Listening to your loved one's Biomusic:
Auralizing biosignals to enhance social connection

MSc Thesis
Human Computer Interaction

Renske Eline Bootsma
r.e.bootsma@students.uu.nl

July 2024

Daily supervisors: Marit Bentvelzen MSc & Dr. Abdallah El Ali
1st supervisor: Prof. Dr. Ir. Judith Masthoff
2nd supervisor: Dr. Almila Akdag

Department of Computer and Information Science
Graduate School of Natural Sciences



Utrecht University



The Lord is my strength and my shield; My heart trusted in Him, and I am helped; Therefore my heart greatly rejoices, and with my song I will praise Him.

Psalm 28:7 NKJV

Above all, I'm thankful for His strength, His rest and His guidance.

I'm very grateful that Marit supervised me during this project, I really valued all your feedback, support, and close involvement. In addition, I want to thank Abdo and Pablo for their guidance during this project; for providing feedback, thinking along and welcoming me into their "gezellige" Distributed and Interactive Systems group at CWI. I want to thank my colleagues from CWI for helping me with technical implementations, participating in my user tests, and of course, all my participants for making time and enabling me to perform this study! Lastly, I want to thank my friends and family for all their support and prayers 🤍.

Renske Bootsma
4 July 2024

Abstract

Nowadays, more and more communication is online, but non-verbal cues and emotions appear to be difficult to convey through the online format. Therefore, research has been done towards sharing biofeedback in communication, showing positive effects on social connection. A rather unexplored format of sharing biofeedback is music, which is a shame because music can evoke emotions, but also convey emotions. Therefore, we propose generating music based on biofeedback: **biomusic**, and researching its effect on empathy and social connectedness between loved ones. Based on the results of three design iterations, we created biomusic by connecting heart rate to the tempo of the music, electrodermal activity (EDA) to a chord played in the background and an EDA peak to a sound effect. We evaluated the use of biomusic in communication by performing a within-subjects evaluation with twenty dyads of loved ones, containing nine senders and twenty receivers. The senders created a voice message and a text message for their loved one, while their biofeedback was being recorded. The biofeedback was converted into biomusic and added to both of the messages, after which the messages were displayed to their loved one; the receiver. The receivers indicated their perceived empathy and social connectedness after listening to the voice message and reading the text message with and without biomusic. The results showed varying opinions towards the use of biomusic in communication, with some receivers stating that it did not add anything and others being very enthusiastic. The biomusic did not have a statistically significant effect on the perceived empathy and social connectedness, but in the interviews, the participants indicated feeling a bit more emphatic and socially connected when the biomusic was added, especially with the voice message. They indicated being interested in adding biomusic to special types of communication with close relationships such as emotional conversations, but indicated being less interested in adding biomusic to a text message, due to the asynchrony of the text and the music. This study used one way of creating biomusic and tested its effect on two types of communication. Therefore, we suggest extending this work, including different target groups and communication means and experimenting with different sounds, biofeedback and musical elements. We conclude that the current research showed that biomusic had varying effects on social connection, providing new insights into the use of melodic biomusic in communication, focusing on asynchronous communication between loved ones.

Contents

1 Introduction **7**

2 Background **8**
2.1 Sharing Biofeedback . . . 8
2.2 Empathy . . . 8
2.2.1 Measuring Empathy . . . 9
2.2.2 Empathy and Sharing Biofeedback . . . 9
2.3 Social Connectedness . . . 11
2.3.1 Measuring Social Connectedness . . . 11
2.3.2 Sharing Biofeedback and (Social) Connectedness . . . 12
2.4 Music and Biofeedback . . . 14
2.4.1 Biomusic . . . 14
2.4.2 Biomusic and Communication . . . 15
2.5 Research Gap . . . 16

3 Creation of Biomusic **17**
3.1 Selecting Biofeedback . . . 17
3.1.1 Type of Biofeedback . . . 17
3.1.2 Type of Elements . . . 17
3.2 Exploring Hardware . . . 18
3.3 Exploring Software . . . 18
3.3.1 Music Production Software . . . 18
3.3.2 Controlling Ableton Live with the Biofeedback . . . 19
3.4 Mapping Process . . . 19
3.4.1 Gaining Inspiration from Literature . . . 19
3.4.2 Setting Requirements for Creating Biomusic . . . 20
3.5 Initial Mapping . . . 21
3.5.1 Mapping Biofeedback Elements to Musical Elements . . . 21
3.5.2 Implementation . . . 22
3.5.3 Gaining Expert Feedback . . . 23
3.6 Second Mapping . . . 23
3.7 Workshop . . . 24
3.7.1 Participants . . . 24
3.7.2 Discussed Variables . . . 24
3.7.3 Content of the Workshop . . . 25
3.8 Final Mapping . . . 28

4 Evaluation **31**
4.1 Pilot Test . . . 31
4.1.1 Participants . . . 31
4.1.2 Measurements . . . 31
4.1.3 Procedure . . . 32
4.1.4 Results . . . 34
4.2 Alterations . . . 34
4.3 Reviewed Protocol . . . 35
4.3.1 Particpants . . . 36
4.3.2 Data Analysis Plan . . . 36

5 Results **39**
5.1 Empathy and Social Connectedness Scales . . . 39
5.2 Direct Questions . . . 40
5.3 Interviews Senders . . . 43
5.3.1 Using Biomusic to Convey Emotions . . . 43
5.3.2 Interaction Partner . . . 44
5.3.3 Contexts to Use Biomusic . . . 44
5.3.4 Communication Type . . . 45
5.3.5 Music Taste . . . 45
5.3.6 Using Biomusic in the Future . . . 45
5.4 Interview Receivers . . . 46
5.4.1 Empathy . . . 46
5.4.2 (Not) Distracted by the Biomusic . . . 46
5.4.3 Social connectedness . . . 47
5.4.4 Type of Communication . . . 47
5.4.5 Emotional conversations . . . 48
5.4.6 Interaction partner . . . 48
5.4.7 Sound of the music . . . 49
5.4.8 Using Biomusic in the Future . . . 50

6 Discussion **51**
6.1 Answering the Research Question . . . 52
6.2 Contribution and Comparison with Literature . . . 52
6.3 Limitations . . . 53
6.3.1 Creation of the Biomusic . . . 53
6.3.2 Evaluation of the Biomusic . . . 54
6.4 Future Work . . . 55

7 Conclusion **56**

References **57**

Appendices **66**

A Workshop **66**
A.1 Consent Form and Questionnaire . . . 66
A.2 Protocol . . . 69
A.3 Slides . . . 74

B Quick Scan **76**

C Pilot Test **92**
C.1 Questionnaires and Interview Questions . . . 92
C.2 Protocol Sender and Receiver . . . 99
C.3 Voice Message Topic Insipration . . . 111

D Reviewed User Test **112**
D.1 Consent Sender . . . 112
D.2 Consent Receiver . . . 115
D.3 Protocol Sender . . . 118

D.4 Protocol Receiver 122
D.5 Questionnaires 125
D.6 Protocol Converting the Biofeedback 132
D.7 Slides Sender 134
D.8 Slides Receiver 136

1 Introduction

In some situations, being physically present while communicating is impossible, for example when having long-distance relationships or family members living abroad. Fortunately, the rise of communication technology enables us to keep in touch, both in auditory and visual formats, with the younger generations already preferring computer-mediated communication over face-to-face communication [111]. However, non-verbal cues are difficult to convey through online communication, which can affect communication and understanding of emotions and attitudes [111]. To overcome this, various ways of enriching online communication have been researched. Emojis and different modalities have been provided to communicate states or emotions, and during the last years sharing biofeedback has been explored [84]. Namely, biofeedback provides information about the physiological state of a person, offering the opportunity to convey feelings and emotions [69]. Especially between loved ones, these emotions, feelings and the ability to understand each other are important. Therefore, quite some research has been done towards sharing biofeedback in different types of modalities between close relationships, showing a positive effect on communication [32, 52, 84], empathy [41, 94] and connectedness [64, 69, 90, 115].

One modality of visualising biofeedback for sharing between people is rather unexplored:

Music.

Music is listened to all over the world and is applied in different settings and with different goals: listening for fun, relaxation and focusing during work [39] but also in therapeutical settings such as Music Therapy [2]. Furthermore, it has a positive effect on one's health [57], and people use music to match or change their emotions [39]. In addition to evoking emotions, music can also convey emotions [107]. Besides its potential to convey emotions, using music as a format for sharing biofeedback also has the advantage of not requiring visual attention or physical needs. Therefore, we were interested in exploring this biofeedback application.

Some work has been done towards biofeedback, communication and music, in which music is often altered based on biofeedback. In addition to *altering* music based on biofeedback, music can be *generated* based on biofeedback: **biomusic** [11, 14, 15]. Biomusic is a conversion of physiological data into an auditive format, giving insights into the state of a person. Hearing the biomusic of a person has proven to be valuable for communication between people [11, 14, 15] and offers opportunities to research its effect on loved ones. Therefore, we dive into the combination of biomusic and communication between loved ones.

