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MARIE SKŁODOWSKA-CURIE ACTIONS

Doctoral Networks
Call: HORIZON-MSCA-DN-2021

PART B

Lullabyte

Unravelling the Effects of Music on Sleep through Musicology, Neuroscience, Psychology and Computer Science

This proposal is to be evaluated as:

[DN]

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LIST OF PARTICIPATING ORGANISATIONS

Consortium Member	Legal Entity Short Name	Academic	Non-academic	Awards Doctoral Degrees	Country	Dept. / Division / Laboratory	Scientist-in-Charge	Role of associated Partner of link to beneficiary
Beneficiaries								
1. Technische Universität Dresden	TUD	x		x	DE	Institute of Art and Music	Miriam Akkermann	
2. Radboud university medical center	RADBOUDUMC	x			NL	Donders Sleep & Memory Lab	Martin Dresler	
3. University of Stuttgart	USTUTT	x		x	DE	Institute of Parallel and Distributed Systems; Scientific Computing	Dirk Pflüger	
4. Aarhus University	AU	x		x	DK	Department of Clinical Medicine - Center for Music in the Brain	Kira Vibe Jespersen	
5. Paris Brain Institute (Institut du Cerveau)	ICM	x		x	FR	Hôpital de la Pitié-Salpêtrière	Thomas Andrillon	
6. CNRS	CNRS	x		x	FR	Dept. of Robotics and Automation, FEMTO-ST Institute	Jean-Julien Aucoutier	
7. Universitat Pompeu Fabra	UPF	x		x	ES	Department of Information and Communication Technologies	Sergi Jorda	
8. Royal Institute of Technology, Stockholm	KTH	x		x	SWE	Division of Media Technology and Interaction Design	Sandra Pauletto	
9. Endel	Endel		x		DE	Endel, App for personalized soundscapes to help focus, relax, sleep		
Associated Partners								

10.Université de Fribourg	UNIFR	x		x	CH	Department of Psychology	Björn Rasch	PI – hosting PhD for whole fellowship
11. Stichting Radboud Universiteit	SRU	x		x	NL	Stichting Radboud Universiteit	Not Applicable	PhD awarding university in cooperation with RADBOUDUMC (2)
12. PHONOS	PHONOS		x		ESP	Location, space for music events	Sonia Espi	Hosting the composer in residency, organizing concerts
13. Starlab	Starlab		x		SPA	Sensor concepts and software for neuroscience data analysis services	Aureli Soria Frisch	Workshop and trainings
14. Arenar	Arenar		x		NL	EEG headband developer	Samir Raut	Workshop and trainings
15. Benkana Interfaces	Benkana		x		GER	Electronic Information Technology Start-up	Michael Engler	Workshop and trainings
16. Mentallab	Mentallab				GER	Solutions for biomechanical recordings	Sebastian Herberger	Workshop and trainings
External Advisory Board								
Gina R. Poe??		x			USA	Neuroscientist, Lectureperformer		Workshop and trainings
Isabel N. Schellinger ??		x	x		GER	Researcher and US based Start-up founder in medical sector		Workshop and trainings
Gert Scobel??					GER	Developer and talkmaster for TV-science formats		Communication, Dissemination
Pausl Davis??					UK	Initial Developer of Ardour (open source sequencer)		Workshop and trainings

Data for non-academic beneficiaries:

Name	Location of research premises	Type of R&D activities	No. of full-time employees	No. of employees in R&D	Web site	Annual turnover (in Euro)	Enterprise status	SME status
Endel	DE				Endel.io			yes

Declarations:
No inter-relationship between different participating institutions or individuals (e.g. family ties, shared premises or facilities, joint ownership, financial interest, overlapping staff or directors, etc.) has been identified in the consortium.

List of abbreviations:

AI	…
BRECVEMACA	…
	Consortium Agreement
CAPEX	Capital Expenditure
DC	Doctoral Candidate
DMP	Data Management Plan
DN	Doctoral Network
DOI	Digital Object Identifier
EAB	External Advisory Board
EC	European Commission
ECTS	European Credit Transfer System
EEG	…
ERC	European Research Council
ET	Executive Team

EU	European Union
GA	Grant Agreement
IP	Intellectual Property
IPR	IP Rights
IRP	Individual Research Project of DC
KPI	Key Performance Indicator
MIR	Music Information Retrieval
ML	…
PCDP	Personalized Career Development Plan
PhD	
PSG	
SaM	
SB	
US	
WP	Work Package

1. Excellence

1.1 Quality and pertinence of the project's research and innovation objectives

1.1.1 Introduction, objectives and overview of the research programme

Realising potential. Music has been used by humans for its soothing qualities for centuries, but there is still little scientific understanding how music affects the brain before and during sleep, and which musical qualities are particularly effective from both a subjective and an objective perspective. In Lullabyte, an interdisciplinary team of musicologists, neuroscientists, psychologists and computer scientists will leverage both highly controlled laboratory-based sleep studies and large-scale sleep data from wearable EEG, combined with machine learning strategies and MIR-based music analysis for discriminating single musical features as well as asking for eventual cultural biases to elucidate which specific musical features affect sleep physiology. Lullabyte closes a gap in the current research field in Europe and beyond: bringing together researchers from radically different fields in an unprecedented collaboration, Lullabyte aims to understand the basic mechanisms of how music influences sleep in order to foster innovative applied research on individually and dynamically synthesized, brain-inspired music for sleep, and to generate and critically discuss uniquely large and open data sets in the intersection of sleep and music research.

The Lullabyte network will train a group of 10 interdisciplinary doctoral candidates (DCs) in the fields musicology, neuroscience/psychology, and computer science with a structured approach to develop strong and intersectorally applicable research skills in empirical research on the effects of music and sound on sleep.

Challenges in the bigger picture. Music has strong effects on the human brain: inducing happy or sad mood, activating motor programmes up to trance-like dancing, or lulling the recipient into sleep. Some musical genres directly aim at neurophysiological effects. For example, lullabies have been used across human cultures and historical ages with the sole aim of transferring the recipient into a different physiological state; and the contemporary market for music fostering sleep and relaxation across all ages is growing steadily. The 'somnogenic' effects of certain types of music are confirmed by empirical research on adult patients with sleep disorders and healthy volunteers.[1] At the same time, knowledge about the neural mechanisms underlying these strong physiological effects is sparse. Two main problems have so far hampered research projects on the effects of music and sleep: **First**, a plethora of different music styles, musical structures and musical principles exists – a combinatorial explosion makes it practically impossible to test all of these in each combination. **Second**, distinct expertises from remote areas of research are necessary not only to cover musicology and sleep research, but also potential technological and data science strategies to make progress in this complex combination of research obstacles. **Third**, as shown during the COVID-19 pandemics, music for sleep has become an upcoming industry. A substantial increase of sleep music demands has been observed, illustrated e.g. by search requests and playlists at Spotify. App creators, spin-offs and health care companies have gained interest in the topic, predominantly in the US, funding foremost composers to experiment with music for sleep, or experimenting with AI-based approaches to artificially create universal lullabies.

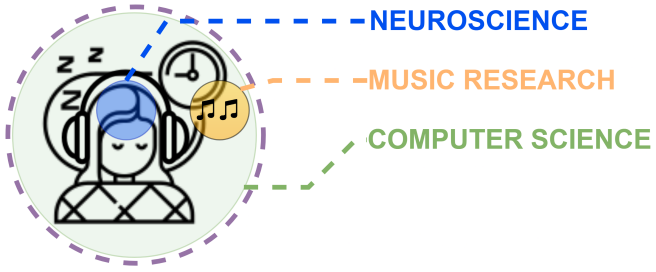

Figure 1.1a: Disciplinary mapping

Lullabyte establishes a European network of excellent institutions from different areas, which allows us to carry out a broad range of interlinked studies, combining the expertises of music research, psychology and neuroscience of sleep, and data science within. This creates a strong interdisciplinary and international network of researchers and leading non-academic partners, providing basis for cutting edge research and innovative training tailored to the special needs of this interdisciplinary field of music and sleep. This, together with the recently growing number of publications on music and sleep as well as a growing interest in the use of music for both, personal smart health applications and the use of music in clinical context, clearly shows the timeliness of Lullabyte network.

Shared Vision. Our network aims at interdisciplinary research in music and sleep. Examining the neurophysiological effect of music on sleep has to be based on joint fundamental research in three areas, neuroscience, computer science and music research. The interdisciplinary combination of these research fields offers a unique chance to identify musical parameters and their effect on sleep quality that can be traced by EEG measurements, which goes beyond the research approaches to date. The Lullabyte network's partners have already fundamentally contributed to the internationally renowned state of the art of research in their domains. Bringing them together with leading non-academic partners promises a high impact beyond excellence in research.

State of the art. Music can influence humans in various ways. It is part of the cultural practice and embedded in social

1 See for sleep disorder: K.V. Jespersen et al., 'Music for Insomnia in Adults', Cochrane Database of Systematic Reviews 8 (2015), CD010459, doi:10.1002/14651858.CD010459.pub2; for healthy volunteers: M.J. Cordi, S. Ackermann, and B. Rasch, 'Effects of Relaxing Music on Healthy Sleep', Scientific Reports 9, no. 9079 (2019).

context. On the individual level, music can have direct impact on psychological and physiological aspects.[2] Psychophysiological responses such as such as blood pressure, breath and pulse frequency, skin conductance etc. are often observed in connection to the emotional states of the listeners.[3] This connection is investigated e.g. based on the BRECVEMA framework, which includes the observation of brain functions[2].

A well-known example of the effects that music can have on the human brain, mind and behavior are the soothing effects of lullabies, which are known and used across human cultures and historical ages: classical music repertoire includes an abundance of lullabies. That music can indeed exert *somnogenic* effects is backed up by a body of empirical research.[4] A number of studies have demonstrated therapeutic effects of music in cases of sleep disorders.[5] Also, in healthy volunteers, music has been shown to affect sleep quality as assessed by questionnaires.[6] As a more objective measure, a few studies in recent years have used sleep electroencephalography (EEG) to test the effects of music on brain function and physiological states.[7] However, the underlying mechanisms and processes how and which kind of music improves sleep are basically unknown. This is partly due to the lack of robust metrics about what makes a good night's sleep.[8] Importantly, recent publications have shown how permeable sleepers are to their environment, even when not awaken by sensory stimulations,[9] reinforcing the need to better understand how music could modulate or interfere with sleep.

Thus, despite an increasing body of research on the effects of music on sleep, this interdisciplinary research field clearly needs further examination.[10] On the musicological side, a detailed and systematic analysis of musical characteristics that might affect sleep has still to be performed. The music used in the above cited studies included classical music compositions, as well as music that was considered to be relaxing. This can be linked to experiences from music therapy, where the term *sedative music* is used for calming music sounding „softer, slower, smoother, and more legato"[11]. Decker-Voigt describes an *ergotropic* (activating) and a *trophotropic* (relaxing) *music* which influences the listener's bodily values.[12] Lamboley proposes classical music with few instruments, stable and rather slow tempo, no change in loudness and without complex orchestration or melodic or rhythmic changes, as well as monotonic nature or technical sounds for sleeping.[13] Within the music, musical parameters that can take influence are (if applicable to the single piece) tempo/note density, mode/key, loudness/dynamics, timbre/spectrum, pitch, intervals, melody, tonality and harmony, rhythm, articulation, pauses and musical form.[14] On the neuroscience side, such elaborations on potentially somnogenic musical structures could in principle be tested with detailed electrophysiological analyses of the dynamic changes in

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2 See P. Juslin, 'Emotional Reactions to Music', in ed. S. Hallam, I. Cross, and M. Thaut, *The Oxford Handbook of Music Psychology*, 2016, 197–214; D.A. Hodges, 'Bodily Responses to Music', in ebd., 183–196, doi:10.1093/oxfordhb/9780198722946.013.16; D.A. Hodges, 'The Neuroaesthetics of Music',ebd., 247–262, doi:10.1093/ oxfordhb/9780198722946.013.20.

3 See Hodges, 'Bodily Responses to Music'.

4 Sleep aid: C.M. Morin et al., 'Epidemiology of Insomnia: Prevalence, Self-Help Treatments, Consultations, and Determinants of Help-Seeking Behaviors', Sleep Medicine 7, no. 2 (2006), 123–130, doi:10.1016/j.sleep.2005.08.008; C.A. Brown, P. Qin, and S. Esmail, "'Sleep? Maybe Later…" A Cross-Campus Survey of University Students and Sleep Practices', Education Sciences 7, no. 3 (2017), 66, doi:10.3390/educsci7030066; characteristics: Trahan et al., 'The Music That Helps People Sleep and the Reasons They Believe It Works: A Mixed Methods Analysis of Online Survey Reports'; R.J. Scarratt et al., 'The Music That People Use to Sleep: Universal and Subgroup Characteristic', 2021, https://doi.org/10.31234/osf.io/5mbyv.

5 For a review and meta-analysis see C.-F. Wang, Y.-L. Sun, and H.-X. Zang, 'Music Therapy Improves Sleep Quality in Acute and Chronic Sleep Disorders: A Meta-Analysis of 10 Randomized Studies', International Journal of Nursing Studies 51, no. 1 (2014), 51–62, doi:10.1016/j.ijnurstu.2013.03.008; Jespersen et al., 'Music for Insomnia in Adults'; F. Feng et al., 'Can Music Improve Sleep Quality in Adults with Primary Insomnia? A Systematic Review and Network Meta-Analysis.', International Journal of Nursing Studies 77 (2018), 189–196, doi:10.1016/j.ijnurstu.2017.10.011.

6 E.g. T. Field, 'Music Enhances Sleep in Preschool Children', Early Child Development and Care 150, no. 1 (1999), 65–68, doi:10.1080/0300443991500106; J.E. Johnson, 'The Use of Music to Promote Sleep in Older Women', Journal of Community Health Nursing 20, no. 1 (2003), 27–35, doi:10.1207/S15327655JCH N2001_03; H.-L. Lai and M. Good, 'Music Improves Sleep Quality in Older Adults', Journal of Advanced Nursing 53, no. 1 (2006), 134–144, doi:10.1111/j.1365-2648.2006.03693.x; L. Harmat, J. Takács, and R. Bódizs, 'Music Improves Sleep Quality in Students', Journal of Advanced Nursing 62, no. 3 (2008), 327–335, doi:10.1111/j.1365-2648.2008.04602.x; T. Trahan et al., 'The Music That Helps People Sleep and the Reasons They Believe It Works: A Mixed Methods Analysis of Online Survey Reports', Plos One 13, no. 11 (2018), 1–19, doi: 10.1371/journal.pone. 0206531; D. Lamboley, Einschlafen und durchschlafen - ohne Medikamente: wirksame natürliche Methoden, gesunden Schlaf zu finden, Herder-Spektrum 4655 (Freiburg i.B, Basel, Wien, 1998).

7 E.g. E.-T. Chang et al., 'The Effects of Music on the Sleep Quality of Adults with Chronic Insomnia Using Evidence from Polysomnographic and Self-Reported Analysis: A Randomized Control Trial', International Journal of Nursing Studies 49, no. 8 (2012), 921–930, doi:10.1016/j.ijnurstu.2012.02.019; C.-K. Chen et al., 'Sedative Music Facilitates Deep Sleep in Young Adults', The Journal of Alternative and Complementary Medicine 20, no. 4 (2014), 312–317, doi:10.1089/acm.2012.0050; C.-Y. Huang et al., 'Effects of Music and Music Video Interventions on Sleep Quality: A Randomized Controlled Trial in Adults with Sleep Disturbances', Complementary Therapies in Medicine 34 (2017), 116–122, doi:10.1016/j.ctim.2017.08.015; K.V. Jespersen et al., 'A Randomized Controlled Trial of Bedtime Music for Insomnia Disorder', Journal of Sleep Research 28, no. 4 (2019), e12817; Cordi, Ackermann, and Rasch, 'Effects of Relaxing Music on Healthy Sleep'.

8 T. Andrillon and S. Kouider, 'The Vigilant Sleeper: Neural Mechanisms of Sensory (de)Coupling during Sleep', *Current Opinion in Physiology* 15, Physiology of Sleep (2020), 47–59, doi:10.1016/j.cophys.2019.12.002.

9 T. Andrillon et al., 'Neural Markers of Responsiveness to the Environment in Human Sleep', Journal of Neuroscience 36, no. 24 (15 June 2016), 6583–6596, doi:10.1523/JNEUROSCI.0902-16.2016; C. Blume et al., 'Standing Sentinel during Human Sleep: Continued Evaluation of Environmental Stimuli in the Absence of Consciousness' ['Standing Sentinel during Human Sleep'], NeuroImage 178 (2018), 638–648, doi:10.1016/j.neuroimage.2018.05.056; Andrillon and Kouider, 'The Vigilant Sleeper'; K.R. Konkoly et al., 'Real-Time Dialogue between Experimenters and Dreamers during REM Sleep', Current Biology 31, no. 7 (2021), 1417-1427.e6, doi:10.1016/j.cub.2021.01.026.

10 J. Loewy, 'Music Therapy as a Potential Intervention for Sleep Improvement', Nature and Science of Sleep 12 (2020), 1–3, doi:10.2147/NSS.S194938.

11 Hodges, 'Bodily Responses to Music', 184.

12 H.-H. Decker-Voigt and E. Weymann, Aus der Seele gespielt: eine Einführung in die Musiktherapie, 2000.

13 See Lamboley, Einschlafen und durchschlafen - ohne Medikamente.

14 A. Gabrielson and E. Lindström, 'The Role of Structure in the Musical Expression of Emotions', in ed. J.A. Sloboda, Handbook of Music and Emotion: Theory, Research, Applications, 2010.

brain signals that co-vary with the musical dynamics. This comprehensive examination in combination with asking for cultural and demographic aspects can point out which musical characteristics have an effect on the sleep quality. An interconnected experimental setup including the subjective and objective decomposition of musical features would thus be needed to advance research into the music-sleep relationship.

Research Objectives. The overall aim of Lullabyte is to elucidate the neural mechanisms underlying the sleep-inducing effects of music and to discriminate single musical features and their effect on sleep quality by leveraging controlled laboratory studies, large sleep datasets from home recordings, and machine learning and data science strategies, as well as developing a framework for interdisciplinary and interlinked data which combines the research data of all examinations within Lullabyte network. This large data set is used to conclude on the effects of specific music pieces on the effect on the sleep quality of individuals, and to ask for cultural biases to elucidate which specific musical features affect sleep physiology. Within and based on this highly multidimensional and interdisciplinary research, we create a comprehensive research and training network on the intersection of sleep research, musicology and computer science. The network will provide high-level interdisciplinary training both in the methods used in each of the involved research communities and in particular in exploring and exploiting the mutual benefit of the complementary research and analysis skills of these fields.

