "went quite fast" and expressing interest in a longer version.

5. Discussion

This study explored how a personalised sonification of sleep can be developed through an iterative, participant-centred design process. A key insight is that sound preferences in this context are shaped by personal associations and their acoustic properties. The participant consistently related sounds to specific places, memories, and experiences, indicating that meaning was constructed through lived context. This shaped both the selection of sounds and how they were interpreted within the sonification. This is reflected in the participant's description of the sonification as "like mine" and "homely", indicating that personalisation was not only functional but experiential. Compared with prior sleep sonification systems based on researcher-defined mappings, this case shows how personalisation can turn sonification into a reflective listening artefact grounded in the listener's associations, sensitivities, and intended use.

The iterative participant-centred process was central to bring out these nuances. Across interviews, the participant moved from general preferences to more specific expectations around continuity, narrative flow, and stage representation. This process revealed sensitivities that would be difficult to anticipate otherwise, such as the aversion to perceptible looping or animal/insect sounds and the acceptance of disruptive sounds when representing unexpected awakenings. It also enabled refinement of how the sonification functioned beyond representation, for example as a tool for transitioning between states (e.g. wakefulness to restfulness or vice versa). At the same time, the evaluation highlights aspects that need further refinement particularly regarding clear data communication. While the sonification was experienced as coherent and engaging, distinctions between sleep stages were not always clearly perceived, particularly for REM, which was expected to stand out but did not. This can be addressed by refining the mix, sound choices, and exploring less linear temporal compression strategies.

This process also highlighted the importance of personalisation when designing soundscapes for intimate contexts such as sleep, where sound is experienced in vulnerable and personal settings. In this case, the use of participatory methods enabled the participant to shape how their data was represented, supporting a sense of safety and comfort. This suggests that involving individuals in the design process can support more appropriate and ethically sensitive outcomes. However, while participant preferences can provide meaningful design anchors, they should also be critically expanded to avoid simply reinforcing familiar sleep-sound associations.

Based on this case, three provisional design considerations appear particularly important. First, personal associations may need to be treated as central design material, as they strongly shape how sounds are interpreted. Second, use context should be explicitly considered, as the sonification may serve multiple purposes (e.g. reflection, relaxation, or state transition). Third, iterative design is important, as preferences and sensitivities often emerge through exposure and discussion rather than through selection of predefined options. Given the single-participant format of this exploratory study, these findings should not be read as generalisable design principles. Instead, they can be seen as situated insights into how one participant negotiated sound, sleep data, and personal meaning that provide initial knowledge for designing novel, personalised sleep sonification systems.

6. Conclusions

This study shows how personalised sleep sonification can be developed through an iterative, participant-centred design process. By involving the participant in shaping sound selection and mapping, the sonification moved beyond data-driven representation toward an experience grounded in personal meaning, context, and expectations. Future work should extend the approach to several participants and examine how sonifications of multiple sleep instances can support comparison and reflection across naps or nights.

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References

[1] S. Khosla et al., "Consumer sleep technology: An american academy of sleep medicine position statement," *Journal of clinical sleep medicine*, vol. 14, no. 5, pp. 877–880, 2018.

[2] T. Hermann, A. Hunt, and J. G. Neuhoff, *The sonification handbook*. Logos Verlag Berlin, 2011.

[3] A. Choubey et al., "Sleeping soundly: An interdisciplinary approach to communicating individual sleep experiences through a shared sonic domain," in *Proceedings of the Conference on Sonification of Health and Environmental Data (SoniHED)*, 2025.

[4] S. Chin, N. W. Whitmore, N. Perry, J. Paradiso, and P. Maes, "Eeg sonification improves sleep staging performance in novice stagers," *Plos one*, vol. 20, no. 9, e0329711, 2025.

[5] C. M. Fernandes, D. Migotina, and A. C. Rosa, "Brain's night symphony (brainsy): A methodology for eeg sonification," *IEEE Transactions on Affective Computing*, vol. 12, no. 1, 2018.

[6] T. Andrillon and D. Oudiette, "What is sleep exactly? global and local modulations of sleep oscillations all around the clock," *Neuroscience & Biobehavioral Reviews*, vol. 155, p. 105 465, 2023.