For this, background literature is studied in Chapter 2, focusing on sharing biofeedback, empathy, social connectedness and biomusic, after which the research focus is described. These related studies are used to inspire the creation of the biomusic, described in Chapter 3, and the setup of the evaluation in Chapter 4, after which the experiment results are noted in Chapter 5. These results are discussed, after which conclusions are drawn in Chapter 6 and Chapter 7 respectively.

2 Background

In addition to the individual use of biofeedback, work on sharing biofeedback in communication has increased in the past years [84]. Moge et al. [84] show in their systematic review of 64 social biofeedback systems a diversity of applications and conclude that biofeedback has been used for creating connections over physical distance. Different studies towards the use of biofeedback for stimulating empathy and social connectedness can be distinguished. However, none of the studies in Moge et al. [84] discuss using biofeedback in communication by creating music.

2.1 Sharing Biofeedback

Sharing heart rate is one of the most common applications of biofeedback communication. Research from 2010 already shows that sharing heartbeats in Virtual Reality (VR) is promising for increasing intimacy between people [49]. Expressive heart rates are later on used for supporting social interactions, providing a playful form of communication and enabling a way of providing updates and expressing emotions [66]. Sharing heart rate can also be communicated through haptic feedback to convey excitement [93] and change valence and arousal [42]. Alternatively, participants have shown to favour visual breathing feedback over haptic feedback during collaborative tasks, being an insightful window into others [28].

More specifically, work towards sharing biofeedback between acquaintances and loved ones has been done, since people feel more comfortable sharing their biofeedback with close relationships, and indicated this to be the most meaningful [66]. Howell et al. [47] created a visualisation of skin conductance on a t-shirt, which was used amongst friends when having a conversation. When the skin conductance increased, white patterns appeared on the shirt. Experiments showed that the shirt functioned like social cues, associating it with emotions, and enabling social performances such as engagement with others. However, the ambiguity of information and meaning hindered validation but prompted reflection [47]. Reflection and conveying an emotional state were also the research topics of Peeters et al. [91]. They created a prototype to visualize heart rate and galvanic skin response by using colour.

Jiang et al. [52] also focus on remote communication and sharing biofeedback between close relationships. They launched the online app *IntimaSea* which visualizes the current stress levels of individuals of dyads based on heart rate variability. Participants were enabled to send messages and were notified when the stress level of their partner was high. IntimaSea created awareness, provided emotional support to help their partner manage stress, created the feeling of being together and provided to mediate relationships [52]. However, sharing biofeedback can be found overwhelming and sensitive, and can give a sense of being watched. Therefore, careful considerations should be made towards with whom the feedback is shared [52, 84].

2.2 Empathy

The Cambridge Dictionary defines empathy as "the ability to share someone else's feelings or experiences by imagining what it would be like to be in that person's situation". However, a universal definition in scientific literature cannot be found. In research towards eliciting empathy through sharing biofeedback, some avoid giving a definition [94, 96],

whereas others formulate their own [30, 95], choose one definition [68, 79, 85], or quote and combine several [41, 50, 86, 97, 98, 100, 117].

Cuff et al. [19] state that the diversity and inconsistency in defining empathy negatively impacted research and practice. Based on their literature review towards definitions of empathy, they specified that "the emotions of the targets are similar but not identical", and that "empathy is automatically elicited but is also subject to top-down controlled processes". Therefore, empathy consists of both affective elements, (being an emotional response) and cognitive elements (understanding the other's emotion) [19]. The multidimensionality of empathy has also been highlighted by Hall and Schwartz [38], which analysed almost 500 studies that defined and used empathy. We refer to empathy following the formulation of Cuff et al. [19] which is based on their review of definitions, since it highlights both affective and cognitive elements of empathy: "Empathy is an emotional response, dependent upon the interaction between trait capacities and state influences [...] The resulting emotion is similar to one's perception and understanding of the stimulus emotion, with the recognition that the source of the emotion is not one's own."

2.2.1 Measuring Empathy

Similar to the diversity in definitions, works measured (elements of) empathy through a variety of methods. Hall and Schwartz [38] categorized the different measurement characteristics of empathy and the majority of the reviewed studies use self-reported empathy and measure empathic concern and perspective-taking. In 34% of the 393 studies, the Interpersonal Reactivity Index (IRI) [22] has been used as a measurement of empathy, after which the Empathy Quotient (EQ) [6] and Batson scale [7] are commonly used with 8% and 7% respectively. Lima and Lima Osório [63] confirm in their meta-analysis the popularity of the EQ and IRI but conclude that there is no golden standard for measuring empathy. These questionnaires focus mainly on answering quotes related to individual empathy and combining these into an empathy score.

Some of the researches towards sharing biofeedback also measure empathy using the IRI [117] or Batson scale [50, 97]. Other predetermined scales were used [30, 68, 79, 86, 96, 98], but empathy has also been measured by stating context-based questions [41, 85, 86, 117] or qualitatively, by analysing open questions and doing word analysis [94, 95].

2.2.2 Empathy and Sharing Biofeedback

Sharing biofeedback in close relationships A few studies have been done towards sharing biofeedback between loved ones and empathy. Due to the lack of emotional awareness through online textual communication, *HeartChat* was created [41]. HeartChat is a chat application which includes the heart rate of the sender of the message. For the experiment, the authors included three different visualisation types: heartbubbles, heartlight and a heartbutton. After testing with close relationships, an increased awareness of the self and the other was reported. In addition, curiosity about the other's feelings was aroused and empathy was supported [41]. Another research created the physical prototype *Breeze* to send and receive breathing patterns between loved ones [32]. The breathing rate of the couples synchronized when wearing the device, and the participants became empathetic. The authors conclude that Breeze can be used to stimulate empathy, and connectedness and create a bond in remote communication. [32].

Stimulating empathy between romantic couples who were physically together has

also been researched. Rojas et al. [94] created *Us*: a wristband that was worn by couples and measured skin conductance. Based on the measurement, the arousal of the participant was categorized as 'high' or 'low' and the transition between the categories triggered a haptic nudge on the wristband of the partner. Results show that the wristbands increased the attention and made the participants more aware of their partner's emotional state. In addition, by using the wristbands, participants changed their way of talking, for example using more first-person plural pronouns and altering tone and choice of words. Overall, Us has been shown to stimulate empathic behaviour between romantic couples, giving promising directions for sharing biofeedback between loved ones [94].

Empathy through virtual reality Alternatively, communication between close relationships through VR has been researched in the *DYNECOM* project [50, 51, 97, 98]. DYNECOM is an immersive social meditation environment that uses electroencephalography (EEG) feedback and breathing rate. It conceptualizes the participants as avatars, and visualizes both their individual biofeedback and the synchronization between the participants, by using colour and movement [50, 51, 97, 98]. This increased the social presence [50, 98], synchrony between the participants and self-reported empathy [50, 51]. These researches align with Schoeller et al. [100], which discuss works towards combining VR and biofeedback for immersive social situations, fostering empathy between humans. Muñoz et al. [85] apply VR in a gaming context for teenagers aiming to promote empathy, and use respiration and brainwaves to control time and telekinesis respectively. Their preliminary results support combining biofeedback and video games for online collaboration and arousing positive emotions [85].

Sharing biofeedback in non-close relationships Other research has been held towards empathy and sharing biofeedback in non-close relationships. In his master thesis, Min [81] designed a physical setup to increase empathy between strangers. When two participants put their hands on sensors, their heartbeats were measured. When these heartbeats aligned, the music increased and when the heartbeats did not align, music faded away. Results show an increase in empathy through the hearts of the participants communicating with each other [81]. Increased arousal and empathy were also found by Rosello [96], who created *HeartBit*. This device passed over the heart rate of another person in the same room by haptic feedback. Holding the device when watching a video together increased the understanding of the emotional variability of the other. However, this can be influenced by the increased arousal and heart rate variability of the participants with the biofeedback condition [96].

Four other studies used sharing heart rate in their empathy research among non-close relationships: Winters et al. [117] showed that playing a heartbeat together with a photo of a virtual person changed the observed emotional state and increased their ability to "feel what the other was feeling". In an online setting, Murali and Bickmore [86] shared the heart rate of a speaker with its audience while persuading them to take a trip to France, Italy, and Spain. Sharing the heart rate information increased the empathic accuracy of the audience and the participants gained insight into the emotions and state of the speaker, creating an "empathic connection" [86]. Similarly to Winters et al. [117], Meijer et al. [79] visualized the heartbeat of a delivery worker and/or included a photo and showed this while the participants were waiting on their delivery. They investigated the effect of adding these visualisations on different types of empathy: affective, cognitive and compassionate. However, in contrast with Min [81], Rosello [96], Winters et al. [117] and

Murali and Bickmore [86], sharing and visualizing heart rate did not significantly increase the empathy [79]. This could be due to the different contexts in which the studies have been held, and different empathy measurements that have been used [79].