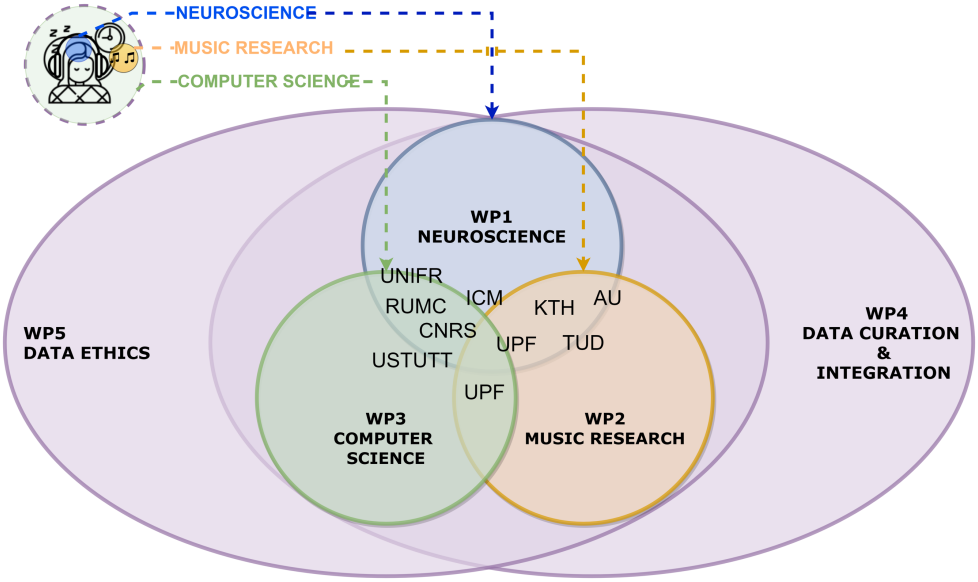

Figure 1.1b: Mapping of the DCs withing Work Packages WPs

We aim to train a new generation of radically interdisciplinary researchers who will not only stimulate disciplinary research with their broad perspectives and skill sets, but will also be uniquely suited to transfer into industry positions. This creates a generation of interdisciplinary researchers in natural sciences, humanities and computer science/engineering, who has a more comprehensive and inclusive understanding of approaches used by remote fields of research.

Lullabyte is thus **composed of 10 PhD projects**, which each tackle a specific sub-question (see 3.1.3 and table 1.3a).

Across all DC projects Lullabyte has 3 overarching, specific scientific objectives (neuroscience, music research and computer science), which are paralleled by 3 research work packages, 2 overarching work packages (see Figure 1.2), and 4 supporting work packages. The specific scientific objectives are:

1. Elucidate the neurophysiological mechanisms underlying the sleep-inducing effects of music (WP1). Abundant empirical evidence demonstrates that music can help to fall asleep. To elucidate the underlying mechanisms of this phenomenon, we seek to test the neurophysiological and emotional effects of different kinds of acoustic stimuli from simple noise to elaborated music on sleep electrophysiology. We aim to develop and validate two main strategies to optimize and personalize acoustic stimulation procedures, one coming from neuroscientific perspective focusing on tracking the EEG signal during sleep while listening to selected sound and music, and second looking at the subjectively rated music and sleep effects coming from a psychological and music research related perspective. The novelty is to combine these two strategies and combine scientific measurements with subjective impressions, which now allows to also address possible discrepancies between objective and subjective results. By creating a feedbacking system between these two main strategies, it will be possible to develop personalised and adjusted models to predict the optimal sleep music for a given individual, which will also allow to fully address the diversity of potential users. These findings are not only relevant for enhancing sleep quality measurably and subjectively accordingly, and lead to better subjective relaxation and recovery of the sleepers, "cracking the code of thalamic gating,"[15] can also be used to enhance safety features, such as to design better working fire alarms (37% of US fire fatality occur during sleep)[16] and less intrusive medical alarms during anaesthesia or critical care, where 60% of ICU patients report insomnia or sleep deprivation.[17]

15 The thalamic gating hypothesis: M.T. Alkire, R.J. Haier, and J.H. Fallon, 'Toward a Unified Theory of Narcosis: Brain Imaging Evidence for a Thalamocortical Switch as the Neurophysiologic Basis of Anesthetic-Induced Unconsciousness', Consciousness and Cognition 9, no. 3 (2000), 370–386, doi:10.1006/ccog.1999.0423

16 See M. Ahrens, 'Home Smoke Alarms: The Data as Context for Decision', *Fire Technology* 44 (2008), 313–327, doi:10.1007/s10694-008-0045-9.

17 See K. Persson Waye et al., 'Improvement of Intensive Care Unit Sound Environment and Analyses of Consequences on Sleep: An Experimental Study', Sleep Medicine 14, no. 12 (1 December 2013), 1334–1340, doi:10.1016/j.sleep.2013.07.011.

2. Clarify the musicological features and structures of sleep music (WP2). Music that is subjectively rated to foster sleep quality seems to share musical features even though being grounded in different musical styles. To see which musical features are shared and learn if these features can be separated by effect, we will analyse the music that is subjectively rated suitable for sleep concerning musical features based on 4 basic aspects (timbral features, loudness, tonal features, rhythmic features) as outlined in the MIRtoolbox[18] in order to outline the majorly shared features, and confront these with the features found in culturally grown sleep music. This allows to conclude on basic musical features predominantly present in modern sleep music and relate them to cultural environment, and biographic and demographic information of the individuals. By employing the five general sonification strategies, new sound and music will be generated inspired by the sleep music features and tested regarding their subjective and measurable effects on sleep, creating an interactive real-time loop between sleep tracking and individualised sonification. We thus aim to gain novel insights on the effects of distinguishable musical features the different sleep musics share and learn how these features effect the soundness of sleep, in order to be able to enhance measurably and subjectively the sleep quality through an individually generated music. We are aware that the study of the musical features embeds a broad range of aspects that have to take into account a cultural, demographic and gender diversity. We therefore address this actively in recruiting a diverse group of participants as well as a broad range of different musics.

3. Computational objectives (WP3). Computational aspects are embedded in all stages of the research in WP1 and WP2. The special emphasis hereby is on the one hand to address the variety and heterogeneity of data gathered, and to develop and implement new analytical approaches and predictive machine learning techniques that can cope with its unique properties. The software will be designed modular and flexible and embed the very specific needs of this interdisciplinary project, providing for the first time a set of software tools that is targeted to users from several disciplines. The connected development of a suitable data scheme, as outlined in WP4 enables us to acquire, process and analyse data by all DCs. On the other hand, and to be able to cope with resource-constraints due to personalization and data acquisition in unsupervised environments, algorithms have to be developed that are optimal with respect to their computational complexity, and their implementations have to be computationally efficient and hardware-aware to enable its use in the field. We aim to create analysis and synthesis processes with an efficiency that is orders of magnitude higher than current approaches designed for lab-use can provide, enabling its use on a laptop in combination with wearable EEG devices for home use. We hence aim to develop fast and efficient processes which are capable of dealing with the given heterogeneous data sets.

4. Objectives related to data curation and integration (WP4). There is little objective data available that provides a scientifically sound basis for the analysis of the effects of music/sound on sleep. This derives from the heterogeneity of the data and the multitude of its sources, which requires to develop new strategies for data provisioning, processing and management such as dedicated software for data pre-processing and analysis pipelines that can be used jointly by several participants supported by collaborative platforms. To provide a profound data basis for research in Europe, we will develop a pilot structure for these interdisciplinary data sets. The pilot provides easily accessible annotated data and is accompanied with software developed for a very interdisciplinary user base, including setting up processes and structures of data management that enable partners to access data among each other, uniform structures of data and metadata and the prototypical integration of the data management. This completely novel structure provides the basis for developing an international shared open access data structure which can be used to collect and gather data in an interdisciplinary Open Data community effort in order to foster further European and international research.

5. Objectives related to Data Ethics (WP5). While digital ethics continuously gain more and more interest, research on data ethics concerning big and linked data sets is yet underrepresented. Thus, we will explicitly work on the ethical implications related to the use of data-driven and artificial intelligence (AI) technologies in research and development in the context of sleep and music. Hereby, we will identify the major risks, outline implications such as for example pros and cons concerning big (personal) data collection and use of these data for gaining insight in health issues related to music and sound effects on sleep and relaxation versus privacy issues and the risk of commercial use by third party companies and the control of data-driven applications, and develop a set of recommendations for data ethics from this tailored to the need of the field of music and sleep. The knowledge gained in this WP will be applied to the different DC projects by defining transversal and practical methodologies for human-centred and trustworthy AI research.

Programme Overview. The research on music and sleep in the Lullabyte network focuses on gathering, comparing and interpreting subjective and measurable effects of music on sleep throughout all sleep phases. We will examine the underlying mechanisms for music influencing sleep and sleep quality while also separating the different underlying mechanisms for sleep induction on the neurophysiological level,[19] and the relationship between the subjective and measurable effects of music and sleep and demographic and biographic information.

Lullabyte's overarching goal is to elucidate the effects of music on sleep from musicological level over psychological mechanisms to basic neurophysiology of acoustic processing. We will generate a rich and interdisciplinary-fed dataset

18 O. Lartillot and P. Toiviainen, 'MIR in Matlab (II): A Toolbox for Musical Feature Extraction from Audio', *Proceedings of 8th Interna- 659 Tonal Conference on Music Information Retrieval*, 2007, http://ismir2007.ismir.net/proceedings/IS- 660 MIR2007_p127_lartillot.pdf.

19 cf. P.N. Juslin and D. Västfjäll, 'Emotional Responses to Music: The Need to Consider Underlying Mechanisms', Behavioral and Brain Sciences 31, no. 5 (2008), 559–575, doi:10.1017/S0140525X08005293.

containing information generated by all involved disciplines, and – in a joint interdisciplinary venture – gathered by all partners, which ensures a much higher degree of diversity, disciplinarity, and internationality than possible by single projects. The data will be derived from both qualitative and quantitative empirical methods. Participants will include both healthy sleepers but also patients with insomnia. Based on the overall dataset, new analytical approaches and predictive machine learning techniques will be developed that can cope with the heterogeneity of the data. The network will also develop metrics of sleep quality from brain recordings suited for situations in which sleepers are exposed to music and tailored for real-time brain computer interfaces. Personalisation of the methods and predictions finally bring back the human in the loop and provides a starting point for analytic and creative sonification.[20] Providing personalized real-time feedback requires, however, efficient hardware-aware implementations of conventional and new algorithms for both analysis and generation of new input stimuli.[21] This holds in particular in non-stationary settings as intended here, e.g., with wearable sleep EEG. There, real-time demand has to match limited resources such as computing power or battery life. We commit ourselves to the generation of Open Source Software wherever possible.

In summary, to address our three objectives, we have developed three scientific and two supporting work packages: WP1 will focus on the neuroscientific investigation of the effects of music on sleep, WP2 will focus on the musicological analysis of different kinds of sleep music, WP3 aims to integrate these approaches leveraging large datasets and machine learning strategies based on efficient algorithms and implementations. In addition, these WPs are accompanied by two overlapping WPs: data curation and integration (WP4) and research on ethics of data (WP 5), both of them addressing the interdisciplinary data acquisition in all PhD projects.

WP1: Neuroscience. Sleep is an oscillating physiological process by the brain and for the brain. Within this work package, we will apply several state-of-the-art electrophysiological approaches to elucidate the neural effects of different kinds of acoustic stimulation including music on the brain during wakefulness and different phases of sleep. We will test effects of acoustic stimulation on EEG arousals and awakenings in both controlled lab environments and naturalistic home settings. In multiples studies, healthy participants will explicitly or implicitly listen to different kinds of acoustic stimuli from simple noises of different sound levels to preferred or non-preferred music before and during sleep (DC1, 4), while wearing state-of-the-art high-density EEG for few highly controlled studies or wearable EEG systems for large-scale recordings (DC2, 5, 6, 7, 8, 10). Beyond physiological signals, also tests of memory, emotion and dream experiences will be assessed to evaluate the effects of music on sleep in several levels (DC2, 4, 5, 8, 10).

WP2: Music research. In music research, a diverse set of candidate sleep music pieces is identified both theoretically from the musicological literature and empirically from harvesting streaming platforms for the best rated pieces from sleep-themed song lists (DC1). This music collection is examined with qualitative and quantitative methods: Through systematic ratings by volunteers regarding the experienced calming and somnogenic effects, and other relevant aspects such as likability, the music is categorised and cross-matched with demographic and personal information of the volunteers (DC1, 4, 9) as well as with sleep measurements (DC 7, 10). In parallel, the perceived music is analysed using Music Information Retrieval (MIR) techniques on musical parameters such as tempo, pitch range, harmonic structures melodic lines, average loudness but also music genre, instrumentation and formal complexity (DC1, 7). Continuous parametric ratings and in-depth interviews will monitor potential differences not only between, but also within single musical pieces, thus identifying potentially relevant musical parameters. The results will be reflected against the background of the cultural environment (DC1, 4).

WP3: Computer science. The heterogeneity of the data sources and types poses a challenge for classical data science and machine learning approaches. The combination of time-dependent and noisy real-time measurements (EEG) with textual and categorical data (surveys, web-based analysis) cannot be treated with solitary standard approaches. This requires new methodological developments tailored to the peculiarities of music for sleep. For example, post-sleep surveys (perceived sleep quality) could lead to stationary input/tuning to time-dependent predictive models such as long-short term memory models (DC2, 10); and machine learning can help to identify clusters of study candidates with similar reactions to the same musical stimuli (DC3). Personalization "at the patient" has to be realized in real-time (DC 3). While we can expect distinct subpopulations to react similar due to cultural imprint, "real" personalization requires real-time analysis and feedback, e.g through sonification (DC3, 7, 8). Time-consuming algorithms have to be moved to the offline stage (e.g. pre-trained), and efficient implementations are required to cope for constraints in time or energy consumption.

WP4: Data curation and integration. Sleep recordings provide rich data sets with different modalities, which traditionally come in different formats and offer multiple options for analysis. The Lullabyte project will for the first time develop a pilot structure for a linked large dataset on the multifarious data resulting from the research outlined in WP 1-3. These approaches will include solutions for data provisioning, processing and management, as well as standards that provide easily accessible annotated data and embed dedicated software for data preprocessing and analysis pipelines (DC2, 3) that are used jointly by and are streamlined across the project partners using interfaces suitable for a very interdisciplinary user base (DC2). All DCs will contribute to the development of this pilot and

20 Turning data into sound see: T. Hermann, A. Hunt, and J.G. Neuhoff, eds., The Sonification Handbook (Berlin, Germany, 2011).

21 See S. Cirit et al., 'Development of Real-Time EEG Application on an Ultra-Low-Power DSP', *International Symposium on Code Generation and Optimization (CGO)-ODES* (presented at the Workshop on Optimizations for DSP and Embedded Systems, Seattle, 2009), 1–6.

integrate their research data as far as possible in order to ensure the usability across different research environments and to develop a sustainable structure which will be open source and accessible for easy re-use and validation as is Lullabyte's research data.

WP5: Data ethics. Research related to sleep and music has the potential to facilitate new opportunities in the development of data-driven applications and products that can have a positive impact on people's mental and physical well-being, as well as contribute to security aspects. However, there are also some risks arising from these technologies, e.g. related to privacy, bias/fairness or transparency, which should be assessed and minimized. Developing an easy-accessible, interdisciplinary and big linked data set as outlined in WP4 therefore needs a parallel reflection on these aspects. Data-driven AI processes can help to get robust and stable predictions, however, outlining possible risks of the implementation of AI processes helps to develop safe projects in the future. Hence, all DCs will be trained in basic data ethics and then contribute to develop a set of recommendations for data ethics with special emphasis on the heterogeneous and interdisciplinary data as acquired in Lullabyte. The DCs will apply these considerations on their individual projects.

Table 1.1a: Work Package List

WP No.	WP Title	Lead Beneficiary No.	Start Month	End Month	Activity Type[1]	Lead Beneficiary Short Name	DC involvement
1	Neuroscience	5	7	48	RES	PBI	1, 2, 4, 6, 7, 8, 9, 10
2	Music research	1	7	48	RES	TUD	1, 4, 6, 8, 9, 10
3	Computer Science	3	7	48	RES	USTUTT	2, 3, 7, 8, 10
4	Data curation and integration	2	1	48	RES	RADBOUDUMC	All DCs
5	Data ethics	8	7	48	RES	KTH	All DCs
6	Training programme	4	1	48	TRA	AU	All DCs
7	Dissemination and Communication	7	1	48	DIS	UPF	All DCs
8	IP and Exploitation	6	1	48	EXP	CNRS FEMTO-ST	All DCs
9	Management	1	1	48	MGT	TUD	All DCs

[1)] MGT: Management; RES: Research; TRA: Training; DIS: Dissemination and communication; EXP: exploitation

1.1.2 Pertinence and innovative aspects of the research programme

Sleep research has been primarily tackled by a mono-disciplinary approach within neuroscience, sometimes reaching out to psychology, but substantially lacking an awareness and research on the music and its features used in sleep studies (see 1.1.1 State of the art). Lullabyte goes beyond this state-of-the-art research by combining the rather distant research fields neuroscience/psychology, music research, and computer science. Bound together by the shared, topic-specific

interest, namely which musical feature can be distinguished to have specific effects on sleep in order to enhance sleep quality, Lullabyte brings together these research fields in a unique network, constituted by three central integral research sections: neuroscience/psychology of sleep; musical and acoustic features influencing sleep; algorithmic and implementatory aspects of data analysis and music/sound generation. This goes together in Lullabyte's main interest: to understand the basic effects on audible aspects (sound /music) on sleep by a cross-disciplinary approach, using computational techniques to enable both music analysis (e.g. MIR, AI/ML), and music generation (e.g. interactive EEG sonification) in a personalized way. This multi-dimensional approach opens a completely new perspective on the effect of sound/music on sleep, including two novel research areas: the examination of the yet unconsidered sound/music and sonification as auditory stimuli as well as an observation of musical effects on sleep quality throughout all sleep phases. We assume that the rhythm patterns of the brain observed in different sleep-related moments can be promoted or enhanced if the acoustic stimulation follows the same (or compatible/equivalent) patterns. Understanding the connections between music stimuli and sleep improvement enables the development of a controlled generation (personalised) sound and music for sleep.

In order to achieve this, we also develop and pilot a new data scheme for linking the heterogeneous data acquired in Lullabyte, that enables data use and processing across the disciplines based on a technical robust structure. Hereby, we explicitly detected and outline ethical risks connected to data driven applications processing those powerful and large sets of linked data.