[7] D. J. Buysse, "Sleep health: Can we define it? does it matter?" *Sleep*, vol. 37, no. 1, pp. 9–17, 2014.

[8] G. Cay et al., "Recent advancement in sleep technologies: A literature review on clinical standards, sensors, apps, and ai methods," *IEEE Access*, vol. 10, pp. 104 737–104 756, 2022.

[9] K. G. Baron, S. Abbott, N. Jao, N. Manalo, and R. Mullen, "Orthosomnia: Are some patients taking the quantified self too far?" *Journal of clinical sleep medicine*, vol. 13, no. 2, pp. 351–354, 2017.

[10] E. Capezuti, K. Pain, E. Alamag, X. Chen, V. Philibert, and A. C. Krieger, "Systematic review: Auditory stimulation and sleep," *Journal of Clinical Sleep Medicine*, vol. 18, no. 6, pp. 1697–1709, 2022.

[11] A. Muzet, "Environmental noise, sleep and health," *Sleep medicine reviews*, vol. 11, no. 2, pp. 135–142, 2007.

[12] H. Yoon and H. J. Baek, "External auditory stimulation as a non-pharmacological sleep aid," *Sensors*, vol. 22, no. 3, p. 1264, 2022.

[13] S. M. Riedy, M. G. Smith, S. Rocha, and M. Basner, "Noise as a sleep aid: A systematic review," *Sleep Medicine Reviews*, vol. 55, p. 101 385, 2021.

[14] C. M. Fernandes, D. Migotina, and A. C. Rosa, "Sonification of sleep eeg," in *Proceedings of the 8th International Conference on Digital Arts*, 2017, pp. 161–164.

[15] F. Moradi et al., "A novel method for sleep-stage classification based on sonification of sleep electroencephalogram signals using wavelet transform and recurrent neural network," *European Neurology*, vol. 83, no. 5, pp. 468–486, 2020.

[16] S. Hallak, A. Choubey, and S. Pauletto, "Design and evaluation of the soundasleep app: The impact of emotional states on sound preferences for sleep," in *Forum Acusticum 2025*, 2025.

[17] A. Choubey, A. Cera, and S. Pauletto, "Sonic blankets: Exploring the use of sound-augmented blankets for relaxation and sleep," in *Audio Mostly Conference*, 2024.

[18] A. Choubey, T. van Buijtene, and S. Pauletto, "Investigating context in sonic interaction design for sleep: Bridging users and designers through participatory and ideation workshops," in *Design Research Society Conference*, 2026.

[19] D. Schuler and A. Namioka, *Participatory design: Principles and practices*. CRC press, 1993.

[20] G. Bjerknes, P. Ehn, and M. Kyng, *Computers and democracy-a Scandinavian challenge*. Gower Publishing, 1987.

[21] S. Bødker and J. Buur, "The design collaboratorium: A place for usability design," *ACM Transactions on Computer-Human Interaction (TOCHI)*, vol. 9, no. 2, pp. 152–169, 2002.

[22] M. A. Carskadon, W. C. Dement, et al., "Normal human sleep: An overview," *Principles and practice of sleep medicine*, vol. 4, no. 1, pp. 13–23, 2005.

[23] H. B. Dirik, A. Darendeli, and H. Ertan, "The new wireless eeg device mentalab explore is a valid and reliable system for the measurement of resting state eeg spectral features," *Brain Research*, vol. 1798, p. 148 164, 2023.

[24] A. Gramfort et al., "MNE software for processing MEG and EEG data," *NeuroImage*, vol. 86, pp. 446–460, 2014. DOI: 10.1016/j.neuroimage.2013.10.027.

[25] R. Vallat and M. P. Walker, "An open-source, high-performance tool for automated sleep staging," *Elife*, vol. 10, 2021.

[26] M. Puckette et al., "Pure data: Another integrated computer music environment," *Proceedings of the second intercollege computer music concerts*, pp. 37–41, 1996.

[27] B. Laugwitz, T. Held, and M. Schrepp, "Construction and evaluation of a user experience questionnaire," in *Symposium of the Austrian HCI and usability engineering group*, Springer, 2008, pp. 63–76.