Rojas et al. [95] use a different technique: they visualize the valence of two strangers, having an online conversation. By using machine learning, the tone of voice and facial expressions are analyzed and converted into emotional valence, which is visualized by the corresponding colour. Similar to Rojas et al. [94], results show that the use of first-person plural pronouns significantly increased while sharing the biofeedback, being an indication of empathic responses [1]. In addition, the biofeedback condition was associated with empathy-related behaviours, with several participants reporting an increased self-awareness and awareness of the other's emotions [95].

2.3 Social Connectedness

"Social connectedness", "Closeness", (feelings of) "Connection" and "Intimacy" are all terms that have been used in research towards connectedness between people. Connectedness as a concept has been defined in a variety of ways, which may be caused by its multidimensionality [108]. Townsend and McWhirter [108] address the coherence with relatedness in their review, and state that the definition of Hagerty et al. [37] is the most inclusive definition of connectedness, namely that connectedness "occurs when a person is actively involved with another person, object, group or environment and that involvement promotes a sense of comfort, well-being and anxiety-reduction" [37]. However, connectedness as a concept can also be researched in for example graph theory, in studying linguistics [54]. Social connectedness therefore is a more specific term, suggesting emotional human involvement. It focuses on the concept of the self and belongingness, which is composed of companionship, affiliation and connectedness [60]. Lee and Robbins [60] were one of the first to define and create a scale for measuring social connectedness, and considered it as "an attribute of the self that reflects cognitions of enduring interpersonal closeness with the social world" [59]. This aligns with Haslam et al. [40], highlighting that "the identification with the other is the basis for social connectedness".

2.3.1 Measuring Social Connectedness

The concept of social connectedness has been measured through different methods. The widely used Inclusion of the Other in the Self Scale (IOS) [5] was created in 1992 and has been proven to be reliable for measuring the subjective closeness of relationships [33]. This scale uses a graphical representation of a person relative to another person or community by using circles, being far apart or overlapping. Choosing a picture that best describes the relationship gives insight into the social connectedness between the people [5]. A few years later, the Social Connectedness Scale (SCS) [60] was created, consisting of questions about different dimensions of social connectedness. Also in recent work towards sharing biofeedback, the IOS [30, 45, 64, 68, 87] and SCS [78] have been proven useful. In addition to scales, several works have used qualitative methods to gain insights into the social connectedness between people, for example by holding interviews [45, 64, 65, 67, 69, 115], creating questionnaires [58, 64, 69, 101] or more creative: by letting participants keep a diary [101].

2.3.2 Sharing Biofeedback and (Social) Connectedness

Similar to work on empathy, research towards sharing biofeedback to stimulate connectedness has been done through VR modalities [24, 45, 114], digital modalities [13, 64, 67, 69, 78] and physical modalities [58, 87, 89, 90, 101, 115], between close [64, 67, 69, 87, 89, 90, 101, 115] and non-close relationships [13, 24, 45, 58, 78, 114].

Sharing biofeedback in non-close relationships Desnoyers-Stewart et al. [24] aim to connect people by synchronizing their breathing rate while being immersed in a VR underwater world and Wang and Feng [114] state being successful in "creating a strong embodied experience that strengthens the nudge for synchronization and connection in remote interactions". In addition, visualizing breathing rate and electrocardiogram in an asynchronous game setting has been shown to increase the feeling of social connectedness [45].

Lee et al. [58] designed a more physical prototype, having the same concept as Rojas et al. [94]. The emotional status was real-time shared between two participants using a physical wristband whilst video calling [58]. The wristband changed colour based on galvanic skin response and vibrated to create an artificial heartbeat. Together with the wristband, an online user interface was available, showing the raw data. The enjoyment, closeness and engagement between partners using the biofeedback condition were higher compared to a normal video chat system, promoting the use of biofeedback in communication [58]. These results are in line with the master thesis of Mandolfo [78], which also includes live biofeedback sharing. In his work towards trust between dyads in an online game, he concludes that sharing real-time biofeedback increases social connectedness and social presence and fosters connections between people [78]. Sharing biofeedback in online communication also contributes to feelings of connectedness, influences conversations and enables participants to understand the other's emotional state [13].

Sharing biofeedback in close relationships Sharing biofeedback in remote communication has also been performed between close relationships. Fannie Liu investigated several settings regarding expressive biosignals and concluded in her PhD thesis that biosignals "can foster social connection between people as authentic social cues that stem from our body's reactions to everyday experiences" [64]. She designed and developed *Animo*, a smartwatch application which shared mood representation between close relationships, based on heartbeat [67]. Users could send their Animo, of which the movement and colour were adjusted to the current state of arousal. After a two-week field study, Animo appeared to create more connectedness between partners and evoke more awareness of their individual and their partner's presence. Animo also was a new way of communicating and a conversation starter, just as *Significant Otter* [69]. This smartwatch application extended Animo and enabled romantic couples to share biosignals by animated otter avatars. In the biofeedback condition, the avatars were proposed based on heartbeat, moment of the day, historical data and motion-based activities. When receiving an animation, their partners could react by sending an animation themselves. In both versions of the application (biosensing ON and biosensing OFF), the participants indicated that Significant Otter enabled them to easily keep in touch with their partners. However, sending, understanding and responding to the animations appeared to be easier with sensing ON than sensing OFF. Furthermore, the ON condition supported the feeling of connection, enabling them to share emotions and their current physical state through

representative animations. However, some participants indicated ambiguity regarding the interpretation of animations, limiting communication. Moreover, sensing ON was by some perceived as overly suggestive and sometimes incorrect regarding their current emotions, which caused accuracy and agency concerns [69].

These wearable sharing biofeedback methods [67, 69] were a lot more practical than the setup of Slovák et al. [101] from 2012. They connected a heartbeat belt to a laptop, which was "often too heavy and big to carry around easily if they wanted to move". Yet, their research demonstrated similar results. Sharing heart rate via aural and visual feedback between close relationships can serve as information and topic of conversation and create a connection [101]. Heart rate between romantic couples has also been shared via haptic feedback: Werner et al. [115] created a ring that passed over the heartbeat of their partner via vibration when touching it. Their laboratory study showed promising results, but individual preferences were noticed with one participant enthusiastically indicating that she would want to feel her partner all the time, and another participant indicating that sharing the exact heart rate felt like surveillance. Overall, participants indicated that they felt close to their partner, being able to feel them, creating a feeling of intimacy [115].

Cuddling a pillow that includes the feedback of a close partner has also been researched to create a feeling of connectedness [87, 89, 90]. Nunez et al. [87] shared the hugging gestures of two people having a close relationship while watching a movie. When one of the partners hugged the cushion, the colour of the cushion changed to red, and the cushion of their partner coloured blue. When hugging the cushion simultaneously, both cushions displayed a multicoloured pattern. Participants indicated that it felt like they touched or felt their partner, through the huggable coloured interface, just like the haptic prototype of Werner et al. [115]. The interaction of the coloured huggable interface was perceived to be more intimate and social compared to an online and non-colouring cushion. It was concluded that the cushion interface could contribute to a stronger feeling of social connectedness [87]. Another huggable pillow aiming to foster an intimate connection between close relationships is *Lokahi* [89, 90], which displays heartbeats through pulsating coloured lights, whilst visualizing the level of synchronization between partners. Two versions of the Lokahi prototype differ in shape, but both aim to increase the feeling of connectedness and intimacy between two users [89, 90].

Both social connectedness and empathy Some studies have investigated the effect of sharing biofeedback on both social connectedness and empathy. Participants of Liu et al. [68]'s experiment had to read an interview with a person of a stigmatized group accompanied by the heartbeat, indicated by a number or visualized by a graph. Following, they had to rate their empathy and closeness with the interviewee. Including the graph can increase closeness, and provide information about the heart rate also increases emotional perspective-taking empathy [68]. In the experiment of Feijt et al. [30], the synchronization of heartbeats between participants while watching a movie was visualized by using colour. Higher perceived empathy was found for a higher synchronization and in line with the works of Desnoyers-Stewart et al. [24] and Wang and Feng [114], a higher synchronization gave a higher score on social connectedness [30]. Similarly, Dam [21] visualized in her master thesis the heart rate of two participants, using a graph, while watching a movie and concluded that synchrony leads to higher levels of empathy and social connectedness, compared to asynchronous patterns. Following, Zheng [123] confirmed in his Master thesis that synchronous feedback is positively related to empathy and social connectedness.

2.4 Music and Biofeedback

In earlier research, music and biofeedback have been combined to convey information. For that, multiple naming conventions have been used. Namely, **sonification** is often described as using non-speech audio to convey information [55]. However, whether sonification is music is debatable [112, 113], partly because the definition of music is much less objective. Godt [35] defines **music** as "humanly organised sound, organised with intent into a recognisable aesthetic entity as a musical communication directed from a maker to a known or unforeseen listener". However, this definition can limit the broad concept of music, since defining music also depends on the listener: "Music is whatever people say it is" [35], and "if one chooses to listen to something as music then it is music" [112, 113]. Therefore, a universal definition of music cannot be formulated.