This new approach of combining research disciplines with shared and linked data sets provides the basis for groundbreaking developments concerning music for sleep, such as future projects using individually and interactively personaliseable, non-pharmaceutic smart-health solutions/applications which are suitable for individual as well as for clinical use at affordable costs. These follow-up projects meet a current need which is already mirrored e.g. a growing number of sleep music/relaxation music klicks and buys on music platforms.

Innovative key aspects and future of research for music and sleep. The strong research background as well as the interdisciplinary work experiences and excellent training skills of the involved partners enables us to establish a sustainable and highly demanded training for the DCs, which will be carried out by all involved areas and international and interdisciplinary non-academic and artistic associated partners. As the training contains not only methodical and soft skill trainings, but also a broad range of soft skill training for working in an intradisciplinary, international and highly competetive contexts as well as innovative outreach activities, the DCs will have one year work experience in interdisciplinary teams as well as international research experience within their own research project provided by the secondments. This will foster a new generation of excellent European researcher with an international background above-average compared to the other researchers of their academic age. In addition, the DCs will get a well-balanced and close training in small groups by our non-academic partners, who can be met also in a private atmosphere during the trainings camps which allows the DCs to create strong networks already at an early stage and elicit the non-academic job market as well as the needs and requirements right from the start of their career.

A very special opportunity are the meetings with the two composers in residency (one in the second, one in the third year) who will be present at the trainings camps, and available for collaboration during their one month artistic residency, if a shared interest with a DCs project can be detected. This allows the DCs to learn from a completely different perspective on both, the way of thinking and working and the take on music and sound made for sleep. To our opinion, the change to work with artist is a unique possibility to get a new view on the research question and also to reflect the own questions, approaches and methods in a special way. In addition, these cooperations can pioneer future projects and enhance the DCs understanding of what it means to create valid music especially with an emphasis on sleep.

With this broad and linked interdisciplinary approach, Lullabyte goes beyond the state of the art of the fast growing field of sleep research, as well as music research: despite the usual silo thinking within the individual disciplines, we bring together three seemingly distant disciplines (neuroscience/psychology, music research, computer science) by combining their methods and perspectives, and employ shared interest in the mechanisms behind the measurable and experienceable effects of music and sound on sleep. Lullabyte hence provides an intermediate step towards a later automated data collection, data analysis and personalized music and sound play back, e.g. based on smart health applications. Therefore, we develop a technically demanding pilot scheme for data pooling, as well as actively reflect on data security considered and data ethics – an aspect that allows, once clarified, also the integration of big players such as e.g. google in the future.

Key innovations and progress on the state-of-the-art envisaged by the team include: a scientifically sound **understanding of the effects of music on sleep**, from its **historical influences** on societal formative influence up to its implementation; **identifying relevant musical features** and their **influence on the brain** (EEG and PSG data) **such as** psychoacoustically categorized short- and long-term features including timbral, tonal and rhythmical features;[22] a thorough **understanding** of the **influence of sleep music and lullabies** on **different phases of sleep** and transitions from wakefulness to sleep or sleep to wakefulness; a **quantification of the impact of music exposure** during sleep

22 O. Lartillot and P. Toiviainen, 'MIR in Matlab (II): A Toolbox for Musical Feature Extraction from Audio'.

on vigilance and cognitive performance the following day; discriminating **musical features vs. auditory stimuli**; **understanding musical** features that are **generalizable in order to personalise music**/sound for fostering sleep; developing a **personalized smart health application** with huge impact; an in-dept understanding of **the effect of sounds (alarms**) concerning waking up; an **adaptive analysis of data** and **generation of music in real-time** required to adjust to individual perception; and the creation of the **world-wide first large data set** on the **neurophysiological influence of music on sleep** (Open Data).

1.2 Soundness of the proposed methodology

1.2.1 Overall methodology

Intertwining, music and sleep will be examined involving disciplinary methods but also using newly and specifically developed data-based approaches on music and sleep data.[23] In sum of all studies within Lullabyte, effects are examined for music considered to be sleep inducing, and for music listened before going to bed, during the process of falling asleep, and during sleep. After awakening (in the morning, after an alarm), subjective sleep quality and individual state (e.g. mood, alertness, energeticness, cognitive performance) will be assessed with questionnaires. This unique and heterogeneous dataset will allow to test the effects of different musical pieces both in their entirety and their internal second-by-second musical parameters on both the macro- and microstructure of the time-logged sleep EEG traces. The methods underpin the projects workpackages' interdisciplinarity and scientific high approach.

Data acquisition: In WP1 and 3, we will combine two ongoing developments in the field of sleep research: (1) instead of relying on low-density EEG as typically used in standard polysomnography to assess the quantity and quality of sleep, we will use a multi-modal approach combining high-density EEG with additional peripheral measures such as ECG; (2) leveraging the recent development of personal portable EEG, making the large-scale recording of EEG data feasible in home settings and without the direct monitoring/intervention of a research team. These two evolutions increase both the quality and quantity of data, and we will devise novel analytic routines, inspired from computational neuroscience and machine learning, to pre-process, clean and analyse these data. The collected data sets will be used in WP1-5.

In WP1 and 2, we will combine both objective (neurophysiological) and subjective (questionnaires) evaluations of sleep to better understand music's impact on different aspect of sleep, from the improvement of physiological variables to a perceived increase of sleep quality. For the analyses of neural recordings, we will go beyond classical analyses and automate the extraction of classical sleep features but also of novel approaches to sleep analyses (complexity measures, local aspects of sleep, etc.).

Data exploration/sonification: There are a number of methods that can be used to sonify sleep data for real-time or non-real-time analytic and creative application.[24] In WP 2 and 3, we aim to integrate *Parameter mapping,* involving mapping data characteristics to acoustic or musical parameters (also called *musification*), *audification*, as is most appropriate for large temporal data sets and periodicity, noise, and repetitive patterns can be effectively displayed, *model-based sonification,* where the resulting sound can be considered a representation of that model/data set, as well as a*uditory icons*, which communicate information metaphorical, showing quite intuitively the relationship between the data and the sound, and *earcons,* short musical motifs. In addition, we want to explore real-time sound/music transformation while people are going to sleep or during sleeping, aiming at faster sleep induction, better quality of sleep, better quality of waking up, smooth transition between sleep phases, minimizing or blocking second-hour insomnium, etc. The transformations are studied concerning amplitude (e.g. binaural beats) and frequency modulation, tempo changes by means of time-stretching algorithms, and modulated filtering (e.g. progressively reducing high frequencies, or make those changes in sychrony with specific electrical signals).

Exploration of music and cultural effect: In WP2, the music will be examined coming from three approaches: a historical approach which is predominantly used for examining the heritage and development of the lullabies in Germany, Denmark and Spain, a sociological and psychological approach is combined, using surveys and interviews for examining the listening habits and musical preferences of the participants related to their biographic and demographic information as well as the sleep habits and preferences related to the auditory environment, and a music analytic approach using music information retrieval MIR techniques in order to analyse the presented musical pieces and auditory stimulies while falling asleep or sleeping e.g. using the feature set of the MIRtool box,[25] in order to extract features shared by those musical inputs that are either subjectively rated sleep enhancing or measurably sleep inducing. The results of all three approaches are confronted and combined, as well as for the first time linked back to the neuroscientific findings.

Data curation and integration: In order to develop a suitable structure for the interdisciplinary data collected in Lullabyte, we start in WP4 with a pilot phase in which we develop two data stories in order to create two realistic use cases based

23 For data driven methods see E. Ponsot, P. Arias, and J.-J. Aucouturier, 'Uncovering Mental Representations of Smiled Speech Using Reverse Correlation', The Journal of the Acoustical Society of America 143, no. 1 (2018), EL19–EL24, doi:10.1121/1.5020989; L. Goupil et al., 'Listeners' Perceptions of the Certainty and Honesty of a Speaker Are Associated with a Common Prosodic Signature', Nature Communications 12, no. 1 (2021), 861, doi:10.1038/s41467-020-20649-4

24 Hermann, Hunt, and Neuhoff, The Sonification Handbook.

25 V. Alluri et al., 'Large-Scale Brain Networks Emerge from Dynamic 638 Processing of Musical Timbre, Key and Rhythm', *NeuroImage* 59, no. 4 (2012), 3677–3689; O. Lartillot and P. Toiviainen, 'MIR in Matlab (II): A Toolbox for Musical Feature Extraction from Audio'.

on which we then outline on how to implement a data management that facilitates easy data integration and integrative analyses. The results are used to develop a matching data scheme that allows to integrate the needs of all of Lullabyte's data sets. This data scheme is then tested and validated according to data management principles as well as technical constraints such as data storage, shared meta data, accessibility and usability, and compatibility for OpenAccess use.

Data Ethics: Based on the DCs project and in combination with WP4, the risks arising from the use of technologies which show an urgent need to be assessed and minimized, are identified, collected and set in relation to already existing strategies on data ethics in WP5. This provides the basis for reflecting the identified risks also related to global challenges (European Green Deal, UN Sustainable Development Goals, MSCA Green Charta) and develop recommendations on data ethics and how this can be implemented in academic and non-academic projects.

1.2.2 Integration of methods and disciplines to pursue the objectives

Exposure. To achieve the goal of identifying the underlying mechanisms of the effect of music and sound on sleep, an interplay of the disciplines involved as well as a combination of the methods is incomprehensible. This is mirrored in the within the work packages (see table 1.1a) and the individual DC projects that all include methods from different disciplines (see table 3.1d). To foster this interdisciplinary research, we provide a an adequat training including basic training in all for the DCs relevant disciplines by secondments, in the local trainings, by the graduate schools, and especially in the trainings camps where e.g. all DCs receive a basic training in EEG recordings, programming, sonification, and examining cultural aspects concerning music (see table 1.3c). This enables all DCs to integrate and carry their own projects based on embedding different methods as well as makes them aware of the significances, each acquired data set comes along with when processing the linked data.

Complementarity. Interdisciplinarity is the main characteristics of the research on music and sleep. In training the DCs in different methods and perspectives coming from all involved disciplines, the DCs will be well prepared to meet the extended requirement in this field. Lullabyte will provide them with a high employability based on their methodical skill set and their cross-disciplinary work experience with academic and non-academic partners. This broad range of experiences does not only apply for the distant disciplines, but also for the combination of the various neuroscientific approaches as represented by the neuroscience- and psychology-related partners.

1.2.3 Gender dimension and other diversity aspects

Lullabyte includes a special focus on diversity and gender aspects as we aim to also reflect on and analyse the potential influence of sex, gender and diversity related aspects on music perception during sleep.

Gender dimension: Gathering data on the effect of music on sleep requires a careful consideration of gender and diversity aspects. In WP1 and 2, we will pay particular attention that there is a gender balance within the participants during acquisition. We will also consider gender dimension and demographics, as well as cultural backgrounds, when examining musical preferences in WP2. Previous studies show that there is a strong bias concerning gender in both, research design, e.g. lullabies have been examined with a focus on mothers' singing (no fathers' singing),[26] and in the results, e.g. it has been shown that women show stronger emotional responses to music than men.[27] In addition, it can be seen that sex as well as hormonal status (menstrual cycle as well as oral contraceptives) have an impact on sleep, memory and sleep-related memory consolidation.[28] Cultural imprint is an important aspect considering the historical development of lullabies and the perception of music (WP1 and 2). Data sets in previous studies on cultural aspects have been very limited in size so far.[29] They have thus not been able to provide an overall representative sample.

Further Diversity aspects: When examining the effect of auditory stimulies and music on sleep (WP1 and 2), we will, in addition to an equal gender-balance, also aim to include a sufficient number of participants from different groups and different countries. In one of the projects in WP2, we will explicitly focus on 3 different cultural backgrounds (Germany, Denmark, Spain), taking into account the related geographically influenced diversity, ethnic groups, as well as demographic and biographical data, which requests also a balanced diversity in aspects such as age, education, cultural training, language, etc. These aspects will be taken into account also when examining the data (WP3-5).

1.2.4 Open science practices

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26 A.M. Cevasco, 'The Effects of Mothers' Singing on Full-Term and Preterm Infants and Maternal Emotional Responses', Journal of Music Therapy 45, no. 3 (2008), 273–306, doi:10.1093/jmt/45.3.273; D. Fancourt and R. Perkins, 'The Effects of Mother–Infant Singing on Emotional Closeness, Affect, Anxiety, and Stress Hormones', Music & Science 1 (2018), 1–10, doi:10.1177/2059204317745746.

27 A. Goshvarpour, A. Abbasi, and A. Goshvarpour, 'Gender Differences in Response to Affective Audio and Visual Inductions: Examination of Nonlinear Dynamics of Autonomic Signals', Biomedical Engineering: Applications, Basis and Communications 28, no. 04 (2016), 1650024, doi:10.4015/S1016237216500241.

28 L. Cahill, 'Why Sex Matters for Neuroscience', *Nature Reviews Neuroscience* 7, no. 6 (June 2006), 477–484, doi:10.1038/nrn1909; L. Genzel et al., 'Sex and Modulatory Menstrual Cycle Effects on Sleep Related Memory Consolidation', *Psychoneuroendocrinology* 37, no. 7 (2012), 987–998, doi:10.1016/j.psyneuen.2011.11.006; L. Genzel et al., 'Diminished Nap Effects on Memory Consolidation Are Seen Under Oral Contraceptive Use', *Neuropsychobiology* 70, no. 4 (2014), 253–261, doi:10.1159/000369022; A. Alonso, L. Genzel, and A. Gomez, 'Sex and Menstrual Phase Influences on Sleep and Memory', *Current Sleep Medicine Reports* 7 (2021), 1–14.

29 See A.M. Unyk et al., 'Lullabies and Simplicity: A Cross-Cultural Perspective', *Psychology of Music* 20, no. 1 (1992), 15–28, doi:10.1177/0305735692201002; J.M. Esteve-Faubel et al., 'Women's Songs: The Lullaby in the Spanish Autonomous Region of Valencia', *Western Folklore* 73, no. 1 (2014), 69–116; S.E. Trehub, A.M. Unyk, and L.J. Trainor, 'Adults Identify Infant-Directed Music across Cultures', *Infant Behavior and Development* 16, no. 2 (1993), 193–211, doi:10.1016/0163-6383(93)80017-3.

Addressing open science in Lullabyte goes beyond a pure open access publication of data. In order to educate the mindset of all involved researchers, we embed workshops and trainings for the DCs on open science and open access strategies, and seek to include public participation in the research process. According to the guidelines on Open Research Data and Data Management, we aim to share knowledge and data as early as possible in the research process through registered reports (e.g. pre-registered at OSF), pre-prints, EU platforms (e.g. Open Research Europe ORE or Horizon Results Booster)[30], or interaction with citizen neuroscientists in order to help to bidirectionally exchange the latest knowledge with relevant actors.[31] We aim to use Open Source Software if possible, and link to Open Source Software Projects. We will mainly use Python-based applications and integrate our skripts and tools if possible e.g. with MEI. We hence aim to foster openness on the level of tools and scripts (WP4), but will also point out limits concerning open access and open use of data sets (see WP5). To achieve this, a workshop on open science practices for all DCs will take place in the first training camp in cooperation with SLUB Dresden. We also aim to have all our projects preregistered or at least make the design of the experiments and studies available (e.g. via platform OpenScience Framework OSF or by publishing with Journals with publication guarantee if the design is successfully preregistered). We hence will train our DCs for this and encourage preregistration within their PhD projects. All resulting publications of Lullabyte will be either Open Access publications (OA journals or pre-print server, e.g. arXiv, HAL), or, if applicable, with secondary publication rights according to the green standard (see also dissemination and 1.2.5).

1.2.5 Research data management (RDM) and management of other research outputs

The research data management is divided in three sections: **Section A - Data management of the individual projects:** Original raw data (EEGrecordings, surveys, music), codes, methods and scripts used for producing data and sonifications (data and audio files) will be stored according to the individual member organizations and the requirements and habits of the research field (data from sleep tracking are e.g. formatted to comply with Neurodata without borders[32] and also the analysis scripts will use that format) and/or university at the responsibility of each beneficiary. Fulfilling FAIR principles, i.e. considering which data to publish, considering where to publish to platforms (such as DarUS, a data platform tailored to natural sciences with data provenance, sharing and documentation established and facilitated by Stuttgart University), or public repositories (e.g. B2Share or Zenodo), the research data is published according to the open access policy of the EU following the Open Science Practices as outlined in 1.2.4 and national guidelines (e.g. German following the recommendations of NFDI4culture), and guaranteeing an archiving for at least 10 years due to EU standards. We expect to store up to 1TB data per DC project, which will cost around XXX Euro for storing.

Section B - Central support and review of data management: Setting up a consortium policy, organizing RDM lectures, evaluating individual data management planning reported by all DCs. This will be managed by Lullabyte's project officer who will also be part of the RDM team (described in Section C), and has the overall responsibility for Lullabyte's data management.

Section C – Data management for data integration: We aim to embed all data sets within Lullabyte's network-wide structure which is developed based on the knowledge at RADBOUDUMC and tailored to the need of the network's interdisciplinary heterogeneous data. For the initial set-up, a data platform specialist will be employed for 6 months to help setting up the structures in cooperation with the RDM team (DC2, DC3, the coordinator, and the project officer, RADBOUDUMC and USTUTT), which will manage the platform closely related to WP4 under supervision of RADBOUDUMC. The Lullabyte-data repository is fed by all DCs. As outlined in WP4, these structures will help to pilot an interdisciplinary linked data-set (combining music and sleep data). To achieve this, a meta data scheme will be created that enables interdisciplinary analysis pipelines for big data on sleep and music and processes for data integration (see WP4), aiming at developing the basis for a data management scheme that can serve as basis for the world-wide first and largest interdisciplinary and linked data-set in the field of music and sleep research, opening up new possibilities for future interdisciplinary analysis pipelines for big data on sleep and music as a community service. The pilot and the inherent dataset will be published under open access as described in Section A.

Publication: All resulting data sets will be made publicly availabe in two instances: at the beneficiaries' institutions and in Lullabyte's own platform. It is intended to develop the pilot structure (created in WP4) as an overall structure which can serve as a third interdisciplinary instance covering interdisciplinary data sets as well as providing meta information for linking the data under Open Science conditions. The centralized webpage of Lullabyte will function as a comfortable access point for all openly shared materials and published papers. All research projects will use preprint servers and aim to publish in open-access journals or according to green standard in case of high impact journals to disseminate their findings (see also 2.3.1.1). The webpage will thus contain links to all publications resulting from the project as well as to links to Lullabyte's social media content (Youtube, Twitter, Instagram) and services such repositories.

30 Open Research Europe (ORE) https://open-research-europe.ec.europa.eu/?mc_cid=0abeb12a98&mc_eid=cc6f810faa; Horizon Results Booster www.horizonresultsbooster.eu/ (last access Nov 6. 2021).