Work has been done towards the sonification of biofeedback, in which existing music was adjusted based on biofeedback, for example by changing the rhythm of the music based on a person's heartbeat. Using the auditory format to convey biofeedback by adjusting music has been used in movement optimization, for example to provide insights into weightlifting movements [73], upper limb movements [20], and running behaviour [23, 72, 74, 109, 110]. These researches show the advantage of solely auditory feedback, which is that no visual attention is required.

Furthermore, music adjusted by biofeedback has been used to realize a healthier heart rate variability [46] and to lower stress levels [31] in for example education [29] or while driving cars [10]. Recommendations for listening to music based on biofeedback have also been shown to reduce stress while air travelling [70] and to identify and change emotions [26].

2.4.1 Biomusic

In addition to *altering* existing music based on biofeedback, some researchers *generate* music based on real-time biofeedback: **biomusic** [34, 116]. Although biomusic appears to be used as a torturing method of the CIA [53], other known applications are only well-intended. The "Music for a Solo Performance (1965)" by Alvin Lucier is known as fundamental for biofeedback sonification. During his performance, Lucier's brainwaves directed percussion instruments [75, 104]. Numerous artists and musicians were inspired by the use of EEGs, which made that biomusic has been used in the expression of art and composition in diverse works [3, 16, 88, 106]. For example, Miranda and Brouse [82] and Miranda et al. [83] touch upon the development of music, based on EEG data, and Hinterberger and Baier [44] research the different brainwaves connected to musical elements for developing EEG-based music.

During the past ten years, Grace Leslie has experimented with creating music by incorporating physiological signals [61, 62]. As a researcher and musician, she is interested in the field of music perception and cognition, and understanding the roles of perceptual mechanisms and anatomies in perceiving, understanding, remembering, and responding to music [62]. She focuses on the sonification of EEG data, sometimes combined with other biosignals such as heart rate. While real-time playing the sonification of her brainwaves, she creates a musical expression of her physiological state, while playing the flute [61, 62].

The creation of EEG-based music can also be combined with other physical elements, like Hadjileontiadis [36] show in their research. There, EEG data is combined with the hand gestures of the director of an instrumental ensemble, adding an extra dimension to the live music [36]. Another form of music creation based on EEG data is

explored in a study by Ardito et al. [4]. They use EEG data of a dancer to compose sheet music, which is real-time played by two musicians. The physiological state of the dancer is expressed, by which the dancer adapts her choreography according to what she hears [4].

Besides focusing on the *creation* of biomusic, *using* the biomusic in scientific experiments has also been researched. For example, Deuel et al. [25] focus on the creation of the biomusic, after which they test whether participants can control the music and its potential for therapeutic applications. Wu et al. [120] investigate the difference in EEG-music during different sleep stages and Ehrlich et al. [27] use EEG-based biomusic as a feedback method for their affective state to stimulate a closed-loop interaction. The system captures the listener's current affective state in real-time and enables the participants to mediate their emotions, by interacting with music [27]. Relatedly, in the research of Bergstrom et al. [8], participants were asked to change their arousal state. This was investigated in three different settings: listening to relaxing music, listening to a tone generated based on the participant's heartbeat, and listening to music altered based on the heartbeat. Here, the last two conditions appeared to be more efficient compared to listening to relaxing music, showing the effect of the sonification of a participant's biological data [8].

The biomusic described in the previous sections concerned mainly EEG-based music. However, other biofeedback inputs can be connected to musical elements, such as temperature, respiration, skin conduction, blood volume pulse, electromyogram and electrocardiogram [105]. Yokoyama et al. [121] record heart rate, and convert this to pitch and note intervals to create biomusic. The biomusic was played to the participants during their work, to investigate its effects on the worker during mental workload. Varying reactions were observed, with an increased subjective workload and a decreased physiological workload when the biomusic was played [121]. Mainka et al. [76] use another type of feedback: they subtract the arm swing behaviour of someone with Parkinson's disease and generate music based on this data. This music is real-time played to the participant, causing an increase in the arm swing range of motion, symmetry of arm swing, sternum rotation and stride length [76].

2.4.2 Biomusic and Communication

The previously described studies focus on the generation of biomusic and its use in *individual contexts*: how the biomusic can express an individual's state or change a person's behaviour. However, little work has been done towards investigating the effect of *sharing* a person's biomusic. Blain-Moraes et al. [11] were the first to focus on the communication of biomusic. They acknowledged the difficult situation of individuals with profound multiple disabilities (PMD), of being unable to communicate with their caregivers, limiting the ability to perceive personhood [11]. They generated real-time music, based on the electrodermal activity (EDA), skin temperature, blood volume pulse and respiration of the person with PMD and connected these signals to the musical elements pitch, key, tempo and articulation respectively. This biomusic was real-time played to the caregivers of the person with PMD, after which interviews showed that most caregivers responded positively to the biomusic, causing improvement in their interaction and perceptions of the person with PMD [11].

Based on this research, Cheung et al. [14] performed a study among children with profound disabilities and their caregivers. Similar to the work of Blain-Moraes et al. [11],

the disabilities of the children caused difficulties in communication with their caregivers; identifying emotions can be extremely challenging for these children [14]. Therefore, Cheung et al. [14] focused on creating biomusic, following a similar method as Blain-Moraes et al. [11], and recorded the biomusic of the children in both a relaxed and a stressed state. These recordings were played to their caregivers, who were able to accurately distinguish the emotions of the children based on the biomusic [14].

More recently, Chou-Ren et al. [15] investigated using biomusic for communication, being the first ones to share the biomusic of two in-person participants simultaneously. However, their creation of biomusic differs from the work of Blain-Moraes et al. [11] and Cheung et al. [14]. Namely, Chou-Ren et al. [15] control a kick drum, tube air and bass with heart rate, breathing rate and electrodermal activity respectively, thus the alterations in biofeedback affected the tempo, and not musical elements such as pitch, key or volume. In addition to the biomusic, they synthetically created music that is not distinguishable from real biomusic. Playing this 'fake' and 'real' biomusic, they compared the effect of the music on the closeness and empathy between the dyads, for both conditions. Interestingly, the results showed that for both the 'real' and 'fake' biomusic, the closeness and empathy were higher than in the control condition without biomusic. In addition, biomusic is found to provide as much information as other social communication channels such as facial expression [15].

2.5 Research Gap

The research of Blain-Moraes et al. [11] and Cheung et al. [14] show the value and possibilities for using biomusic in communication. However, these studies have focused on communication with people with disabilities, where biomusic was a substitute for communication, whereas biomusic can provide possibilities for communication between people without disabilities, being an addition to their communication. Biomusic can serve as a modality of visualizing biofeedback, which can be shared to positively influence communication, as highlighted in sections 2.1, 2.2.2 and 2.3.2.

Chou-Ren et al. [15] were the first to research sharing biomusic between dyads but were limited to non-close relationships. Furthermore, their biomusic contained solely elements altering the tempo, and no melody was included. Therefore, following existing research towards sharing biofeedback and its effect on empathy and social connectedness, we propose researching sharing biomusic between loved ones to enhance empathy and social connectedness, leading to the research question of this study:

How do loved ones experience using biomusic in communication and how does this affect their empathy and social connectedness?

3 Creation of Biomusic

The first step was to focus on creating the music. For that, insights from experts in the fields and previous work have been gathered. The research of Yokoyama et al. [121], Blain-Moraes et al. [11], Cheung et al. [14] and Chou-Ren et al. [15] are, to our knowledge, the only published studies that describe their mapping of biofeedback to musical elements. Therefore, these works served as an inspiration for our creation process. First, we selected the biofeedback, hardware and software to use, after which we focused on mapping the biofeedback to musical elements.

3.1 Selecting Biofeedback

Biomusic consists of biofeedback data which are mapped to musical elements. Therefore, we started selecting these core elements.

3.1.1 Type of Biofeedback

(Non)-EEG data Interestingly, most of the biomusic applications discussed in section 2.4 focus on using EEG data. However, a drawback of using these signals is that they are measured using sensors on the head through expensive technology, not available for day-to-day use and which can be perceived as uncomfortable and inconvenient for the users [103]. In addition, the works using EEG data were not focused on sharing biofeedback and using this for communication. The research of Blain-Moraes et al. [11], Cheung et al. [14] and Chou-Ren et al. [15] are, to our knowledge, the only ones focusing on sharing biomusic for communication and all use non-EEG biofeedback to create the biomusic. That, together with the impracticality of the EEG data in our setting, led to the decision to focus on using non-EEG biofeedback.

Heartrate, respiration and electrodermal activity The goal of the biomusic was, just like other modalities have shown, to enhance feelings of empathy and social connectedness (see sections 2.1, 2.2.2 and 2.3.2). However, the choice of which biofeedback to use was important. Ideally, the biomusic extends the conversation, conveying information and emotions.

Kreibig [56] showed in her review of 134 publications a clear coherence between emotions and different types of cardiovascular, electrodermal and respiratory responses. She summarized that heart rate was increased for both positive and negative emotions and decreased when emotions appeared with an element of passivity. Changes in respiratory activity were also related to emotional activation, for example by a decreased inspiratory duty cycle in amusement, which can be caused by the effect of laughing on respiration, or an increased breathing frequency when feeling anger, fear or surprise. Furthermore, sadness, contentment and relief were associated with decreases in electrodermal activity, and all other emotions increased electrodermal activity [56]. Therefore, we used **heartrate**, **respiration** and **electrodermal activity** to create biomusic.

3.1.2 Type of Elements

The research of Yokoyama et al. [121] is quite specific, by using one algorithm to convert heart rate into pitch and note intervals. Blain-Moraes et al. [11] and Cheung et al. [14] use a more elaborate approach for creating the music: they map EDA to melodic pitch,

(finger) skin temperature to key change, blood volume pulse to tempo and respiration to effects [11, 14]. Chou-Ren et al. [15] use a slightly different approach, still using the heart rate to direct the drum and breathing rate for adding an effect, but by controlling a bass by EDA signals. Therefore, they, in contrast to Blain-Moraes et al. [11] and Cheung et al. [14], do not include a melodic pitch or key but only focus on tempo [15]. They made this decision, based on the work of Bernardi et al. [9], which demonstrates a synchronization between tempo and musical emphasis and physiological aspects such as respiration and heartbeat, while listening to music. However, melodic music has also been proven to evoke and convey emotions [107], affecting physiological aspects [56]. Therefore, we decided to include both rhythmic and melodic musical elements in our biomusic.

3.2 Exploring Hardware

After deciding on the biofeedback elements, we explored the hardware options: searching sensors and checking the availability. Since we chose to use heart rate (or ECG), respiration and EDA, we had to search for sensors enabling us to record these data. For this, the output data type of the sensors had to be considered, the accuracy of the measurements and the user experience of the sensors. Ideally, the sensors should not distract nor influence the user during the experiment.

After considering multiple sensor options, we chose to use the Empatica E4[1] (hereafter referred to as Empatica) wristband. The Empatica is a wireless wristband that measures multiple physiological signals, amongst others ECG and EDA. Unless it appeared that the Empatica measures EDA less reliably than alternatives [80], it has been widely used for physiological sensing, also in the work of Chou-Ren et al. [15] for creating biomusic. Furthermore, the Empatica solely requires attaching a wristband, thus being easy to use during the user test, and the Empatica was available at the institutes. Chou-Ren et al. [15] combined the Empatica with the Vivalink chest monitor[2] to include respiration, however, respiration sensors were not easily available for us to use. After reconsidering the number of sensors and biofeedback elements, we decided to focus solely on heart rate and EDA, to keep the mapping and amount of signals to a minimum.

3.3 Exploring Software

During the search for appropriate hardware, we explored the software possibilities for connecting data to a sound being produced. We used the Neurokit2 package[3] [77], which enabled us to clean, process and analyse physiological data in Python. It also enabled the creation of a fake dataset without noise, which enabled focusing solely on the creation of converting biofeedback into music. We started with converting recorded data into music, instead of focusing immediately on live conversion of biofeedback into music.

3.3.1 Music Production Software

One of the first things we decided was the music production software. A variety of music production applications exist, but we chose to use Ableton Live 12[4] (hereafter

[1] https://www.empatica.com/
[2] https://www.vivalink.com/wearable-ecg-monitor
[3] https://neuropsychology.github.io/NeuroKit/index.html
[4] https://www.ableton.com/en/live/

referred to as Ableton). Sufficient support options were available, and Ableton is a widely known application, focusing on creating live music. It offers a lot of possibilities to map different features, direct instruments and add effects. Since the goal of this study was to generate music in real time by mapping biofeedback data to musical elements, this software appeared to be appropriate. After choosing the music production software, we could focus on searching for possibilities to direct Ableton with the data.

3.3.2 Controlling Ableton Live with the Biofeedback

Since the biofeedback data were in numeric format, we started searching for possibilities to convert these numbers into sounds in Ableton. After experimenting with using a Digital Audio Workstation in Excel[5] the visual programming language Pure Data[6] and Open Sound Control (OSC) [119], we decided to use Musical Instrument Digital Interface (MIDI). We created a MIDI port using loopMIDI[7], and used the `python-rtmidi` package[8] to send commands to Ableton through `midiout.send-message()`. We loaded sound samples to a drum pad in Ableton and added instruments to the channels. Using the MIDI commands, we could start and stop playing sound samples and control a sample instrument by playing a specific pitch and velocity. How to set up the connection and load all required instruments and samples can be found in our **Supplementary Materials**[9].

3.4 Mapping Process

After determining the biofeedback elements, we had to determine to which musical elements these could be mapped. We did this through three mapping iterations, as can be seen in Figure 1, and based the first mapping on literature, technical hardware and software limitations and possibilities and trial and error. ChatGPT[10] has been used for coding, and our **Supplementary Materials**[9] contains the code for the initial mapping, second mapping, workshop and final mapping, together with the Ableton Live set and sound samples.

3.4.1 Gaining Inspiration from Literature

Our goal was to use the music to convey information, although it should not distract the participants while conversing. Therefore, we started by gaining inspiration from previous works [11, 14, 15].

While listening to the biomusic example of Cheung et al. [14], we noticed the rapidly changing melodic pitch, corresponding with small changes in EDA. However, due to the individual alternating pitch, it created an incoherent whole which was quite distracting. Their chords in the background with key change did however provide an informative non-distracting sound. In addition, the whooshing seashore sound (hereafter referred to as whoosh sound) played during respiration was a good representation of the participant's breathing pattern. Connecting the heart rate of the participants to the beat and tempo of the music felt intuitive, following previous works. We did not have an audio sample of the

[5]https://github.com/DylanTallchiefGit/xlStudio
[6]https://puredata.info/
[7]https://www.tobias-erichsen.de/software/loopmidi.html
[8]https://pypi.org/project/python-rtmidi/
[9]https://github.com/RenskeEline/Biomusic_supplementary_material
[10]https://chatgpt.com

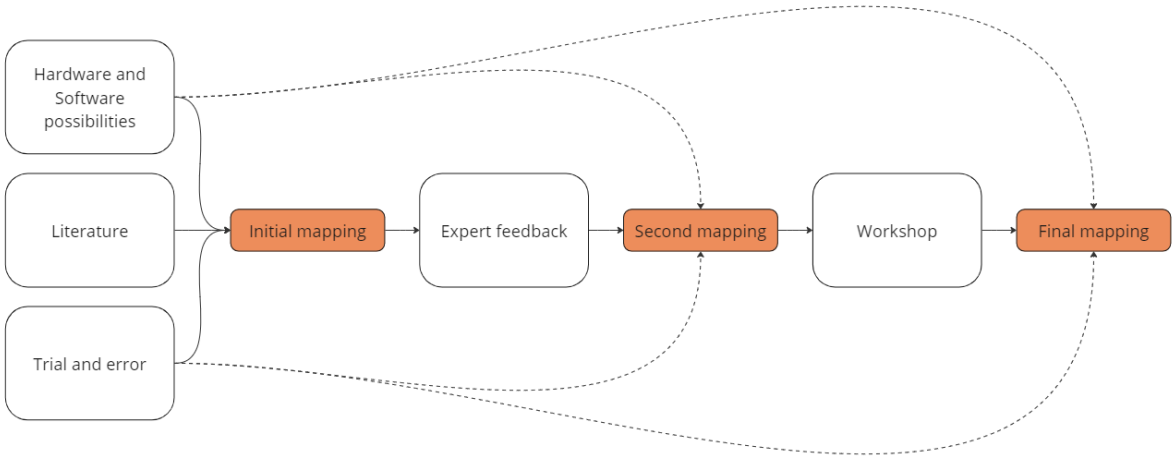


Figure 1. *Flow diagram showing the three iterations of the process of mapping biofeedback elements to musical elements, for creating biomusic.*

biomusic of Blain-Moraes et al. [11], but based on their description, it sounded similar to the work of Cheung et al. [14], except for replacing the whoosh sound for an alternation in articulation.

In contrast to Cheung et al. [14] and Blain-Moraes et al. [11], the biomusic of Chou-Ren et al. [15] solely focused on rhythmic elements, thus not containing any melodic elements. They also connected the heart rate of participants to the tempo, but used a kick drum playing twice in quick succession, to simulate the sound of a heart beating. This, combined with the lack of musical elements, made it feel like listening to a person's heartbeat rather than music. Similar to Cheung et al. [14], Chou-Ren et al. [15] played a whoosh type of sound while exhaling, but used EDA differently by playing a saturated bass tone when an EDA peak was occurring. This indication of changing EDA is quite useful since this has been related to emotional activation [56].

3.4.2 Setting Requirements for Creating Biomusic

Based on the analyses of Cheung et al. [14], Blain-Moraes et al. [11] and Chou-Ren et al. [15], we formulated the following requirements for creating our biomusic.

- The music should contain melodic background music, changing based on biofeedback
- The music should not contain a rapidly changing melodic pitch
- The music should contain an indication of an EDA peak
- The music should contain a tempo, based on the heartbeat of the participant, but not simulate its sound

3.5 Initial Mapping

Based on the requirements and the chosen hardware, we experimented with matching biofeedback to musical elements. Using the Empatica, we had access to the accelerometer (ACC), blood volume pulse (BVP), electrodermal activity (EDA), interbeat intervals (IBI), temperature (TEMP) and heart rate (HR) data, of which we wanted to use EDA and HR as argued in Section 3.1.1.