31 See R. ter Horsta and M. Dresler, 'The Quantified Scientist: Citizen Neuroscience and Neurotechnology', *AJOB Neuroscience* (in press).

32 'Neurodata Without Borders – The Kavli Foundation', accessed 30 October 2021, https://www.nwb.org/.

1.3 Quality and credibility of the training programme

1.3.1 Overview and content structure of the doctoral training programme (DTP)

Our DCs: We seek to recruit ten international promising, young scholars with an excellent education, open minds and a strong interest in working in this highly interdisciplinary field (for recruitment strategy see 3.1).

Training Objectives. Lullabyte's training program follows ***three major aims***. We want to

1. Provide a high-quality training for both, disciplinary and interdisciplinary aspects in academic and non-academic research context at the intersection of neuroscience, music research and computer science; and
2. Favour and foster the experience of working with academic and non-academic partners; and
3. Stimulate the emergence of new approaches within the research working on sleep research/EEG and music research/music production employing computer science practices.

This will be achieved by an **individual training** with an emphasis on disciplinary and interdisciplinary research at the host institution (disciplinary) and the two secondments (interdisciplinary), as well as in seminars of the local graduate school (general training, soft skills), as well as in **networkwide trainings** (interdisciplinary, soft skills, transferable skills), which culminate in our annual **trainings camps**.

Table 1.3a: Recruitment Deliverables per Beneficiary

No.[1]	Host[2]	PhD[3]	Research topics (abbreviated)[4]	Start[5]	Duration[6]	S1[7]	S2[8]
DC1	TUD	TUD	Identifying of musical features of sleep music – WP1, 2, 4, 5	7	36	UPF	AU
DC2	RADBOUD -UMC	SRU	Analysis pipelines for big sleep data – WP1, 3, 4, 5	7	36	USTUTT	ICM
DC3	USTUTT	USTUTT	Real-Time Data Analysis and Predictions – WP3, 4, 5	7	36	ICM	AU
DC4	AU	AU	Factors determining the choice of sleep music – WP2, 4, 5	7	36	UPF	USTUTT
DC5	ICM	ICM	Effects of acoustic stimulation of the sleeping brain: optimization of sound levels and subjective measures – WP 1, 3, 4, 5	7	36	RADBOUDUMC	UPF
DC6	CNRS FEMTO-ST	UBFC	Cracking the musical code of thalamic gating – WP1, 4, 5	7	36	UNIFRI	GHU
DC7	UPF	UPF	The effect of interactive EEG based sonification and music generation, on sleep induction and sleep quality – WP1, 2, 3, 4, 5	7	36	ICM	Tba
DC8	KTH	KTH	Creative and analytical sound design and sonification of sleep data – WP1, 3, 4, 5	7	36	TUD	ICM
DC9	Endel	TUD	Tba WP1, 2, 4	7	36	RADBOUDUMC	TUD
DC10	UNIFRI	UNIFRI	Sleep, Music and Emotional Processing – WP1, 2, 3, 4, 5	7	36	CNRS FEMTO-ST	AU

Total	10			7	360		

1) Researcher No.; 2) Recruitment Participant; 3) PhD-awarding entities; 4) Further detailed in Section 3.1; 5) Planned Start Month; 6) Duration in months; 7) first secondment; 8) second secondment

Individual training. The ***individual training*** will be structured by the DC's **individual and personalised training plan** (included in the personal career development plan PCDP) which is developed in a joint effort of the DC and the supervisor in cooperation with the co-mentor and co-supervisors at secondment host institution. The individual training is provided by the home institutions and the secondments guided and supported by the supervisors, peer-to-peer training within the network, and self-study programs. The individual trainings plan for each DC also includes **training through participation in conferences,** as well as **training through** two **secondments** (see table 1.3a - for a total duration of one year) each DC is assigned to. Each individual PCDP is subject to feedback and approval by the supervisory board (SB). For a continuous **quality assurance of the PhD projects**, the DCs are in a constant communication with their supervisors. Furthermore, there will be regular review meetings and network wide as well as public evaluations, and a regular review of the DCs' individual training progresses by the SB (for details see 1.4.).

Each DC can also take part in all ***local courses*** offered by the host institution's graduate school or graduate academy (see table 1.3b), in which DCs will be enrolled: TUD Graduate Academy, Donders Graduate School, GRADUS at US-TUTT, Graduate school of health at AU, Engineering School of the Depart. of Information a. Communication Technologies at UPF, "Cerveau Cognition Comportement" (Brain Cognition Behaviour) ED3C at Sorbonne Université, Engineering science and microtechniques Doctoral School at Université de Bourgogne Franche-Comté, and the doctoral school at the School is the School of Electrical Engineering and Computer Science (EECS) at KTH. We recommend, that DCs include at a minimum of three of these courses within their training plan.

Table 1.3b: Excerpt of Local Training Programmes at Host Institutions (approximate ECTS points)

Host	Course, Seminar, Colloquium (ECTS)
USTUTT	Scientific Writing (seminar, 2 ECTS)
SRU	Scientific Integrity Course (seminar, 4 ECTS)
UPF	Integrative Research Seminars (seminar, 4 ETCS)
ED3C	Training in ethics and scientific integrity (seminar, 2 ECTS)
KTH	Entrepreneurship and Start-Ups (Lunch seminar)
KTH	Sharpen up you LinkedIn Profile (Lunch Seminar)
TUD	Career development (seminar, 2 ECTS)
TUD	Leadership and Management Skills (seminar, 4 ECTS)

Network wide training. In addition to individual training during the projects (training through research) and training that is part of their local PhD programs at the home institutions, all students will participate in ***network wide training*** events complementarity to those offered locally at the participating organizations which consists of different formats (see table 1.3b). There are monthly colloquiums (online, Zoom) which are organised alternating by one of the PIs for all DCs for a regular exchange and monitoring the work progress by presentations of the DCs on their projects; in quarter-yearly team science meetings (online, Zoom) with all DCs and all supervisors, DCs will report and evaluate on their research progress, and selected PIs will give short lectures current topics related to Lullabyte. This is accompanied by weekly virtual meetings organized by the DCs themselves for exchange on a peer-to-peer level. At the core of the network wide trainings, there are three annual training camps (in person) with all PIs and DCs, as well as guests from secondments and non-academic partners. They provide specific courses and events on disciplinary and interdisciplinary aspects including trainings of the non-academic partners (see WP6 and table 1.3c), providing interdisciplinary research trainings and networking with future collaborators and industry. Attached to the third trainings camp, there will be a hackathon (hybrid online and in person) for all DCs and PhD students of the secondments and non-academic partners. Furthermore, the DCs are encouraged and supported to organise and establish by themselves a weekly meeting for DCs not only to exchange on their research but also on practical topics in order to foster their own network and provide a platform for co-tutoring on a DC level. The different formats are chosen to provide a balanced combination of lively interaction, regular feedback and at the same time leave space for individual research. The combination of regular online and specific onsite meetings goes along with the green-deal principle of avoiding travel that can be substituted by suitable online formats. In person training will take place for hands-on, practical training and some parts of the social and soft skills training.

The individual as well as the network wide trainings include ***training of research specific aspects*** such as good scientific practice, research integrity, basic disciplinary background lectures for all DCs in all relevant disciplines, analysis

skills (sleep scoring, statistics, programming), presentation skills (project presentation within the monthly meetings, training for conference presentation, elevator pitches and science slams), scientific writing courses, hands-on training (application of polysomnography and wearable EEG, standardized sleep scoring and EEG analysis); ***training of transferable skills*** such as handling of data (data management, ethics), technology transfer, open science practices, gender training, IPR management, grant writing, standardization, management, entrepreneurship and public outreach and exploitation of results (publication, patent evaluation); ***training of soft skills*** with an emphasis on working on the intersection of different disciplines, countries and academic and non-academic partners such as communication skills, the impact of voice in communication; ***job training*** (information on funding start-ups, entrepreneurship, career plans inside and outside academia, CV sessions); as well as ***training of teaching skills*** (tutored teaching, introduction to pedagogy, teaching platforms, hybrid settings, and feedback strategies). In addition, the training includes also ***networking*** with international researchers (visiting scientists), industry partner and artists, as well as invited talks and presentations by internationally renowned speakers from academic and non-academic fields.

Training camps. At the core of the network-wide training are 3 cross-disciplinary two-week trainings camps for all DCs with a major emphasis on sleep / data acquisition (1st year), data analysis (2nd year) and music / data interpretation (3rd year). In addition, all camps include technical training from different disciplines, soft-skills, guest lectures of international researchers, workshops and job-training by non-academic partners, and inspirational workshops with performing artists and composers. In the initial training camp, there will also be an introduction in the organization of the network, planned schedules and platforms in use, as well as mingling events for all network participants.

First years' trainings camp focuses on data acquisition and sleep research. This includes disciplinary introductions (neuroscience, music, data science), first hands-on experience on technical equipment (operation of EEG), methods (scientificcally sound surveys), tools (git, confluence, data repositories, Zoom, Mattermost/Slack, Trello), work processes (preregistering, research tools), and introductions in ethical and legal aspects (data integrity during training, legal aspects, gender and diversity awareness), as well as a kick-off for the DC's common research and training project Sleep and Music (SaM), in which the DCs will cover together all relevant steps in research on sound and sleep in a small scale project. This project follows the idea of training through research and enables all DCs to experience all steps taken in these interdisciplinary field. Over the three years, this project is enriched by the DCs' individual experiences and thus designed to develop from an introductory training project to a project enabling peer-to-peer training also on a research level. The kick-off camp ends with distributed tasks (surveys on sleep and music habits, EEG measurements) to be processed individually and commonly (using the E-Learning platform OPAL) until the next trainings camp.

Second years' trainings camp focuses on data analysis, bringing in trainings on data processing and analysis from the view of the different involved disciplines. This goes together with training on data management and data interpretation, dissemination, entrepreneurial training. Training on the job is provided by workshops under guidance of our non-academic partners. It also comprises the second workshop on SaM, which starts with poster presentations on the individually and commonly processed tasks (progress, challenges, results), followed by a round table discussion on the major challenges and strategies for problem solving and a guest lecture on interdisciplinary research organization. The DCs will distribute the next tasks (music selection and stimuli testing) amongst each other and are guided to a self-organizational structure. In addition, there will be workshops on entrepreneurial aspects, presentation skills and a workshop with composer Natasha Barrett, who is invited to work on music and sleep. The result can be heard in a publicly open concert which will be established in cooperation with PHONOS, who will advertise the concert also for their music interested audience.

Third years' trainings camp emphasizes on the aspects of music and data interpretation, and will consist mainly of workshops and job training. It includes a hands-on composition workshop with the second composer in residency, who will develop music together with the DCs, a workshop on the findings in WP5 with Emilia Gomez on future aspects of data ethics, and the final workshop meeting of SaM project, which includes elevator pitches of the DCs' findings, as well as a small semi-public conference prepared by the DCs on topics the DCs decide to be relevant for their outcomes of SaM. This converges with a industry-oriented ***Hackathon***. The camp will also include guest-lectures by non-academic partners and emphasise especially on job training and networking between DCs and our non-academic partners.

The *Hackathon* will be carried out in a 2-day format: after a short introduction and briefing, all participants can start to work alone or in small groups on developing their projects which have to be uploaded 48h after the Hackathon's start, followed by an elevator pitch of each project after the upload deadline. The jury, which is organised in combination with WP8 and our non-academic partners will then evaluate the projects and premiere the winners on the next day in a final ceremony. The aim of the Hackathon is do develop demos or pilots for new applications suitable for an industrial use in the sectors individual health care, medical health care, smart health, as well as applications fostering sleep via music or sounds. Besides Lullabyte's DCs, the Hackathon is open for participation also for all PhD and advanced master students of Lullabyte network members' institutes as well as on application for up to 50 participants. The winning teams will be awarded with a special start-up training and we will seek to match the resulting projects with industrial partners if interested.

In addition to the specific programmes, *all trainings camps* will include speed-mentoring sessions, in which each PI meets

one random DC from the cohort at each camp. The DCs will be randomly assigned to one of the Lullabyte's PIs who is not directly involved in the DC's project for a 1h face-to-face individual meeting. These meetings are designed for informal mentoring on topics the DC's want to bring up and provide the possibility of getting new perspectives on their own project, but also to foster networking between PIs and DCs.

Selected session, such as lectures and talks of our invited guests will be **open to the wider research community.** Key-note lectures will be held in public or hybrid format, afternoon lectures and talks will be documented for the wider research community and accessible publicly on our youtube channel, as are best practice examples.

Table 1.3c: Main Network-Wide Training Events, Conferences and Contribution of Beneficiaries

Lulla byte Training Camp 1 (Donders, NL)	**Lead: RADBOUDUMC**	**Topic: Data acquisition and sleep research**	**Action Month: 9**
Get together, welcome, mingling (1/2 day) Networking action (1/2 day): Sightseeing Donders (Martin Dresler, RADBOUDUMC) Disciplinary introductions and hands-on experience (1/2 day workshops) Introduction into sleep research and technology, in particular EEG (Martin Dresler, RADBOUDUMC) Sleep EEG analysis: sleep scoring and analysis software (Frederik Weber, RADBOUDUMC) Sleep and cognition (Björn Rasch, UNIFRI) Acoustic processing during sleep (Thomas Andrillon, ICM) Surveys and behavioral data in sleep research (Kira Jesperson, AU) Ethical and legal aspects, gender, and diversity awareness (Emilia Gomez, UPF) Peer-to-peer training on research level (Xyz) collaborativity tools (Dirk Pflüger, USTUTT) Training project Sleep and Music (SaM) (1/2 day) Kick-off for the DC's common research and training project Sleep and Music (SaM) (Miriam Akkermann, TUD) Evening and afternoon lectures by Sandra Pauletto/KTH, Samir Raut/Arenar, Sebastian Herberger/Mentalab. EAB? Softskill training intern (1/2 day) Speed mentoring session (all PIs, all non-academic partners of the trainings camp) Introduction to interdisciplinary working, working in teams, and project planning (Xyz)			
Lullabyte Training Camp 2 (Barcelona, SPA)	**Lead: UPF**	**Topic: Data analysis and processing**	**Action Month: 21**
Get together, welcome, mingling (1/2 day) Networking action (1/2 day): Sightseeing Barcelona (Sergi Jorda, UPF) Disciplinary workshops (each 1/2 day)			

Workshop on data processing and analysis (Dirk Pflüger, USTUTT)

Workshop on data in medical context (Jean-Julien Aucoutier, CNRS)

Composition workshops with the composer in residency (Natasha Barrett)

Data management, interpretation, dissemination, and entrepreneurial training (Engineering School at UPF)

On the job training (Starlab)

Training project Sleep and Music (SaM) (1,5 days)

Poster presentations on the individually and commonly processed tasks (all PIs)

Round table discussion on the major challenges (all PIs, all DCs, Natasha Barrett, Aurelie Frisch/Starlab).

Self-guided working session for next tasks (all DCs).

Evening and afternoon lectures by Perfecto Herrera/UPF, Natasha Barrett/composer in residency, Aurelie Frisch/Starlab, **EAB?**

Concert by Natasha Barrett, further concerts and visit of concert space at Phonos.

Softskill training intern (1/2 day)

Speed mentoring session (all PIs, all non-academic partners of the trainings camp)

individual feedback and recommendations based on poster presentations (all PIs)

Lullabyte Training Camp 3 (Dresden, GER)	**Lead: TUD**	**Topic: Data interpretation and music research**	**Action Month: 33**

Get together, welcome, mingling (1/2 day)

Networking action (1/2 day): Sightseeing Dresden (Miriam Akkermann, TUD)

Disciplinary workshops (each 1/2 day)

Workshops data management (research data and open access teams of TUD)

Workshop on data ethics (Emilia Gomez, UPF)

Composition workshops with the composer in residency (XXX)

Training project Sleep and Music (SaM) (1,5 days)

Elevator pitch presentations of DCs' projects (all PIs)

DCs Trainings conference (all DCs, all PIs)

Evening and afternoon lectures by Kira Jespersen/AU, Michael Engler/Benaka Interfaces, Oleg Stavitsky/Endel, **EAB?**

Softskill training intern (1/2 day)

Speed mentoring session (all PIs, all non-academic partners of the trainings camp)

Evaluation and feedback on conference organisation (all PIs)

Hackathon (2 days) (Jean-Julien Aucoutier, CNRS, Dirk Pflüger/USTUTT, Miriam Akkermann/TUD, Oleg Stavitsky/Endel, Michael Engler/Benkana Interfaces)

Innovation through training formats: The training program includes, beside a balanced combination of online, offline and hybrid formats designed along the very specific needs of this interdisciplinary and international research field as outlined above, a strong emphasis on the DCs transferable skills and transdisciplinary work experience to enhance their employability for the academic and non-academic sector. A main focus is hereby, according to the recent working habits, to educate the DCs for a **self-conducted and excellent working manner** and a sensible us of **online and digital tools for working in distributed teams**. We hereby resort to the experiences gained during the COVID-19 pandemic and the recommendation of MSCA Green Charter (3.1), facing a more and more international and virtually driven working style integrating not only established platforms in research (git, confluence) but also agile management techniques (Trello) and low hierarchy communication tools (Mattermost). The same applies also to presentation tools, why we will have our own Twitter and youtube channel and will encourage our DCs to present themselves and reach out to the community also via social media tools. Training thus does include a commitment to digital work forms, a direction, which is not commonly trained in academia.

To proceed this idea of the DCs learning self-conducted work forms in interdisciplinary teams, the training also includes two ***special formats***: the ***common trainings project SaM*** accompanying the DCs individual research projects; this project is introduced and guided through workshops at the trainings camps, and will be carried out by all DCs throughout their three years. This includes smaller tasks that have to be fulfilled individually between the camps as well as collaboratively during the trainings camps. The project is designed to train all tasks that have to be solved when working with sleep research and music ranging from music selection and analysis, to surveys and EEG tracking and analysis. The project experience prepares the DCs for the ***Hackathon*** at the end of the third trainings camp, which will be dedicated to develop applications for music/sound and sleep. This trains the interdisciplinary work skills but also working in teams, which is becoming more important especially in collaborative research fields such as music and sleep research.

In addition, **international networking** has become an inherent part of today's work. In Lullabyte, this is fostered by providing free time slots also within training activities that allow the personal contact between all DCs, PIs and the network's academic and non-academic members. The scope is to activate synergies for new science approaches through joint research, starting with the exchange of information and samples, leading finally to joint publications, patents and products and new ideas – **innovations** that are important for an excellent European research area and beyond.

1.3.2 Role of non-academic sector in the training programme

Non-academic partners will be involved in different levels of the training program: Endel will be directly involved in the research context as beneficiary who will host DC9, who will carry out the research in close collaboration and under scientific guidance of TUD and RADBOUDUMC. The other non-academic partners will be involved in the network wide training events, especially in the trainings camps: workshops will be given by Endel on algorithmic music composition to support sleep; by Mentalab and Arenar on multi-channel and minimal sleep EEG wearables, respectively; by Starlab on telemedicine wireless platforms; and by Benkana Interfaces on medical device regulation. In addition they will support online Q&A sessions where DCs ask for tips concerning their career development plan as well as on-site visits (either all DCs or also smaller groups). This interwoven training and consultation of academic and non-academic partner, which is especially unusual for humanities and social sciences, will contribute to a substantial and job-relevant training according to the EU Principles Guideline, foster the development of DCs transferable skills (e.g. presentation, communication skills IPR), and provide the DCs with realistic job prospects and career opportunities inside and outside academia. Endel, Starlab, Benkana Interfaces, Mentalab and Arenar will hence contribute not only with their disciplinary expertise to the training as well as provide a wide network for the recruitment of additional speakers, they will help to close the gap between excellent research and high employability.

1.4 Quality of supervision

Supervision of DCs will be organized in accordance with the European Charter for Researchers and Principles of Innovative Doctoral Training of the European Commission. Each DC will be enrolled in a PhD program at the host institution. At institutions where the duration of the PhD is scheduled longer than 3 years, the institution will provide funding in order to allow for the completion of the PhD. Lullabyte network will be closely involved in the supervision of each fellow via the shared SB. All supervisors have interdisciplinary and intersectoral skills and are able to provide a substantial and multi-faceted guidance to the DCs. At the beginning of the program, a Personal Career Development Plan (PCDP) will be developed by the supervisors and the DC in cooperation with the co-mentor. The PCDP will include a self-assessment of the DC's skills, career goals, and interest when entering the Lullabyte network as well as an individual training plan for the DC (including local and network activities, secondments, short visits, conference calls) which are closely connected to the DC's research project, and a set of milestones for the research project and the career development. The plan will be approved and periodically reviewed by the supervisor and the SB. The PCDP will also

contain a contingency plan in case the research project does not develop as planned.

Each DC will have a main supervisor (the PI-in-charge of the Beneficiary) and one or two co-mentors (usually PI's of the secondments); one of these will usually become the secondment supervisor. We aim for joint PhD degrees for DC2 and DC9. Each DC will meet supervisor and co-mentor(s) regularly (at least every six months, in person or by zoom), to provide advice about progress in the project. The main supervisor will also be the advisor for the DC's PhD thesis and will commit sufficient time and resources to the supervision. Lullabyte will also provide an 'ombudsperson' (Emilia Gomez) who is not involved as main supervisor and to whom they can communicate to (also confidentially) about any issue that may arise with the main supervisor or in the network collaboration (see 3.1).

1.4.1 Qualifications and supervision experience of supervisors

All PIs have experience in working in diverse, international and interdisciplinary research groups and have experience with foreign students with diverse backgrounds. They commit themselves to the European Charter for Researchers and Code of Conduct as well as the MSCA *Guidelines for supervision* and guarantee a discrimination-free environment, as well as treating all DCs fairly and respectfully regardless of their sex, ethnic origin, sexual orientation, social class, political views, disability and religious beliefs.

The PIs are all leading experts in their respective fields, bringing in a huge scientific impact, which can be seen on the high numbers of publications, citations, awards and successful grants, such as publications/citations (e.g. Perfecto Herrera: >150 publications, 6644 citations, HI 42; Björn Rasch: >100 publications, >7100 citations, HI 36; Martin Dresler: >100 publications, >4500 citations, HI 36), research grants (e.g. Jean-Julien Aucoutier: 1 ERC StG grant, 1 ERC PoC; Sergi Jorda: PI at 2 EU projects; Kira Jespersen: research grant by Helsefonden), and monographs (e.g. Miriam Akkermann: monograph on analysis of computer music at Argus, Björn Rasch: 2 textbooks, Dirk Pflüger: 2 textbooks). They bring in a broad experience in training both in science (e.g. Dirk Pflüger: 10PhDs, Fellow of SimTech Cluster of Excellence; Emilia Gómez: 10 PhDs) and the arts (e.g. Miriam Akkermann: >20 artistic/practical final projects) in the last 10 years, as well as experiences in representative functions (e.g. Sandra Pauletto: UK representative for the EU Cost Action IC0601 on Sonic Interaction Design). Furthermore, Miriam Akkermann, Martin Dresler and Dirk Pflüger have been members of the Young Academy of the German National Academy of Sciences (more information for each PI in form A and B2). The non-academic co-mentor will be closely supported by Lullabyte's PIs.

2. Impact

2.1 Contribution to structuring doctoral training at the European level and to strengthening European innovation capacity

Lullabyte consists of leading researcher experienced in the interdisciplinary field of sleep and music research. Thus, Lullabyte brings together excellent European research and education institutions to realise a common training program combining participation in excellent research and innovative training formats. Lullabyte thus offers DCs a unique training tailored to the special needs of this highly intersectoral work field that cannot be offered by single institutions and that is worldwide not available.

2.1.1 Meaningful contribution of the non-academic sector to the doctoral training, as appropriate to the implementation mode and research field

The non-academic sectors is integrated both, on beneficiary and associate partner level. With Endel, we have a leading and most successful growing company on the marked for generative music applications with special emphasis on relaxing and sleep music. This provides connections to a sector which has been growing especially during the COVID-19 pandemic, where the demand of self-inducing relaxation and sleep enhancement using music cased a huge leap in klicks and sales numbers. (Ref?). Further, start-ups that produce tools used in research (e.g. Starlab, Benkana) as well as start-ups and companies that produce wearables and other home-use sleep enhancement items for the general public (Ref.) will contribute to the training of the DCs, providing insight in relevant industry areas as well as contribute to future-job-training by job-training workshops and lectures by speakers from the non-academic sector for introducing potential career paths in industry. All these non-academic sectors will benefit from both the scientific output we will produce (e.g. standardized, open-access analysis tools, knowledge on the effects of music and sound on sleep) as well as the DCs we will educate.

In addition, Lullabyte will provide also a bridge to the artistic sector. Music for sleep has become a rising market also for composers, but at the same time, the research of composers on the music regarding to sleep features and information of sleep analysis has not yet been fostered. With the two invited composers, this will be actively addressed, creating also matches between research, arts and industry where music and sounds are embedded within products ranging from ear buds with integrated sleep music to sleep music apps.

Matching events for all these groups will be the trainings camps, where the DCs will also learn to identify how output from this project could be used for innovation. Industrial partners will provide DCs with skills in research equipment, entrepreneurship, technology transfer, IP rights, science communication and start-up pitching, which academic partners alone could not deliver. Furthermore, the training by non-academic partners allows DCs to become familiar with an industrial mindset, to manage and fully exploit IP, and/or to start up their own company. The Hackathon at the end of

the third trainings camp (supported by TU Dresden innovation department), will therefore be a test bed and potentially also a kick-off for further innovations, but also a good chance to present themselves for the job market in front of the jury which includes partners and external guests from industry. This will maximize their career prospects and employability.

2.1.2 Developing sustainable elements of doctoral programs

The participating institutions are committed to ensure a sustainable program which provides a durable access to all results such as scripts and data-sets beyond the duration of the funded project for a minimum of 10 years according to the guidelines of DFG.

In education, we will develop and organize training events in close collaboration with the institutes' graduate schools and encourage the graduate programs to adapt the hereby developed formats as most of them are designed applicable to a broader training scope. The trainings camps will be open to other PhD students in the participating institutions as well as external PhDs on application. Talks and presentation that are held will be streamed live to a broader audience and also posted on a dedicated youtube channel, which can be kept indefinitely without costs. We also aim to have as many talks as possible in a hybrid format to extend the access to these lectures. All interested third parties as well as consortium partners can use them in their future training programs. For selected talks, we will organise public online events as we will do for the concerts and concert lecture formats. We hereby connect to a format that was done already at TUD and we hope to foster those kinds of arts and science interactions with our lectures also more broadly. The training materials (lectures, lecture notes, etc.) will be freely accessible through the Lullabyte website. The network training events will serve as the basis for Master and PhD-level courses that will be offered at our institutions for the years to come, enhancing the quality of the inhouse training programs and fostering co-teaching collaborations on an international level.

To provide a sustainability of Lullabyte network, we aim to create a wider sleep-music-research-network for all interested scientists in which we discuss on most recent research findings but also on common training formats. This is fostered by making all our material available and also provide the option to add comments and experiences in forums integrated on Lullabyte website in order to learn and share best practices concerning teaching formats and research training, as well as provide information on our structured program.

With this, the Lullabyte aims to become a European Flagship of a collaborative network in the field of sleep and music research. The network also aims to set up follow-up agreements for future work after the funding period and foster best working and training conditions for future DCs.

2.2 Credibility of the measures to enhance the career perspectives and employability of researchers and contribution to their skills development

Lullabyte provides a multi-facetted training program tailored to the special requirements of the multidimensional and interdisciplinary field of sleep and music research, including a close connection to non-academic partners in training and concerning research questions. This interwoven structure fosters a well-designed exchange between the DCs and all involved partners and prepares the DCs well for the requirements they are facing in academic and non-academic jobs and makes them employable for research and industry.

DC Skills Development. All DCs will gain experience in highly competitive research projects within international and excellent research institutions as well as leading industrial partners carried out at their host institution and during the secondments. This project related work experience, which is monitored closely through the regular meetings, consultations and presentations, will be accompanied by individual, local as well as network wide training offers which are developed and evaluated in close collaboration with each institution's graduate school. This guarantees the high quality of the training offers and ensures the programme's accuracy of scope.

New career prospects and employability at the highest possible level. The DCs will be trained in a new multi-dimensional way and gather advaned communication skills through intersectoral and international training. This meets and matches the high requirements in the dynamic field of sleep and music research and prepares the DCs on the highest possible level for their future jobs in academic context as well as at companies in sectors such as development of sleep or relaxing music and corresponding applications, development of application based on the analysis of music and listening habits, development of tools for sleep research (hardware and software), development of applications and tools for hospitals carrying out sleep research, and all industries working on individualised well-being monitoring related to sleep, relaxing and music.

Impact of the research and training on the fellows' careers. All DCs will gather excellent research skills and will on most recent and up-to-date questions in the field. The skillset will include not only discipline specific methods but also a substantial training in data science, open access and ethics on linked data. These areas are yet rather underrepresented, but will become more and more important in the future as complex linked data will be a growing sector of interest for both, research and industry.

field research related more specialized

awareness of ethical aspects / data protection when dealing with personalized data

what industry benefits from this skillset: employability: potentials, academic/non-academic, interdisciplinary work experience, teaching, leading local research team – teamwork and leadership, excellent research skills, advanced communication skills, understanding and working with entrepreneurial skills and IPR, high level of personal effectiveness, including critical thinking and problem-solving skills, work integrity, social and ethics understanding skills

networking – as potential for future collaboration in the field of SaM

analysis of how elements will make them employable (single aspects in PPT EPC)

link between EU policy and other programs

employment structure as role model for contracts

2.3 Suitability and quality of the measures to maximise expected outcomes and impacts

2.3.1 Plan for the dissemination and exploitation activities, including communication activities

2.3.1.1 Dissemination and Communication Activities, Public Engagement

Several of the consortium partners have extensive experience in media exposure including TV (BBC, CNN, Netflix), radio (BBC, NPR, APM), newspapers (Times, New York Times, Washington Post) and magazines (Time Magazine, Scientific American, National Geographic) that will be utilized for the consortium in close collaboration with the universities' press offices to disseminate the different steps of the project to the general public. Central dissemination point of the consortium will be the project website Lullabyte.org, where the project aims and project partners will be introduced and eventually the collected data and key project results will be described, and publications and media reports will be collected. This website will be flanked by social media accounts for more pro-active outreach activities (in particular Twitter, potentially Facebook, Youtube, Instagram). In addition, the research of Lullabyte will be also made available for a broader real-life public by presenting at the Night of Science (Lange Nacht der Wissenschaften) Dresden, or Girls Day at USTUTT. We hereby aim to address a diverse audience in gender, educational background, ethnicity and culture.

A special format of public outreach will be the concerts of the composers in residency at the summer schools, which will be designed as talk&music events, providing short and easy understandable lightning talks and the music developed in collaboration with Lullabyte. It is also intended to organise one sleep concert, where an interested audience is invited to come to listen to sleep music, relax and sleep on site at mattresses for some hours. All outreach and communication will be supported by the Universities Public Relation Offices of all partners.

Scientific results will be disseminated as green and gold open access in journals of the respective fields or multidisciplinary journals (e.g. Journal for Empirical Musicology, AI music creativity, Neurosciences and Music), and on leading conferences of the respective fields: ISMIR, ICMC, IMS (music research and musicology); ICMPC (music psychology); Worldsleep, ESRS (sleep research); FENS (neuroscience); NeurIPS, IJCAI, ECAI, AAAI (artificial intelligence); ICML (machine learning); EuroPar, ISPDC (efficient real-time implementations); SIGIR, ECIR (information retrieval); and interdisciplinary formats such as the AI music conference. In addition, Lullaby will organize one conference on „Music and Sleep" towards the end of the funding period to present the newly established interdisciplinary perspective, research results, as well as provide a platform to foster further collaborations.

A state-of-the-art data management plan will ensure that the data will be available as quickly and as accessible as possible after acquisition (see 1.2.5).

Table 2.3a: Dissemination activities

DC	Dissemination activity	Exepcted impact	Month
	RESEARCHER RELATED		
1,2	Conference on XYZ, 2022	Presentation of …	
2, 3	Conference on XYZ, 2023	Leading workshop session	
1	Journal Publication – XYZ Journal	Open Access publication	
	Lullabyte Training Camp Presentations, Poster Sessions …???		

	Hackathon		
	STAKEHOLDER RELATED		
1	Stakeholder Meeting for interested industry partners (Year 2 and 3 ???) at local level – could be also online …???	Presentation of current results and applicability into the industry sector	
2	Presenting new results on SaM to persons with insomnia		

2.3.2 Exploitation Activities

Based on the planned outputs of all work packages and input from all partners a comprehensive list of exploitable results (commercial and non-commercial) will be developed by Mx. This will provide the basis for a detailed (joint and individual) exploitation plan identifying type of result, IP, partners' role, rule of access, marketability and exploitation pathways. Appropriate protection measures will be agreed between partners taking account of IP background and results. A market analysis based on desk research and interviews/surveys will be performed for each exploitable result. The exploitation plan will be finalized at the end of the project to facilitate the take-up of results beyond the project duration.

Input from partners will be collected during two dedicated exploitation workshops (???).

Activities: protection of results … results screening for potential to create IPRs before dissemination in order to maximise the impact for Europe. It will ensured that knowledge is properly protected (support by Tranfer Offices).

Collaboration with other stakeholders outside the network – during camps, conferences, fairs etc. – forming new partnerships; IPR related issues will be carefully managed for sustainably network

Exploitation: (commercialization) potential contribution to standards

??? Spin-Offs or Start-Ups possible ??? Exploitation – Verwertung

Result of Hackathon as nucleation point for commercialization via a Lullabyte-App.

Datensicherheit mitgedacht (Ethics)- wenn das geklärt auch Einbindung von big playern möglich (google). Schlafforschung extrem steigern

Transfer the new research setting, move towards industries, higher TRLS, smartphone use for data acquisition

Generalised Zwischenschritt dann individualisiert/personalisiert

2.3.2 Strategy for the management of intellectual property, foreseen protection measures

Within the CA set down the different obligations and rules for the management of the intellectual property rights

There will be potentials for exploitation in WP XYZ at XYZ partner.

Support by valorisation / transfer offices at each beneficiary … lead partner for the action will be … and is experienced in technology transfer …

important partners for fostering exploitations are …

discussion and action of possible exploitation activities within the monthly meetings and follow up.

2.4 The magnitude and importance of the project's contribution to the expected scientific, societal and economic impacts (project's pathways towards impact)

2.4.1 Expected scientific impact(s)

While interdisciplinarity is always asked for but rarely brought to life, Lullabyte is inherently transdisciplinary. It additionally covers several levels of investigation into the effects of sound/music on sleep, from neurophysiological details and behavioral studies to theoretical analysis. Our DCs will be exposed to all involved disciplines and be directly involved in research cooperations with two different research fields via their secondments. Our DCs will be excellentely trained as bridge builders between disciplines and thus serve as multipliers for future research in Europe wether in academia or industry.

The large Open Data data set we will gather will be a nucleation point for further research in Europe. As data in such a quality and quantity is urgently sought for and difficult to obtain, a vast impact can be expected on related research in the future. A joint publication on the data in Scientific Data by Springer Nature accompanying the publication of our data set, will harvest the scientific impact for the participants in the aftermath of Lullabyte. Lullabyte will furthermore serve as the fist large-scale community effort for music and sleep to gather data at home. The software and hardware setup including affordable wearable EEGs together with with real-time control of acoustic stimulation during sleep, user apps, surveys and analytics/generation software can serve as a blueprint to "crowdsource" data acquisitioning also in other fields of research. It will allow Lullabyte to reach out to parts of the publication that are otherwise lost to scientific studies, providing a higher degree of diversity within the test persons. Finally, the availablilty of dedicated software for a standardized analysis of large-scale sleep data will foster a dearly needed harmoization of sleep EEG analysis practices across different labs and can likewise serve as model for EEG researchers in related fields.

2.4.2 Expected economic/technological impact(s)

A key aspect of Lullabyte is the acquisition, handling, and analysis of linked heterogeneous and interdisciplinary big data. Hence, we will develop protocols, scripts and application novel to the field of sleep (see also scientific impact), which can be used to be embedded in new products concerned with smart health, individualised health enhancement, but also security issues and medical services (alarms vs. sleep). Lullabte will create a new data scheme which has the potential to become a new standard for open-access big data in the field of music and sleep research by providing the currently largest, open-access, interdisciplinary data set with music and sleep data, as well as standardized analysis criteria and materials. We will integrate standardized sleep analysis pipelines and music analysis as well as sonification methods based on a consensus approach of existing analyses scripts. In coming from a strong humanities and social science perspective, we also consider the social impact of possible future services, and provide insights in how our approach is grounded within certain cultural constraints. This allows to develop products tailored not only to certain needs regarding sleep, but also to specific markets, using highly technological components that can be embedded in future smartphone applications, allowing increasing efficiency at decreasing costs for production and users.