We made several recordings with the Empatica, to test its functionality and gain knowledge about the common ranges of the values. After the first inspection of our own and a colleague's data, we noticed differences in the ranges of EDA values, meaning that we had to carefully consider the ranges we set for mapping musical elements.

3.5.1 Mapping Biofeedback Elements to Musical Elements

Mapping heart rate to tempo was quite intuitive, following previous work and our requirements. Similarly, indicating an EDA peak with a sound effect was straightforward, since these peaks are specific moments that should be distinguishable, just as indicated in Chou-Ren et al. [15]. To fulfil our requirements, we aimed for melodic background music. Blain-Moraes et al. [11] and Cheung et al. [14] used skin temperature to control the musical key, but since we only used EDA and heart rate, we had to experiment with other possibilities.

In addition to the EDA peaks, we decided we could use the EDA values to indicate information about the current physiological state of the participant. We aimed for lo-fi, slowly changing melodic background music, thus we decided to use averaged raw EDA values since averaging these over a longer period enabled us to gain a more constant, general value on which the background music elements could be based.

Biofeedback element	**Musical element**	**Implementation**
Heart rate	Tempo of the music	Play a tom for every beat at 75% of the average of 4 heart rates. Update the tempo every bar.
EDA values	Chord in the background	Play a chord based on the average of 16 EDA values. The chords consist of three static tones played on a piano, and the type of chord is based on the EDA range: play a C-major chord for the first range of 0 - 0.03 μS and increase the major chord one tone in pitch for each higher range. Update the chord every 4 seconds.
EDA peak	Sound effect	Play a twinkle sound when an EDA peak occurs.

Table 1. *Table containing the initial mapping, showing what biofeedback elements are connected to musical elements, and how these are implemented.*

3.5.2 Implementation

An overview of the initial mapping can be found in Table 1.

Raw EDA - Chords After deciding to use the raw EDA values to create the background music, we wrote a Python function for controlling sounds based on raw EDA values. Since the EDA is measured with a frequency of 4Hz, updating the background music for every value would create too much diversity in tones, resulting in a stressful sound. Therefore, we averaged the EDA values and updated the musical sound per chunk, just as Cheung et al. [14] updated every two bars. After experimenting with the number of seconds, we settled on updating every 4 seconds, thus averaging 16 values, resulting in a calm sound.

Since playing one tone did not sound like music, we decided to map a major chord, consisting of three static tones played on a piano, to each EDA range. After experimenting with the ranges using our own recorded data, we chose to play a different chord every 0.03 μS. We played a C-major chord in the first range (0 - 0.03 μS), and increased the chord by one tone for every range above. This resulted in the initial chord function which calculated the average of 16 values, played the corresponding chord for 4 seconds and repeated the process for the next 16 values. An example can be heard in **Initial mapping - Chords**[11], of which the chords are visualized in Figure 2.

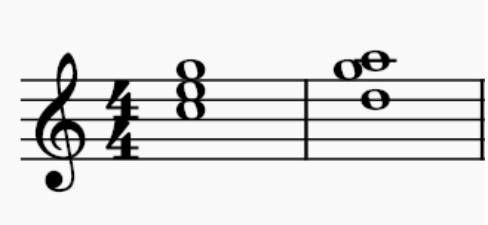


Figure 2. *Two bars of sheet music, visualising how the static chords are played for the initial mapping, as can be heard in* ***Initial mapping - Chords***[11]*.*

EDA Peaks - Sound Effect Using the Neurokit2 package, we subtracted the occurrences of EDA peaks. Using these indications, we wrote a function that played a sound sample when an EDA peak occurred. Chou-Ren et al. [15] also indicated EDA peaks and used a saturated bass sound. However, we wanted to include musical melodic elements and therefore chose a different sound: clinking chimes (hereafter referred to as twinkle sound) as can be heard in **Initial mapping - EDA peak**[12]. Namely, we wanted a soft sound that did not draw too much attention or was too loud but was distinguishable and added a nice sound effect to the music. Concluding, the function looped through the list and played the chime sound when an EDA peak occurred.

Heart Rate - Tempo For determining the tempo based on the heartbeat data, we tried several methods, after which we decided on using heart rate data of the Empatica, which we could interpret as the beat of the music since heart rate is also measured in Beats Per Minute (BPM). We played a drum sound for every beat and updated the BPM for every bar to prevent creating a restless sound, similar to Cheung et al. [14]. For this, we used

[11] https://youtu.be/Kxn2Mq3wXD4
[12] https://youtu.be/nrdckYvW4LY

the average BPM of 4 heartbeats. However, we agreed with Chou-Ren et al. [15] that playing the real-time heartbeat felt rushed and could be anxiety-provoking. Therefore, we changed the BPM to play at 75 per cent of the actual heartbeat since conveying a change in BPM is more important than playing the real-time tempo. An example of the beat indication can be heard in **Initial mapping - Beat**[13].

3.5.3 Gaining Expert Feedback

Using these three functions to create a sound effect for an EDA peak, background chord based on 16 EDA values and tempo based on 4 seconds of heart rate, we used our own recorded data to make biomusic, resulting in the initial mapping, which can be heard in **Biomusic - Initial mapping**[14].

We discussed the result with an expert in digital music; a PhD student in Computer Science, focusing on the Internet of Musical Things and working as a music producer, video editor, and in the fields of computer music, electronic art, and interactivity. Overall, he was enthusiastic about the idea of mapping the biofeedback to the musical elements but we agreed that this first mapping sounded a bit too busy and distracting. He proposed changing the sound of the EDA peak or turning down the volume, making it less prominent. In addition, he initiated looking for another way to play the melodic background music. For example, using a single-tone instrument such as a guitar or a saxophone to play lo-fi in the background, to make the chord in the background sound less static and more musical.

3.6 Second Mapping

Updating Chords Based on the feedback, we changed the chord function based on the heart rate values. Namely, the chord updated every 4 seconds, meaning that it did not align with updating the beat. For example, the chord changed halfway through a bar, possibly out of tune, resulting in a restless whole. We rewrote the function, so that at the beginning of every bar, it averaged the current and previous 15 EDA values, and played the corresponding chord for the duration of that bar. Similarly, we altered the heart rate function, so that it updated the BPM of every bar based on the previous 4 values, instead of statically changing every 4 seconds.

Broken Chords In addition, we experienced playing low-fi chords on a guitar and got inspired by playing broken chords: strumming the tones instead of statically striking all tones simultaneously. Therefore, we changed the chord function to play a broken chord every bar, consisting of individual pitches, with accompanying waiting times of eight or fourth notes, representing a strumming pattern of one chord on a guitar, as can be listened to in **Second mapping - Beat and chords**[15], visualized in Figure 3. This resulted in a function that played a broken chord on a guitar based on the HR and EDA values.

EDA Peak Sound Effect Since the EDA peak sound was deemed too prominent, we decided to change the sound effect into something softer and less prominent: a whoosh

[13] https://youtu.be/x3-MqJ5YzMc
[14] https://youtu.be/9ikkX_scHU0
[15] https://youtu.be/S7xEhBs-Pxo



Figure 3. *Four bars of sheet music, visualising how the broken chords are played for the second mapping, as can be heard in* ***Second mapping - Beat and chords***[15].

sound, similar to what Blain-Moraes et al. [11] and Cheung et al. [14] used to indicate respiration. This can be heard in **Second mapping - EDA peak**[16].

3.7 Workshop

Implementing the changes resulted in the second mapping[17], as can be listened in **Biomusic - Second mapping**[18]. However, variables such as which instruments to use, chords to play, ranges to use, sound effects to use and tempo indication could be changed, influencing the generated music. Therefore, we wanted to gain feedback from musical experts, that would think along the optimal way of creating the music. For that, we set up an interactive workshop, of which the consent form and questionnaire can be found in Appendix A.1, the protocol in Appendix A.2 and the slides of the workshop in Appendix A.3.

3.7.1 Participants

We recruited using purposive sampling, meaning that we selectively asked participants to join based on their characteristics. For our workshop, we selected participants who had experience with programming and playing or creating music, since this background knowledge allowed them to understand the code we wrote, think along technical possibilities and give more in-depth feedback, compared to participants without such background knowledge. The purposive sampling resulted in 4 participants aged 28 to 64 ($mean = 38.8$, $sd = 17.0$, 3 male and 1 female) of which two were professional software engineers, one was experienced with programming for over 10 years and one was relatively experienced with programming both for production-level code and scientific analysis. All participants play(ed) an instrument and two of the participants had experience with online music production.

3.7.2 Discussed Variables

The second mapping consisted of a broken chord, a drum sound at every beat and a whoosh sound for the EDA peak. We wanted to discuss different options for slightly changing these variables so that the optimal music would be generated. The variables we wanted to discuss in the workshop were: How to play the chords, Which chords to play, Which instruments to use, How to indicate EDA peak and How to indicate tempo.

[16] https://youtu.be/D_ciTJieNGs
[17] In the protocols in the Appendix, the "Second mapping" is referred to as "Current mapping"
[18] https://youtu.be/vwhnWsN7JR4



Figure 4. *Image showing the setup of the workshop.*

3.7.3 Content of the Workshop

After positioning all supplies, as can be seen in Figure 4, we welcomed the participants and explained our research focus and the content of the workshop, consisting of three parts.

Part 1. Definition of music The goal of this workshop was to gather opinions regarding the preferred music, based on different mappings of biofeedback to musical elements. Since the definition and concept of music are debatable, as can be read in section 2.4, we started by asking the participants to individually think about the concept of music and to write down elements on sticky notes that were important for something to be classified as "music". After discussing the elements, we organized and categorized the sticky notes, as can be seen in Figure 5. Quite some of the elements connected to music overlapped, with three out of four participants mentioning that music should contain a structure and convey or elicit an emotion. In addition, according to two participants, music should have a rhythm or regularity and some melody or pitch. However, defining the concept of music was deemed very subjective, with some disagreements between the participants, such as the criteria of music consisting of multiple instruments.

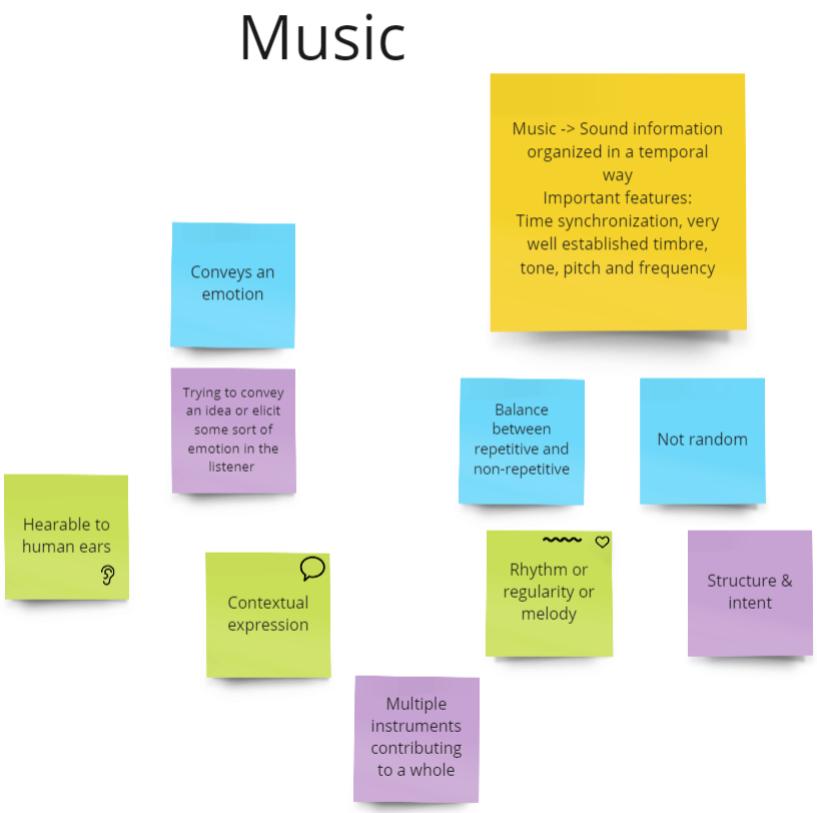


Figure 5. *Sticky notes containing elements that make something being defined as music, as brought up during the workshop.*

Part 2. Connecting musical elements and biofeedback elements For our mappings, we connected heartbeat to tempo, raw EDA values to chords and EDA peak to sound effects. However, we were interested in the participants' ideas regarding connecting biofeedback elements to musical elements. Therefore, we listed our requirements for the biomusic, based on the imagined future application of biomusic in conversations. We let the participants brainstorm in pairs, writing down their ideas on sticky notes and attaching them to the corresponding category. The requirements were as follows:

- it should not be distracting (it should be played at the background of a conversation)
- it should not be annoying to listen to for e.g. 15 minutes
- it should sound like music
- it should be based on the biofeedback of the other participant
- changes in the biofeedback of the participant should be noticeable

Not surprisingly, all participants agreed to use heart rate to influence the tempo or beat of the music, with one indicating that changing the heartbeat could also change the syncopic structure of the beat instead of just the tempo, as can be seen in Figure 6.

The use of the raw and peak EDA values was a bit more divided, with one participant per category stating that they could not think of any application. Three of the participants suggested controlling the melody or pitch using the raw EDA values, with one suggesting

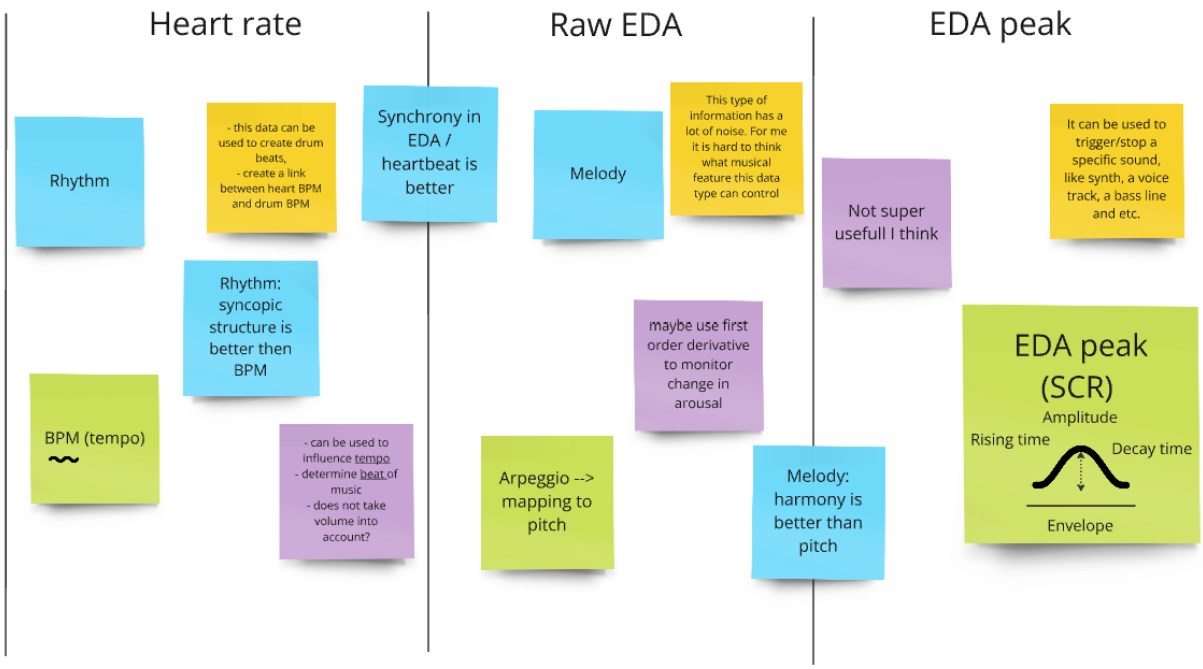


Figure 6. *Sticky notes containing musical elements that can be connected to biofeedback elements, as brought up during the workshop.*

adding more harmonies instead of just raising the pitch. Using synchrony in heart rate and EDA values between participants was deemed interesting, but not applicable in this study. The EDA peak could be used to trigger a musical track or align with the sound wave of the music.

Part 3. Experimenting with different variables The last part was a group discussion regarding the different variables that could be changed in the music. We played different mapping possibilities and used this as a starting point for the discussion.

To our surprise, all participants classified both the initial and the second mapping as "music". The second mapping required more attention and could be more distracting for the participants while conversing with others. However, the second mapping was perceived as more 'pop-ish', making it easier for people without musical knowledge to recognize and listen to. Below, the results per variable are listed.

- How to play the chords - The participants did not have a preference regarding strumming patterns, but suggested combining the initial and second mapping since the initial mapping blends more into the background and requires less attention. Opinions were divided: participant P1 indicated *"After 30 seconds I'm gonna start to find this annoying"*, while participant P4 indicated liking the strumming sound. In addition, they proposed altering the velocity and changing reverb, or creating a song in MIDI commands and altering these based on the biofeedback values, instead of generating new melodies. Overall, participants P1 and P3 indicated prioritizing variety in the sound, to prevent it from being annoying or boring.

- Which chords to play - Participant P1 suggested using the chords of a scale, instead of progressive major chords. Additionally, the participants agree to use the first-order derivative instead of raw EDA value ranges.

- Which instruments to use - All participants agreed that the guitar and piano were good options for the chords since these are familiar and will be less intrusive. However, strumming the broken chords could still be quite demanding, making participants P1 and P3 suggest using a combination of instruments or varying instruments. However, they highlighted that the music should not sound *"plastic"*. Another possibility was to use synthesizers or an organ sound for the static chords, however this may sound ominous.