2.4.3 Expected societal impact(s)

Relaxing sleep is important for a wide range of social actions, such as well-being, activity, memory consolidation, and the willingness to perform. While sleep is in the recent society often rated under efficiency aspects, COVID-19 pandemic showed that sleep and relaxation was not as easy to achieve and music was one of the most common non-pharmacological self-medications for enhancing sleep quality and receive well-being. Lullabyte aims at uncovering the mechanisms behind these effects of music on sleep. The findings of Lullabyte are hence highly relevant for society, as they provide knowledge that can help to provide applications that are easy to use and affordable, offering people from all parts of the society an easy accessible way of enhancing their sleep and thus their well-being. This can help to lower the risk of depression and thus contribute to decrease avoidable mortality, as well as increase the average health of people which fosters activity and willingness to perform in job and in societal context. When knowing the individual effects of music and sound on sleep, we can contribute to health monitoring and enhancement, which can be integrated within in sleep apps of wearables. This would allow individuals to monitor and optimise their own sleep-health. Further, the integration of this knowledge in alarm systems can increase security aspects (efficiency of waking by alarm) and foster faster healing (non-waking through alarms in hospitals).

3. Quality and Efficiency of the Implementation

3.1 Quality and effectiveness of the work plan, assessment of risks and appropriateness of the effort assigned to work packages

3.1.1 Work packages description

Table 3.1b: Description of Workpackages

WP1: Neuroscience	**Lead Beneficiary: ICM**	**M07 – M42**
Partners: ICM, RADBOUDUMC**,** TUD, UBFC, UPF, KTH	**DCs:** 1, 2, **5**, 6, 7, 8, 9	

Objectives: Neuroscientific view on the effects of music and sound on sleep.
O1.1 Measuring the effects of acoustic stimulation on sleep.

O1.2 Elucidating the neurophysiological effects of music on sleep.

O1.3 Examining the psychological effects of music on sleep.

Description of Work and Role of Partners:

Task 1.1	Developing a set-up for studies measuring the effects of music and sound on sleep in a controlled lab and for large-scale home studies: development sleep study: DCs 2, 5, 6, 7; sound embedding: 1, 6, 8, 9.
Task 1.2	Developing strategies to examine the neurophysiological effects of music on sleep: DCs 2, 5, 6, 7.
Task 1.3	Developing strategies to examine the psychological effects of music on sleep: 10 (connected to O2.2 and O2.5).

Description of Deliverables:

D1.1	D1.1.1 Dataset: Full-night high-density PSG data recording the effects of acoustic stimulation on sleep. These recordings will include unperturbed sleep as well as arousals and awakenings in a controlled lab environment. D1.1.2 Data set acquired for large-scale study of effects of algorithmic music on sleep in healthy participants using wearable EEG in home-settings.
D1.2	D1.2.1 Dataset: Full-night PSG data recording the effects of acoustic stimulation on sleep. D1.2.2: Dataset of electrophysiological data (EEG, EMG, cardiovascular) measured in response to large sets of sounds (generated with D1.1). D1.2.3 State of the art report on music-induced sleep and its control by biofeedback D1.2.4 Dataset from the performed experiments (including music descriptions, sleep and behavior measurements, under different experimental conditions) D1.2.5 Open software toolbox for standardized sleep EEG analysis pipelines. D1.2.6 Standards for sleep data analyses and management.
D1.3	D1.3.1 Set of physiological indicators of emotional processing by musical stimulation during sleep identified in healthy participants. D1.3.2 Association between emotional processing induced by music during sleep and sleep quality identified in healthy participants and patients with insomnia. D1.3.3 Dataset on the impact of music sleep playlists on sleep EEG, ECG, respiration and behavioral ratings.

WP2: Music research	**Lead Beneficiary: TUD**	**M07 – M42**
Partners: TUD, AU, UPF, Endel, UNIFR	**DCs: 1**, 4, 7, 8, 9, 10	

Objectives: Music research view on the effects of music and sound on sleep.
O2.1 Overview on music and sounds for sleep.

O2.2 Determining shared musical features in sleep music.

O2.3 Examining the relationship between sleep music and cultural environment in selected regions.

O2.4 Developing music for sleep.

O2.5 Examining people using music and sound for sleep.

Description of Work and Role of Partners:

Task 2.1	Collecting music considered as sleep music: DCs 1, 2, 8.
Task 2.2	Examining music considered as sleep music concerning shared musical features: DCs 1, 8.
Task 2.3	Analysing the relationship between sleep music and cultural environment in selected regions: DCs 1, 4.
Task 2.4	Developing methods for sonification with emphasis on musical features based on sleep data analysis: DCs 7, 8, 10.
Task 2.5	Collecting data on people who use music and sound for sleep: DC 4.

Description of Deliverables:

D2.1	D2.1.1 Data set acquired of music rated for sleep enhancement. D2.1.2 Sleep music dataset collected via survey from people who use music as a sleep aid. D2.1.3 Data set/library of musical, sound design and vocal audio examples that have shown to promote sleep categorised by acoustic characteristics
D2.2	D2.2.1 Data set acquired of shared musical features within the music samples.
D2.3	D2.3.1 Data set acquired of music pieces entitled lullabies from different cultural areas and time periods.
D2.4	D2.4.1 Set of computationally-designed musical stimuli ready to induce emotions during sleep and wakefulness, pilot studies finished, study set up ready.

	D2.4.2 Music processor toolkit D2.4.3 Data set of algorithmically produced music for the use of sleep aid.
D2.5	D2.5.1 Dataset on the characteristics of people using music for sleep, including demographics, sleep quality, general music preferences and motivations for using music as a sleep aid.

WP3: Computer Science	**Lead Beneficiary: USTUTT**	**M07 – M42**
Partners: USTUTT, RADBOUDUMC, UPF, KTH, UNIFR	**DCs:** 2, **3**, 7, 8, 10	

Objectives: Computer science view on the effects of music and sound on sleep.
O3.1 Encountering methods for examining cross-matched data from sleep and music.

O3.2 Encountering strategies for real-time processing of music data.

O3.3 Encountering strategies for generating personalised auditory stimuli.

Description of Work and Role of Partners:

Task 3.1	Developing methods for examining cross-matched data from sleep and music.
Task 3.2	Developing strategies for real-time processing of music data.
Task 3.3	Developing strategies for generating personalised auditory stimuli.

Description of Deliverables:

D3.1	D3.1.1 Software toolkit for analysis of heterogeneous data and Open-Source implementation of real-time analysis of EEG data. D3.1.2 Open data platform for annotated sleep EEG and related data.
D3.2	D3.2.1 Open-Source implementation of parameter-driven real-time audio generation. D3.2.2 Open-Source implementation of coupling of real-time analysis and generation. D3.2.3 Evaluated prototypes of real-time and non-real time sonification of sleep data for creative and analytical purposes. D3.2.4 Python code to generate musical sound stimuli with arbitrary properties in the spectro-temporal space.
D3.3	D3.3.1 Code: Open-source algorithms for optimized, personalized acoustic and musical stimulation during sleep. Open-source algorithms for the analysis of sleep recordings with and without acoustic stimulations (spectral features, automated detection of sleep microstructure, stimulus reconstruction, complexity analyses).

	D3.3.2 Guidelines for implementing personal interventions of music-induced sleep D3.3.3 Evaluated prototypes of personalised interactive sonic objects that embody and affect a person´s sleep behaviour

WP4: Data curation and integration	**Lead Beneficiary: RADBOUDUMC**	**M01 – M42**
Partners: All	**DCs: All**	

Objectives: Data science view on the data resulting from the examination of the effects of music and sound on sleep.
O4.1 Developing methods for cross-matching data from sleep and music data sets.

O4.2 Developing strategies for providing accessibility to these cross-matched interdisciplinary data sets.

O4.3 Developing a pilot with an implemented data scheme designed along the needs of Lullabyte's heterogeneous data set.

Description of Work and Role of Partners:

Task 4.1	Outlining markers for crossmatching data.
Task 4.2	Examining and outlining access options, needs and challenges concerning cross-matched interdisciplinary data sets.
Task 4.3	Select and analyse a small set of heterogeneous data from all acquired data within Lullabyte.

Description of Deliverables:

D4.1	List with markers and connectors for crossmatching data.
D4.2	List with options, needs and challenges concerning cross-matched interdisciplinary data sets.
D4.3	Data scheme for Open data platform for interdisciplinary and linked data sets.

WP5: Data Ethics	**Lead Beneficiary: KTH**	**M01 – M42**
Partners: All	DCs: All	

Objectives: Reflecting on the ethical aspects related to data-driven processes on interdisciplinary linked big data sets as established in Lullabyte.
O5.1 Examining ethical perspectives relevant for interdisciplinary data.

O5.2 Outlining risks concerning interlinked interdisciplinary big data sets and AI-driven/data-driven analysis approaches. O5.3 Developing a set of recommendations for data ethics to be considered for data-driven processes on interdisciplinary linked big data sets.	
Description of Work and Role of Partners:	
Task 5.1	Collecting existing strategies concerning data ethics.
Task 5.2	Gathering and analysing risks appearing related to interlinked interdisciplinary big data sets and AI-driven/data-driven analysis approaches.
Task 5.3	Collecting and selecting recommendation for possible guidelines concerning data ethics.
Description of Deliverables:	
D5.1	List with existing strategies on data ethics.
D5.2	List with risks related to interlinked interdisciplinary big data sets and AI-driven/data-driven analysis.
D5.3	List with recommendations for criteria concerning data ethics.

WP6: Training	**Lead Beneficiary: AU**	**M07 – M48**
Partners: All	**DCs: All**	
Objective: Organise and coordinate all components of ESR training.		
Description: This WP includes the overall organisation and coordination of teaching and training activities (section 1.2). All Tasks are led by AU, and supported by all beneficiaries and partner organisations.		
Task 6.1	Preparing general advertisement information, training of beneficiaries on gender and diversity aspects in hiring and providing support with ESR selection.	
Task 6.2	Supporting establishment of Personal Career Development Plans and monitoring progress of DCs (sections 1.3.1 and 3.1.9).	
Task 6.3	Organizing the monthly online meetings in cooperation with the PIs, supporting the weekly meetings organized by the DCs.	
Task 6.4	Organizing the main frame for the trainings camps with distribution to the individual trainings camps organisers.	

Task 6.5	Monitoring overall training programme execution and individual progress of the DCs. The monitoring will include training activities organized independently at partner institutions, affecting the quality of the training DC receive. It may lead to adjustments in the workshop program where advisable.
Task 6.6	Monitoring inclusion of other institutions in wider network for sharing of training activities

Description of Deliverables:		D6.4	Trainings camp 1.
D6.1	Job announcements in relevant publications/journals.	D6.5	Trainings camp 2.
D6.2	Personal Career Development Plans for all DCs.	D6.6	Trainings camp 3.
D6.3	Annual report on regular meetings.	D6.7	Report on the overall trainings programme.

WP7: Dissemination and Communication	**Lead Beneficiary: UPF**	**M01 – M48**
Partners: All	**DCs: All**	

Objective: Coordinate the dissemination and communication activities.

Description: This WP is responsible for the disseminating and communicating goals and results of Lullabyte. All Tasks are led by UPF and supported by all beneficiaries and partner organisations.

Task 7.1	Organising the setting up of Lullabyte's website in cooperation with Lullabyte project officer, and start using existing LinkedIn, Facebook and Twitter accounts from participating institutions for further dissemination.
Task 7.2	Creating a project logo and project templates to assure consistent professional appearance.
Task 7.3	Recruit additional institutions for the wider Sleep-Memo Network.
Task 7.4	Coordinating all efforts on communication and dissemination, with emphasis on reaching the general public. These include a public relation strategy combining web-based efforts (twitter, youtube channels), media releases, and real live dissemination activities but also centralizing all events hosted within Lullabyte and by associated partners on the Lullabyte website. Assign lead DCs for each platform.
Task 7.5	Developing and implementing the Data Management Plan (DMP), according to FAIR (Findability, Accessibility, Interoperability, and Reusability) and Open Science principles in cooperation with WP4 and WP5, supported by RABOUDUMC and USTUTT.
Task 7.6	Depositing project data and publications on bioRxivl and helping each DCs to develop their public outreach activity

Description of Deliverables:

D7.1	
D7.2	
D7.3	

WP8: IP and Exploitation	**Lead Beneficiary: CNRS FEMTO-ST**	**M01 – M48**
Partners: All	**DCs: All**	
Objective: Coordinate the exploitation activities and the IP management.		
Description of Work and Role of Partners:		
Task 8.1	Assessing and capturing IP to protect the generated knowledge, and promoting the early or broad application of technologies developed.	
Task 8.2	Organising training dedicated to IP and Exploitation.	
Task 8.3	Organizing the Hackathon with distribution in cooperation with WP6 and WP9 as well as handing individual events to DCs. This includes the recruitment of industry partners for the jury of the Hackathon.	
Task 8.4	Monitoring Ips and ethics related to WP5.	
Task 8.5	Organising networking events with industry partner linked to the training camps and in cooperation with WP6.	
Task 8.6	Managing and coordinating IP and exploitation activities if applicable for outcomes within Lullabyte.	
Description of Deliverables:		
D8.1		
D8.2		

D8.3	
Note:	

WP9: Management and Coordination	**Lead Beneficiary: TUD**	**M01 – M48**
Partners: All	**DCs: All**	
Objective: Conduct the full administrative and financial management, reporting and progress monitoring of research and training.		
Description of Work and Role of Partners: This WP is responsible for the management of the consortium and the exploitation of project results. All Tasks are led by TUD, and supported by all beneficiaries and partner organisations.		
Task 9.1	Monitoring actions within Lullabyte to deliver as promised, executing decision making procedures, supervising quality assurance of deliverables, submitting periodic reports, and communicating with the European Commission. This also includes making proposals to the Supervisory Board for significant modifications of the plans according to the Grant Agreement and Consortium Agreement, and financial management of the consortium: Compiling cost reports for the European Commission, providing the European Commission with financial information, and distribution of European Commission funds to the beneficiaries.	
Task 9.2	Organizing recruitment/interview meetings and establishing selection committees.	
Task 9.3	Organizing network meetings such as the summer schools, hackathons, Mid-Term Check meeting, with the local hosts and ESRs	
Task 9.4	Creating a repository of training materials and curriculum to ensure sustainability of project achievement in training. This includes cooperating with WP6 leader for youtube channel hosting talks.	
Task 9.5	Ensuring that ESRs get their PhD awarded, during or after project end.	
Task 9.6	Ethics: Monitoring implemented data protection procedures, and data integrity in collection and processing.	
Description of Deliverables:		
D9.1		
D9.2		
D9.3		

3.1.2 List of major deliverables

Table 3.1b: Deliverables List

No.	Deliverable title	WP	Lead	Type[1)]	Level	Date
Scientific Deliverables						
D1.1					CO/PU	
D1.2						
…						

Management, Training, Recruitment, Dissemination, Communication and Exploitation Deliverables						
D6.1	Training	6		6	Training	6
D7.1	Exploitation	7		7	Exploitation	7
D8	Dissemination	8		8	Dissemination	8
D9	Management	9	MA	9	Management	9

[1)] Type: R = Report; ADM = Administrative (website completion, recruitment completion, etc.); PDE = dissemination and/or exploitation of results; O = Other, including coordination; Dissemination: CO – confidential/ PU – public.

3.1.3 List of major milestones

Table 3.1c: Milestones List

No	Title	WP	Lead	Date	Verification*
M1.1					
…					

*) RSC: Report submitted to Coordinator; SDPW: signed document published on website; IOAA: fully implemented, operable, accessible and announced; MS: manuscripts submitted, DB: experimental data base created, SIM: simulation results obtained – data base created.

3.1.4 Fellow's individual projects, including secondment plan

Table 3.1d: Individual Research Projects

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC1 (PI: Miriam Akkermann)	**TUD**	**Y** (TUD)	**7**	**36**	D2.1.1 Data set acquired of music rated for sleep enhancement. D2.3.1 Data set acquired of music pieces entitled lullabies from different cultural areas and time periods. D2.2.1 Data set acquired of shared musical features within the music samples.

Title: Identifying of musical features of sleep music **– WP**1, **2**, 4, 5

Problem description and hypothesis: Music is influencing our wellbeing as well as sleep quality. The effects of music derive from both biological and cultural aspects. It is, however, not clear, to what extent surrounding culture and early childhood imprinting is takes effect, and which effects can be linked to single musical features. We think that there exist musical characteristics that can affect sleep and that some of them can be traced in (cultural specific) lullabies.

Objectives: Examining music used and subjectively or measurably preferred for sleep/relaxation on musical characteristics in order to extract common musical features, which are then related the cultural context and personal taste in wake state. The DC project is carried out in collaboration close with EG (first secondment) for MIR approaches and KJ (second secondment) for the psychological and demographic aspects. The project gathers and analysis sleep/relaxation music with a special emphasis on lullabies as well as their western ascription as can be seen in published music with matching titles. The research is carried out in close cooperation with DC 4 , DC 7.

Expected Results: We aim to identify musical features that are often contained in sleep/relaxation music and understand the individual effect those features have on sleep. We further aim to discuss the influence of the cultural context and personal taste with special emphasis on lullabies.

Secondment(s): UPF (Emilia Gomez), 6 months starting M20, analysis of music, and AU (Kira Jespersen), 6 months starting M32.

Enrolment in Doctoral degree(s): The DC will be enrolled in the PhD programme at TUD. **Local course program** includes *Musicology, Music Analysis, and Statistics.*

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC2 (PI: Martin Dresler)	**RADBO UDUMC**	**Y** (SRU)	**7**	**36**	D1.2.5 Open software toolbox for standardized sleep EEG analysis pipelines. D3.1.2 Open data platform for annotated sleep EEG and related data. D1.2.6 Standards for sleep data analyses and management. D4.1 Data scheme for Open data platform for interdisciplinary and linked data sets.

Project Title and Work Package(s): Analysis pipelines for big sleep data – **WP1**, 3, 4, 5

Problem description and hypothesis: Sleep recordings consist of rich physiological data. Manual inspection of EEG traces for sleep stage classification is still standard in the sleep field, and sleep EEG analyses are often based on unsystematic subjective decisions. To make big sleep data analysis feasible, automated, systematic and reliable analyses pipelines need a software platform that is still lacking int the field. Furthermore standards for such pipelines and data organization or processing are lacking. A data processing and storing solution for a comparable and consistent comparison between the different consortium partners is thus needed.

Objectives: In this project, we aim to develop a dedicated software solution able to handle big, annotated sleep and related data and standardize analyses pipelines to ensure consistency across the different consortium partners and beyond.

Expected Results: Open software toolbox and big sleep data platform. New standards for constructing sleep analysis pipelines and integrating sleep data with related data. Structured sleep recording database and annotation data structure.

Planned secondment(s): USTUTT (Dirk Pflüger), 6 months starting M18, and ICM (Thomas Andrillon), 6 months starting M32.

Enrolment in Doctoral degree(s): The DC will be enrolled in the Donders Graduate School at Radboud University Medical Center. **Local course program** includes *XXX, XXX and XXX*.

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC3 (PI: Dirk	**USTUTT**	**Y**	**7**	**36**	D3.1.1 Software toolkit for analysis of heterogeneous data and Open-

Pflüger)		(USTUTT)			Source implementation of real-time analysis of EEG data D3.2.1 Open-Source implementation of parameter-driven real-time audio generation D3.2.2 Open-Source implementation of coupling of real-time analysis and generation

Project Title and Work Package(s): Real-Time Data Analysis and Predictions – **WP3**, 4, 5

Problem description and hypothesis: The heterogeneity of data – from surveys to EEG measurements – and ressource constraints – for example due to personalization and the use of wearable EEG devices at home – both provide challenges to the design and implementation of algorithms for analysis and predicition/synthesis. To deal with heterogeneous data by researchers from different disciplines, an easy-to-use software toolkit with access to the common data base is required; and for real-time analysis and generation, efficient hardware-aware implementations have to be developed.

Objectives: The analysis and prediction based on data requires custom adaptations, in particular if the data is heterogeneous and multi-modal and if computational ressources are constraint, e.g., due to real-time requirements. This project aims to study algorithms and develop efficent implementations to 1) combine and analyse data from different sources (surveys, EEG), and 2) close the loop between analysis and generation in real-time to be able to personalize auditory feedback during sleep.

Expected Results: This project will adapt and provide tools for data analysis and prediction tailored to the heterogeneous and multi-modal data gathered in Lullabyte. Efficient implementations provide the basis for personalization via real-time analysis and feedback on the spot.

Secondment(s): PBI (Thomas Andrillion), 6 months starting M18 for EEG data measurements. AU (Kira Vibe Jespersen), 4 months starting M28 for data acquisition and analysis.

Enrolment in Doctoral degree(s): The DC will be enrolled in the GRADUS PhD programme at the University of Stuttgart. **Local course program** includes *Statistics, Deep Learning, Advanced Parallel Programming, Reflection of Intelligent Systems.*

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC4 (PI: Kira Vibe Jespersen)	**Aarhus University AU**	**Y (AU)**	**7**	**36**	D2.1.2 Sleep music dataset collected via survey from people who use music as a sleep aid. D2.5.1 Dataset on the characteristics of people using music for sleep, including demographics, sleep quality, general music preferences and motivations for using music as a sleep aid. D1.3.3 Dataset on the impact of music sleep playlists on sleep EEG, ECG, respiration and behavioral ratings.

Project Title and Work Package(s): Factors determining the choice of sleep music – **WP1, 2**, 4, 5

Problem description and hypothesis: Music is commonly used as a sleep aid, but the music used for sleep covers a broad range of genres and characteristics. Through this project, we will investigate the variability of sleep music by determining the demographic, musical and psychological features affecting the choice of music.

Objectives: We will create a database with users of sleep music containing both music and non-music information. Based on this knowledge, we will build a model to predict the optimal sleep music for a given individual and test this experimentally.

Expected Results: By combining sleep research, music information retrieval and data science, we aim to determine the features influencing the choice of sleep music. These results can be used to optimize sleep music interventions in private and health care settings.

Planned secondment(s): UPF (Emilia Gomez), 6 months starting M18 for music information retrieval analyses. USTUTT (Dirk Pflüger), 4 months starting M32 for machine learning approaches.

Enrolment in Doctoral degree(s): The student will be enrolled in the PhD programme at AU, Health. **Local course programme** includes *Biostatistics and Responsible conduct of research.*

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC5 (PI: Thomas Andrillon)	**Paris Brain Institute (Institut du Cerveau)**	**Y** (ICM)	**7**	**36**	D1.1.1 Dataset: Full-night high-density PSG data recording the effects of acoustic stimulation on sleep. These recordings will include unperturbed sleep as well as arousals and awakenings in a controlled lab environment. D1.2.1 Dataset: Full-night PSG data recording the effects of acoustic stimulation on sleep. These recordings will include unperturbed sleep as well as arousals and awakenings in a home environment. D3.3.1 Code: Open-source algorithms for optimized, personalized acoustic and musical stimulation during sleep. Open-source algorithms for the analysis of sleep recordings with and without acoustic stimulations (spectral features, automated detection of sleep microstructure, stimulus reconstruction, complexity analyses).

Project Title and Work Package(s): Effects of acoustic stimulation of the sleeping brain: optimization of musical features and subjective measures – **WP1**, 4, 5

Problem description and hypothesis: Sleepers are not fully isolated from their environment as the brain continues to process external events to a surprising high level of complexity (Andrillon & Kouider, Current Opinion in Physiology, 2020). This covert auditory processing can be leverage to the benefit of sleepers (e.g. to boost sleep slow waves, to help the consolidation of past memories or form new ones). However, any acoustic stimulation during sleep therefore faces the challenge of carefully finetuning sound features to each individual: while too silent stimulation might be ineffective, too loud stimulation might wake up the sleeping subject. We will leverage state-of-the-art analytic tools (spectral and complexity analyses, stimulus reconstruction techniques) to study the impact of acoustic and musical stimulations on the sleeping brain. We will determine which acoustic features perturb sleep or, on the contrary, allow sleep maintenance. We will also examine the influence of these stimulations on the perceived quantity and quality of sleep.

Objectives: In this project, we aim to develop and validate strategies to optimize and personalize acoustic stimulation procedures during sleep, and further test them with objective (physiological EEG readout) and subjective (post-awakening report) measures.

Expected results: We will map which musical features are best encoded and preserved during sleep, compared to wakefulness, by checking which features of musical stimuli are best reconstructed from neuronal responses. We will also map which musical features increase the likelihood of arousals and awakenings (measured through objective EEG measures) and impact subjective assessments of sleep quantity and quality.

Secondments: UPF (Sergi Jorda), 6 months starting at M6. Purpose: selection of musical stimuli to use during sleep recordings; RADBOUDUMC (Martin Dresler), 6 months starting at M18. Purpose: Data collection of sleep recordings in a home environment.

Enrolment in Doctoral degree(s): The student will be enrolled in the PhD programme at the Doctoral School "Cognition, Cerveau

Comportement" (ED3C Brain Cognition Behaviour). **Local course programme** includes *training in sleep research, brain imaging and statistics*.

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC6 (PI: Jean-Julien Aucouturier)	**FEMTO-ST Institute**	**Y** (UBFC)	**7**	**36**	D3.2.4 Python code to generate musical sound stimuli with arbitrary properties in the spectro-temporal space. This would be integrated in, and distributed open-source as part of our existing CLEESE stimulus generation toolbox (the toolbox for now only does speech stimuli, we would add musical sounds thanks to the project). D1.2.2: Dataset of electrophysiological data (EEG, EMG, cardiovascular) measured in response to large sets of sounds (generated with D1) in awake and sleeping participants. Shared for the community, like the Lalor dataset of naturalistic speech listening
Project Title and Work Package(s): Cracking the musical code of thalamic gating? – **WP1,** 4, 5					
Problem description and hypothesis: A major theoretical model of loss of consciousness under sleep is that the thalamo-cortical relay of information to the primary sensory cortices is disrupted. Because thalamic neurons encode auditory information with specific spectro-temporal receptive fields before projecting sensory afferents to the primary auditory cortex, thalamic gating is expected to affect the transmission of sounds differently depending on their auditory characteristics, e.g. their musical timbre, or whether the go up or down in pitch. Yet, almost nothing is known about what types of sound are favoured for transmission to the cortex during sleep					
Objectives: The project's objectives is to reveal, on an individual basis, what exact type of musical sound is most likely to evoke arousal under sleep and loss of consciousness. To do so, we will use data-driven methods to analyse the electrophysiological responses of sleeping participants to large sets of musical sounds with systematically-varied acoustic properties, and reveal which of these properties evoke maximum arousal					
Expected Results: By "cracking the code of thalamic gating," the project will be able to design better fire alarms (37% of US fire fatality occur during sleep) and less intrusive medical alarms during anaesthesia or critical care.					
Planned secondment(s): UNIFRI (Björn Rasch), 6 months starting at M1 Purpose: data collection on sleeping participants, tbc (Draeger or hospital)					
Enrolment in Doctoral degree(s): The student will be enrolled in the PhD programme at Université de Bourgogne Franche-Comté. **Local course programme** includes *training in sleep research, statistics, clinical training*.					

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC7 (PIs: Sergi Jorda, Emilia	**Universitat Pompeu Fabra**	**Y (UPF)**	**7**	**36**	D1.2.3 State of the art report on music-induced sleep and its control by biofeedback

Gomez, Perfecto Herrero)					D2.4.2 Music processor toolkit D1.2.4 Dataset from the performed experiments (including music descriptions, sleep and behavior measurements, under different experimental conditions) D3.3.2 Guidelines for implementing personal interventions of music-induced sleep
Project Title and Work Package(s): The effect of interactive EEG based sonification and music generation, on sleep induction and sleep quality – WP1, **2, 3,** 4, 5					
Problem description and hypothesis: @Sergi					
Objectives: Exploring how interactive music generated with a closed feedback loop using EEG, can influence/improve sleep related processes. Sleep induction with alpha waves syncronisation: Alpha waves are indicators of relaxation; they are usually a prerequisite for sleep induction. Music can be generated or manipulated in ways that its content follows typical alpha-waves rhythms, and it can also be processed in order to generate binaural beats that follow alpha waves. Can this alpha music be helpful to induce alpha waves and consequently to induce sleep? Explore personalised real-time generated music during sleep and its consequences on sleep quality and dreaming.					
Expected Results: @Sergi					
Secondment(s): First secondment ICM (Thomas Andrillon), X months starting MX, second secondment XXX (name PI), X months starting at MX					
Enrolment in Doctoral degree(s): The student will be enrolled in the PhD programme at UPF Engineering School of the Department of Information and Communication Technologies **Local course programme** includes XXX					

Fellow	**Host Institution**	**PhD Enrolment**	**Start Date**	**Duration**	**Deliverables**
DC8 (PI: Sandra Pauletto)	**KTH**	**Y (KTH)**	**7**	**36**	D2.1.3 Data set/library of musical, sound design and vocal audio examples that have shown to promote sleep categorised by acoustic characteristics D3.2.3 Evaluated prototypes of real-time and non-real time sonification of sleep data for creative and analytical purposes D3.3.3 Evaluated prototypes of personalised interactive sonic objects that embody and affect a person´s sleep behaviour
Project Title and Work Package(s): Creative and analytical sound design and sonification of sleep data – **WP1,** 2, 3, **4, 5**					
Problem description and hypothesis @Sandra					

Objectives: Exploring the overlap between what is generally accepted as "music" and what could be considered more generally sound design for sleep (for example the use of environmental sounds to help sleep). Identifying which acoustic features are involved in promoting sleep and if they have a similar role in different sound signals (e.g. abstract sounds, vs instrumental music). We will also examine the role of vocal sounds and the singing voice in promoting sleep. The collaboration with the first secondment will support this research. This knowledge will then be applied in the development of different kinds of sonic interaction devices based on sleep data and sonification. Examples could be: a real-time sonic feedback of sleep data, or a personalised interactive sonic object that embodies a person´s sleep behaviour and that, through interaction, promotes a new and healthier relationship with one´s sleep behaviour. The second secondment will support this, as well as the collaboration with researchers at UPF, Barcelona.

Expected Results: We aim to identify how sound design, music and vocal sounds affect sleep differently. We further aim to use this knowledge by developing personalised interactive sonic applications that promote healthy sleeping behaviours.

Secondment(s): Miriam Akkermann for 6 months starting M20, and Thomas Andrillon for 6 months starting M32 (or maybe UPF, Barcelona??)

Enrolment in Doctoral degree(s): The DC will be enrolled in the PhD programme at KTH. **Local course programme** includes *Research Methods in Media Technology and Human-Computer Interaction, Sonification, Humanistic HCI, Statistics.*

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC9 (PI: XXX)	**Endel**	**Y** **(Radboud University / TU Dresden)**	7	36	D1.1.2 Data set acquired for large-scale study of effects of algorithmic music on sleep in healthy participants using wearable EEG in home-settings. D2.4.3 Data set of algorithmically produced music for the use of sleep aid.

Project Title and Work Package(s): TITEL **– WP 1, 2**, 4, 5

Problem description and hypothesis: Based on subjective experiences and theoretical considerations, first algorithmically generated music has been synthesized, however an empirical test if and to what degree such music actually aids sleep still has to be performed.

Objectives: This project aims at an empirical test of the effects of algorithmically generated music on sleep, using large-scale data acquisition using wearable EEG in home-settings.

Expected Results: Empirical insights into the efficacy of algorithmic music in inducing, stabilizing and deepening sleep.

Secondment(s): MD, DP

Enrolment in Doctoral degree(s): The DC will be enrolled in the Donders Graduate School at Radboud University Medical Center and at TU Dresden Graduate Academy. **Local course programme** includes *Statistics*, *Research Methods in Media Technology, training in sleep research.*

Fellow	Host Institution	PhD Enrolment	Start Date	Duration	Deliverables
DC 10 (PI: Björn Rasch)	**Université de Fribourg**	**Y** (UNIFR)	**1**	**36**	D2.4.1 Set of computationally-designed musical stimuli ready to induce emotions during sleep and wakefulness, pilot studies finished, study set up ready. D1.3.1 Set of physiological indicators of emotional processing by musical stimulation during sleep identified in healthy participants. D1.3.2 Association between emotional processing induced by music during sleep and sleep quality identified in healthy participants and patients with insomnia.
Project Title and Work Package(s): Sleep, Music and Emotional Processing – **WP1,** 2, 3, 4, 5					
Problem description and hypothesis: During waking, music induces emotions. It is still unknown, to what extent music listening during sleep activates emotional processing and induces emotional reactions. In the project, we will compare emotional reactions (e.g. skin conductance response (SCR), breathing, heart rate, emotional mimicry etc.) and brain oscillations (measured by EEG) induced by music during wakefulness and different sleep stages (N1 – N3 sleep and REM sleep).					
Objectives: Participants will listen to different emotion-inducing short musical pieces during waking and sleeping while EEG, EOG, EMG, SCR, HR and breathing are recorded. Emotional ratings will be assessed, sleeping participants will be awakened and sleep mentation will be assessed. In a different condition, participants will be allowed to sleep while listening to music, and sleep mentation and sleep quality will be assessed in the morning. Subgroups of participants will be recruited to test different musical preferences (e.g. heavy metal vs. Classical music). Healthy participants will be recruited in the first parts of the project. In the second part, music inducing positive emotions will be used to test emotional reactions and sleep quality improvements in patients with insomnia.					
Expected Results: 1.) Emotional reactions and underlying oscillatory correlates to music are maintained during sleep 2.) The degree of emotional reactions to music depend on the depth of sleep and musical preferences 3.) Music inducing positive emotions leads to positive sleep mentation and improved sleep in healthy participants and insomnia patients.					
Secondment(s): FEMTO-ST (FR), JJ Aucouturier. *Relatively early in the project (ex. Start+6?) for 3 months ? Purpose: training in computational methods to design emotional musical stimuli, and Aarhus University, Kira Vibe Jespersen, around half way through to conduct study with insomnia patients?*					
Enrolment in Doctoral degree(s): The DC will be enrolled in the PhD programme @Björn. **Local course programme** includes *XXX*					

3.1.5 Network organisation

Network Coordination: The network is coordinated by TUD (Coordinator: Miriam Akkermann). The tasks of the coordinator include oversight of administration and financial coordination, organization and chairing of Supervisory Board meetings, communicating with the European Commission and preparation of the yearly scientific report. The Coordinator is supported by the the Coordination Team (CT), consisting of Lullabyte's Project Officer, and the EU Project Manager at TU Dresden (EPC project manager), for maintaining records of the scientific and training progress of the DCs and set-up communication channels for communication and interactions. A Consortium Agreement will be drafted (using the current DESCA model) and signed by all beneficiaries, which will cover responsibilities of all parties and their liabilities towards each other, governance structure, financial provisions and handling of IP rights. A sharepoint will be set up for the management of the project and to ensure encrypted access for all project information, data and other results.

Administrative and Financial Management: The European Project Centre EPC of the TUD will take the main

responsibility and, through their experience, make sure that all EC reporting requirements are met in time and with the expected quality. Supervision and coordination of legal, financial and administrative issues to support communication and collaboration between project partners and to form a repository for project documentation will be carried out by ensuring the following: Each partner's legal, financial, administrative management; Legal / contract (change) management of core contract, Description of the Action and Consortium Agreement (including a dispute management, defining the rights and obligations of the partners, based on the DESCA model); Communication between partners and to the European Commission; Monitoring and collecting deliverables according to the Description of the Action; Monitoring of milestones; External reporting to EC (collection, review and submission of technical and financial reports, including financial statements and related certification); Budgeting and distribution of funds; Internal reporting; Internal dissemination of information (establishment and maintenance of an internal website and communication platform.

Strategy for dealing with scientific misconduct. All DCs and all other participating scientists will be instructed about the Research Ethics rules of Lullabyte, which are based on the European Code of Conduct for Research Integrity of the European Science Foundation and all European Academies. Additionally, all DCs will be trained in research ethics, correct data handling, and handling of scientific misconduct within the training program. Accordingly, data fabrication and falsification, plagiarism and the failure to meet ethical and legal requirements are considered as scientific misconduct. All consortium members are obliged to report scientific misconduct directly to the SB who will ensure an appropriate response. It will also inform the involved university and can include the local ombudspersons in the process of the individual case. Potential consequences involve official reprimand for negligence and dismissal for purposely done violation.

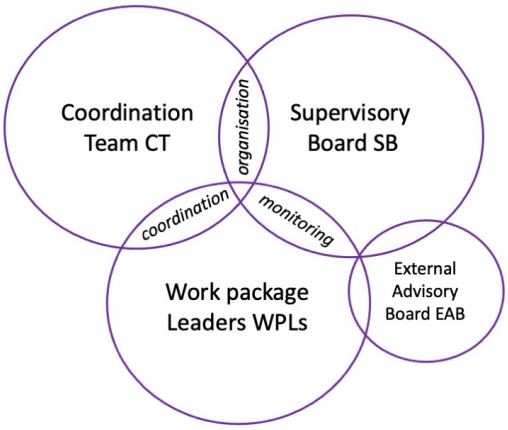

Figure 3.1 Project Organisation

Decision making. Decisions are taken following the layers and roles of the network's organization depending on scope, affected group and impact either guided by the joint governing structures or by those responsible in a certain role. Major decisions within the Lullabyte network are commonly taken by the SB in the meetings in a democratic process. In case of urgent reconcilements, decisions can be also taken by email or in ad-hoc virtual meetings. Specific decisions on the DCs' research projects are developed by the DC, the supervisor and the co-mentor and submitted for the SB's attention. Decisions related to very clear organisational tasks can be taken by the CT if the overall direction was approved by the SB. These decisions are reported to the SB in the regular meetings.

Progress monitoring. The progress monitoring obliges to the SB and is processed within in the SB meetings organized by the CT. The PIs and DCs will report individually and in detail on their achieved results. The WPLs gather the information and prepare short progress reports which include progress planning and identifies delays, and then present comprehensively on the progress within the WPs and the planning of the upcoming term. This includes also a discussion of risks and protection of IPR. The quality of the individual research projects will be discussed between PI and co-mentor, and the DCs will get regular and instant feedback in order to develop a substantial research project resulting in the DCs' dissertations, which will also undergo external reviews (the distinct process is following respectively the PhD awarding institutions' guideline and may differ a bit from each other).

Conflict Resolution. We aim to prevent conflicts from escalating by clear communication and hope to be able to settle arising conflicts friendly, if possible, and ideally bilateral, or with conciliation of the coordinator. For the DCs, there is an ombudsperson within Lullabyte (Emilia Gomez) for confident communication who will help to solve conflicts, mediate conflicts, and in case can also address problems to the SB, on behalf of the DCs. In case of sever conflicts between partners, we will bring in a third arbitrator from a not in the conflict involved partner as an external and independent authority, for example the TUD "conflict pilots" or a similar entity at another host institution, for conciliation.

3.1.6 Joint governing structure

The Coordination Team (CT). The CT is responsible for the operational processes within Lullabyte, which includes monitoring the compliance of the project members, collecting, reviewing and submitting reports and deliverables to the European Commission, preparation the SB meetings (preparing the agenda, chairing, organizing the minutes, and monitoring the implementation of decisions), handling the administration of the financial contribution from the EC and other obligations defined in the CA. The SB is the ultimate decision-making organ of the network, it will instruct the CT. The SB consults with the external advisory board and the WP-leader board for supervision on the project. The WP leaders board communicates with the DCs and their supervisors. This CT will closely work together with the local administrators, the WPLs and the SB, and facilitate the organizational aspects necessary to have a successfully working network, as well as help with monitoring milestones, progress reports and in the preparation of deliverables. The CT

will be based at TUD. The Lullabyte Project Officer will be recruited and paid by Lullabyte network.

External Advisory Board (EAB). We plan to appoint three internationally renowned scientists from in- and outside EU) as **External Advisors (EA)**. The SB can invite the EA to its meetings, but the EA have no voting rights. The EA are invited to participate in the training camps and give lectures and workshops.

Temporary Exploitation Committee(s). This group is temporary formed in case there appear tasks connected to IPs depending on the individual need. It includes members form the involved university, external advisor, the WPL of WP8, as well as the IP manager, who is informed when IPs are generated. The committee evaluates e.g. whether it is worthwhile to apply for an IP right in consultation with the respective participants.

DC Forum. All DCs are members of the DC forum which elects two DCs as their spokes-persons. These DCs will be part of the SB and can act on behalf of the DCs based on their mandate. The DC Forum is self-organised by the DCs with initial help by the CT. We aim to have a gender balanced DC Forum.

Leadership at Work Package Level. The work package leader WPL, identified in the individual WP sections, are responsible for the timely delivery of reports and WP results to the SB, proposing changes of the work plan to the SB, and alerting the SB and the coordinator in case of delay in the performance of the WP.

3.1.7 Supervisory Board

The **Supervisory Board (SB)** is the central decision-making body of Lullabyte. It consists of all PIs as the representatives of each beneficiary and partner organization, two elected DCs of the network, and Lullabyte's project officer; the EPC project manager has a consultative role to the SB. The SB thus contains representatives of all academic and non-academic stakeholders. An appropriate gender balance will be respected in the board's composition. The SB shall be deemed to be duly authorised to deliberate, negotiate and decide on all matters. The SB will oversee the quality of the program and ensure an adequate balance between scientific/technological and transferable skills training, which will be achieved through individual research projects and training (set down in the PCDP), appropriate to the needs of each recruited DCs. Involvement of the non-academic sector in the SB aims to ensure that the skills acquired by DCs fulfil the needs of both academia and the non-academic sector and enhance the inter-sectoral employability of the researchers. The SB will also establish an active and continuous communication and exchange of best practice among the participating organizations to maximize the benefits of the partnership. Finally, it will oversee the quality and quantity of supervision which will be evaluated by annual questionnaires filled by the DCs.

The SB is responsible for the supervision of the project and its high-quality execution and to support the coordinator. It meets every 6 months (6M meetings) and schedules online conferences on demand. Tasks include: finalising and passing the CA based on current DESCA model; monitoring the work of the project, the individual WP, and the coordinator; ultimately taking decisions regarding changes in the Lullabyte network or the SB, and to resolve potential conflicts; if necessary, propose modifications of the work plan; and support the coordinator monitoring milestones, progress reports and in the preparation of deliverables.

3.1.8 Recruitment strategy

During months 1-6, 10 excellent DCs will be recruited for the research training projects and employed for 36 months at the beneficiaries' institutions beginning in month 7. All beneficiaries are equal opportunity employers and will strictly apply their regulations. In awareness of our responsibility towards any job applicant we subscribe to The European Code of Conduct for the Recruitment of Researchers (EURAXESS European Charter for Researchers) and to the Principles for Innovative Doctoral Training. With this, we contribute to develop an attractive, open and sustainable job market for researchers in Europe, taking into account the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers and the Charter of Fundamental Rights of the European Union for all aspects of the recruitment. The recruitment will be main focus for the first SB meeting, which will include an especially designed recruitment training for all PIs with focus on interdisciplinary competences organized by TU Dresden Graduate Academy.

Recruitment Process. We plan to advertise the positions of the DCs jointly, right after the Grant Agreement is signed and the project website is publicly available at EURAXESS platform, in top-class scientific journals (Nature and Science), on job sites (including ZEIT.de, Forschung&Lehre, French…, Netherlands, doktorarbeit.de etc.), dedicated mailing lists (e.g. XX, AMM), social media platforms (e.g. ResearchGate, Facebook, Twitter) and local homepages of the participating organizations and their broad network. In their application, candidates are asked to outline a research project that matches the research field and questions as published at the project website. Besides a letter of motivation, two letters of recommendation by former supervisors or mentors will be requested. All applications will be cross reviewed by the network's PIs in order to establish a common short-list of candidates from which we will select a team of excellent DCs, as well as assign supervisors and co-mentors. We aim to fill the positions as quick as possible to be able to start all projects latest at M7, in order to prepare the training programmes as individual as possible in time. To ensure a high and shared quality of the selected DCs, all PIs will start the recruitment process with a common recruitment training for the selection process wherein we also develop our common selection criteria for Lullabyte. We hereby commit ourselves to recruit the DCs in a common recruitment process following an open, transparent, impartial and equitable recruitment procedure on the basis of the applicants' scientific skills and the relevance of their research

experience.

Selection. All applications are collected by both, the coordinator and the individual institutions, and gathered a TU Dresden-server based encrypted Share Point, providing all application material accessible for all PIs. Each PI will create a shortlist of suitable candidates and communicate those to the coordinator. The short-listed candidates will be discussed with all PIs. In the selection process, we will consider the impact of the proposed training on the individual researcher's career and aim to recruit a balanced gender representation within the group of Lullabyte's DCs by promoting genuine equal access opportunities for all genders throughout the recruitment process following the European code of conduct for Research Integrity. We are especially aware to attract a diverse cohort of DCs, not only related to gender, but also to heritage and personal special needs. Hereby, we closely follow the recommendations and methods provided in the European Gender Innovations Novel. In addition, the PIs will bring in long-standing expertise in recruitment of young researchers and relevant knowledge on national and EU-wide regulations from both, academic and non-academic sectors, as well as different disciplinary backgrounds. The selection process will be evaluated by an internal peer-review process similar to an online assessment centre; each recruitment is hereby guided by the recruiting host institution.

3.1.9 Progress monitoring and evaluation of individual projects

The DCs' individual PhD committees are mainly responsible for progress monitoring. In regular meetings with the SB, the committees will report about the individual project's process. In addition, they consult with the SB whenever a major delay or problem arises in one of the projects. The PhD projects will be discussed by DCs and supervisors and evaluated at network meetings, and during annual reviews. Adjustments on the level of the individual research projects and in the PCDP will be made if necessary for the development of the researcher. The supervision will be evaluated annually by anonyme and non-anonym questionnaires.

3.1.10 Risk management at consortium level

Since all partners of Lullabyte have already collaborated successfully in the past within international and interdisciplinary projects, the risk to the overall structure of the network is low. Nonetheless, one could envision potential implementation risks (Table 3.1e). Despite the coherent structure of our network, there are very few interdependencies between individual DC projects. Thus, delays in one subproject will not affect the progress of others. In case if any risk appearing in Lullabyte on either the overall structure or connected DC projects, e.g. technical risks and delays, this has to be reported to the coordinator who will communicate with the SB and organise according actions in cooperation with the project officer, such as immediate risk mitigation measures, ad hoc meetings as well as further actions to monitoring the risk management.

Table 3.1e: Implementation Risks (Impact: I, Likelihood: L | Low: L, Medium: M, High: H)

R	WP	Description	I	L	Risk-mitigation measures
Training & Supervision					
R1	WP6	Difficulties organizing trainings (local, camps, workshops)	M	L	Early and realistic planning of the trainings, immediate communication of vacancies, close contact between partner and CT for support, if training cannot be organised due to travel restrictions, an alternative online training will be hosted instead
R2	WP1-5	Not enough supervision/ dispute DC with supervision	M	M	Internal disputes will be solved by an ombudsperson and the supervision team
R3	WP6	Low participation of external experts (composers, trainers)	M	L	Depending of the timing and specifics of the withdrawal, the SB will organise adequate substitution through qualified experts
Research					
R4	WP1-5	Delay in progress reports	H	L	Early communication on deadlines and close monitoring of reporting process during the whole project duration ensures timely implementation,

					enough buffer time for delays is implemented
R5	WP1-3	Technical problems at one of the host institutions	L	L	The research basis of each project is EEG recordings, music analysis and/or sonification methods. All these techniques are well-established in each lab. In case of issues, other partners can help with trouble shooting and problem solving, eventually also lab access for other DCs
R6	WP1-3	Analysis scripts cannot be created that equally work on any data types	H	L	Instead of one script for one event all recording techniques, more individual approaches are developed
R7	WP1-3	Issues in compiling big data	M	M	If we run into any problems, we will first contact similar endeavours and ask for help (e.g. XXX)
R8	WP1-3	Underestimation of time for tasks	M	M	Close and critical monitoring of each task during whole project duration ensures timely implementation, enough buffer time for delays is implemented for each task
R9	WP1-3	No access to facilities due to COVID-19 (hospitals)	H	L	All partner have developed strategies of safety and hygiene processes that enables at least limited access; also, the DCs research projects linked to hospitals consider an extra time buffer for enabling changes in the time line
Impact					
R10	WP7	Less dissemination activities	H	L	Careful planning and close monitoring of the DCs projects ensures the timeliness of the research and resulting dissemination, in addition, online dissemination formats will be emphasized as they are independent from e.g. pandemic situations
R11	WP8	IP conflicts	L	L	A consortium agreement will be prepared and signed by all beneficiaries and partners that includes measures which can be used in case a partner does not abide by the rules
Management					
R13	WP9	Delay in recruitment	L	M	Early and realistic project planning, immediate communication of vacancies, fast recruitment process, close contact to administration to ensure visa and employment process in time
R14	all	Long-term sickness, parental leave, pregnancy	L	M	Additional Support from supervisors, adjustment of work-load/reallocation of tasks, additional student assistance employed
R15	all	Covid-19 situation	L	H	Ensuring working remotely, monitoring of remote working time – online meetings, medical and psychological support if necessary
R16	WP1-5	DC withdraws from the	H	L	The leaving DC will be replaced by another qualifying DC who will receive

		programme prematurely			a personalized training plan depending on the timing of the event. The host will seek additional funding to make a complete PhD project possible.
R17	WP1-5	One of the partners withdraws	L	L	Depending of the timing and specifics of the withdrawal, the SB will relocate the project to another beneficiary with similar competences (if not yet in the consortium) or in consolidation with the DC decide to arrange and request to replace the host by another beneficiary
R18	all	Potential overrun of budget	M	M	Urgent meeting of the SB, review budget and arrange cost savings

3.1.11 Gender aspects

The Lullabyte partners will seek to promote gender equality at all stages of the project cycle, especially as this is not yet reflected in the involved research fields. The project recognizes that the equal representation of men and women as well as taking into account non-binary people, and the consideration of gender in the articulation and implementation of the project are crucial in achieving excellence. Lullabyte will achieve this goal in terms of implementation: we aim for and promote gender equality our proposed activities, i.e. concerning the recruitment of the participants for our real-life experiments, technology developments, trainings and capacity building activities, as well as at the dissemination activities. We commit ourselves to treating all users equally and will ensure-by-design that access to all activities is provided on equal terms. Our approach is working not only gender neutral but inherently sensitive. Special attention will be given to potentially vulnerable persons belonging to social, and ethnic or other minorities. All members will be abiding to ethics regulations of autonomy and self-determination and confidentiality, and aim at an equal gender participation in all activities. We especially aim to make women visible by setting gender-specific indicators for women, and where applicable, account for migration status, disability and race/ethnicity, access to recourses, educational status, age, etc. We also emphasize to use a gender-neutral language in our publication and communication activities. Additionally, we will translate these documents in our members languages to also serve higher dissemination purposes, aiming also at diverse audiences through the utilization of our various networking partners. Especially regarding social media, the project takes into consideration the recommendations from the Amsterdam Conference (2013) on "Media and the Image of Women", and thus no offensive behaviour will be allowed. For technologic tools developed in WP 3 and 4, neutral language, designs and examples will be used, and an 'easy-to-use' policy will be applied. AI-driven systems will provide decision support and guidance to operators towards zero^2 policies' and procedures' implementation.

3.1.12 Environmental aspects in light of the MSCA Green Charter

The Lullabyte ensures to implement their network activities under the pre-condition of reducing travel, reduce, reuse and recycle project-related materials and promote green purchasing if necessary. Project events, trainings and meetings are planned according to sustainability aspects, and held online or hybrid to avoid unnecessary travel; when traveling, use low-emission forms of transport if possible. Training that cannot be done online will be performed in person during the trainings camps. Further, all members will be encouraged to present at conferences online to further decrease avoidable travel and incorporate the ideas from the Green Charter. We will train our DCs to develop an awareness on environmental sustainability, share ideas and examples of best practice, and commit to the environmental-friendly practices as already implemented at beneficiaries' and partner institutions, e.g. EMAS at TUD.

3.2 Quality, capacity and role of each participant, including hosting arrangements and extent to which the consortium as a whole brings together the necessary expertise

3.2.1 Appropriateness of the infrastructure of the participating organisations

Lullabyte network consists of 10 beneficiaries and X partners which provide adequate infrastructure for administration and organisation, such as **International Offices** that help with visa application, working permit, living accommodation, finding a family doctor speaking English, learning the language of the host country, finding **child care** opportunities, etc.; state-of-the art laboratories and equipment accessible for all DCs resources through their host institution and secondments (Table 3.2a). All participants have extensive experience in frontline research, training and supervision. Moreover, they employ experienced researchers that will assist in the training and supervision of DCs.

Table 3.2a: Facilities and infrastructure

Beneficiary / Partner	Labs	Provided most relevant infrastructure

TUD	SoundLab, fully equipped Audio Studio suitable recording and listening experiments.	Modern computer workstation workplaces and unlimited access to the Saxonian supercomputer center ZIH Dresden which is currently upgraded with an investment of 650,000 €. The group owns software licenses for many commercial codes (Gaussian, VASP, TurboMole, Wien2k, FEFF, as well as for development tools)
WP1		
WP2		
WP3		
WP3		
WP3		

Additionally, **Transfer Offices** or **Patent Information Centres** support the DCs in IP management and sometimes also offer trainings in patent search and patent application (like at TUD, where all DCs may join). **Press Offices** and Public Relation Departments will help DCs in communicating effectively and appropriately (e.g. support in preparing press releases, giving interviews, print articles, social media). The beneficiaries **Graduate Academies** will support the DCs through their diverse qualification programmes (transferable skills and competences) and also provide career consultation. At last, **libraries** will help and support the DCs in finding published information about their research topics.

3.2.2 Consortium composition and exploitation of participating organisations' complementarities

The consortium spans over a new interdisciplinarity of excellent academic and non-academic partners necessary for discovering and investigating the effects of music and sound on sleep in a new depth, combining explicitly social sciences and humanities with computer science and neurological and medical research as well as actively contributing to open science practices and emphasizing the yet underestimated aspect of data ethics in combination with data-driven approaches. Each beneficiary has one core competency which is essential for the success of this project, as well as state-of-the-art facilities which will be available for training and research within this DN (see B2 for individual competences and facilities) and fundamental experience in interdisciplinary research settings. The close involvement of our non-academic partners ensures the transfer of knowledge between academia and industry.

The diversity of the beneficiaries and partners in this network allows an attractive training program for young researchers. Here, academia and industry work in close cooperation. The non-academic partners will provide training which is essential for a new innovative generation of scientists (i.e. how to form a company, file a patent application, transfer academic knowledge to industry, etc.). DCs benefit from the individual training programs of the network members as well as from the various courses their host institutions offer in their graduate programs, and have the chance to establish and tighten contacts with the non-academic partners.

3.2.3 Commitment of beneficiaries and partner organisations to the programme

All beneficiary institutions integrate the fellows in their local graduate training programmes, which includes, administrative support for an easy start at the new location, language courses, support in getting settled in the new environment, and childcare. All institutions provide modern working environment and are equipped due to the need of the DCs. All DCs will be enrolled at the host university and can participate in all courses the host institutions' graduate schools offers. The beneficiaries provide administrative support for managing the funds of this network and for the daily accounting. TUD, hosting the coordinator, will host the project officer who will get training provided by the EU office of TUD and by the German National Contact Point.
The associate members (research institutions, industry partner and a cultural institute) will bring in a strong link to academic and non-academic research projects and demands as well as societal interaction inside and outside EU. They are interested in exploiting the knowledge of Lullabyte's DCs, and also offer them high-quality trainings and job-related insights in providing lectures on IPR, commercialising scientific products and entrepreneurship.
All academic partners are committed to spend time on the supervision of the DCs, and WP-leaders have reserved extra time to additionally coordinate the WP they lead. The consortium coordinator reserved 30% of her time to lead the consortium. The commitment of the non-academic beneficiary and partner organisations to actively contribute to the research and training plans of all DCs is laid down in letters of commitment (see section 7).