- How to indicate the EDA peak - The participants indicated that the chimes sound of the initial mapping was a nice distinguishable sound. In contrast, the participants did not recognize the whoosh sound in the second mapping, making it a less appropriate option. Overall, participants agreed that the choice of the sound sample was very subjective. They suggested choosing our favourite sample after determining the way of playing chords, based on the frequency of the EDA peak occurring: if the peak occurs every other second, a less pronounced sound was favoured.

- How to indicate tempo - Lastly, all participants agreed on using some percussion or beat indication. Participants P3 and P4 agreed to like multiple drum elements but advised us to use a maximum of 2 or 3 elements to prevent people from finding it annoying. In addition, when combining multiple elements, we should make sure that it does not sound fake. Alternatively, participant P3 suggested varying the number of elements, for example using more drum elements when there is a major change in biofeedback.

3.8 Final Mapping

Alterations Based on the results of the workshop, we altered the second mapping to create the final mapping, which met the requirements set up in Section 3.4.2. We merged the initial and second mapping and altered the velocity of the individual strings on the guitar to let the music merge more into the background, becoming less demanding and distracting. Therefore, the guitar is playing a broken chord on a guitar (with the same strumming pattern as the second mapping, as shown in Figure 2), whilst an organ is playing the same chord statically in the background. Furthermore, we altered the chord function, so that it used the first-order derivative of the EDA values, instead of the raw values, meaning that the first chord played is always a C-major chord, and for every 0.025 μS distance from the baseline value, the chord changes one major chord up or down. For differences bigger than 0.1, the range increased exponentially, meaning that for bigger differences, the chords were less sensitive to change. Lastly, based on the relatively low frequency of an EDA peak occurring, we changed the sound effect for an EDA peak occurring back to the twinkle sound of the initial mapping, but lowered the volume, aiming to get a distinguishable but not overwhelming sound. An overview of the final mapping of biofeedback to musical elements can be seen in Table 2, and a sound example of the final biomusic is played in **Biomusic - Final mapping**[19]. Another sound example of the final mapping is played in **Biomusic fast - Final mapping**[20], illustrating the effect of a higher heart rate.

[19]https://youtu.be/BPCIe2-SoSo
[20]https://youtu.be/9jOA4KxePDw

Biofeedback element	Musical element	Implementation
Heart rate	Tempo of the music	Play a tom for every beat at 75% of the average of 4 heart rates. Take the average of the current and previous 3 values and play the average BPM for one bar. After playing the four beats, calculate the time that has passed and skip the corresponding values.
EDA values	Chord in the background	Play a broken chord during one bar, based on the difference between the baseline value and the average of the current and previous 15 EDA values. After playing one bar, calculate and skip the number of values that have passed.
EDA peak	Sound effect	Play a twinkle sound when an EDA peak occurs.

Table 2. *Table containing the final mapping, showing what biofeedback elements are connected to musical elements, and how these are implemented.*

(Non) Real-time data After hosting the workshop and creating the final mapping, we tried converting these functions into processing real-time biofeedback. However, the process of subtracting real-time feedback from the Empatica, cleaning, processing and converting this into music turned out to be non-fitting for the scope of this research. Therefore, we decided not to focus on real-time biofeedback anymore, but to switch to asynchronous communication, thus converting recorded data into music.

Data preparation We finalized the creation process by adding data-cleaning functions. For that, we checked for values that were out of range and used mean imputation to replace such values. For heart rate, the range of 40 - 120 BPM has been chosen, and for EDA 0 - 12 μS, since these values correspond with the average ranges in which the data would fall for a relaxed person; following the work of Cheung et al. [14].

After checking the data ranges, we upsampled the EDA values to 20Hz using the `nk.signal_resample()` function of the Neurokit2 package, since the frequency of 4Hz from the Empatica E4 was unsuitable for appropriate cleaning and use of the data, following the work of Chou-Ren et al. [15]. Adding to that, we used the `nk.eda_clean()` function to clean the EDA data, split them into phasic and tonic components by using `nk.eda_phasic()`, and detect the EDA peaks based on the phasic EDA values by `nk.eda_peaks()`. The heart rate data was not processed any further.

For cropping the biofeedback data, we created templates, which can be found in our **Supplementary Materials**[9], together with a demo of **Cropping voice message**[21] and **Cropping text message**[22]. In the template, the starting time and time stamps could be pasted, after which it indicated the values that had to be deleted (in orange), as can be seen in Figure 7.

[21]https://youtu.be/HH9DK9m036Q
[22]https://youtu.be/wfzH4n9NY04

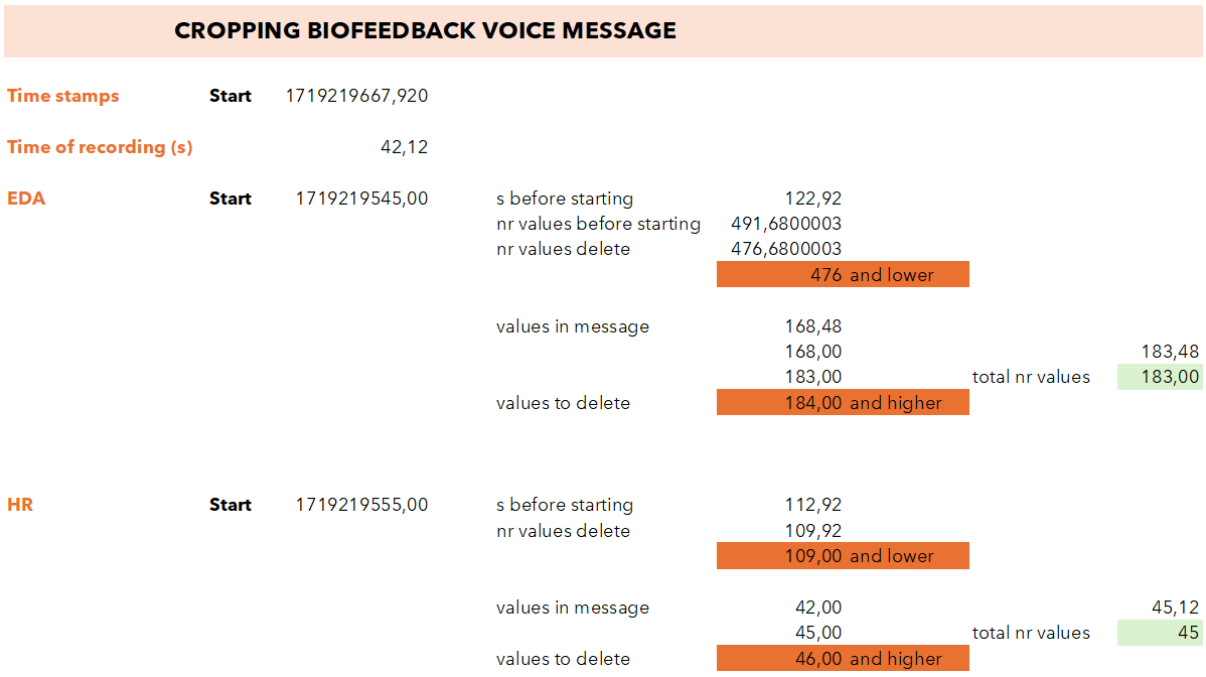


Figure 7. *Screenshot of the cropping biofeedback template, showing the row numbers that had to be deleted to crop the biofeedback for a recorded voice message, based on the time stamp and duration of the message.*

Final functions To conclude, we used two functions to create the music. The first function looped over the EDA values and played the twinkle sound when an EDA peak occurred. The second function looped through the heart rate values, and based on the average heart rate, it played one bar at 75% of the corresponding BPM. Within that bar, a chord was played based on the average EDA values. Finally, after playing one bar, the current index was updated based on the passed time within the bar.

4 Evaluation

Using the final mapping of the biomusic, we conducted a user evaluation aiming to answer the research question. For this, we performed a within-subjects evaluation, in which all participants tested all conditions: receiving a message with biomusic and without biomusic. We chose to use this setup to reduce the influence of the interaction partner on the experienced empathy and social connection. In addition, empathy and social connection are experienced differently per person, so letting every participant compare all conditions reduced this influencing factor and enabled asking the participants' feelings towards the biomusic being added. Finally, the within-subjects setup enabled a smaller number of participants, which was convenient for this setup since recruiting dyads of loved ones was challenging. For this research, the Ethics and Privacy Quick Scan of the Utrecht University Research Institute of Information and Computing Sciences was conducted (see Appendix B). It classified this research as low-risk with no fuller ethics review or privacy assessment required.

4.1 Pilot Test

Initially, we set up the user test consisting of two different voice messages, one with and without biomusic, and questioned empathy and social connection for both conditions. After performing the first three user tests, we altered parts of the protocol, resulting in the reviewed user test setup, described in subsection 4.3.

4.1.1 Participants

Since we focused on loved ones, dyads of close relationships were recruited. For this, convenience and snowball sampling were used, by asking acquaintances to join with one of their loved ones. The term *Loved ones* was defined as dyads that have a close relationship, for example, a romantic couple, close friends or family members. We recruited 3 dyads of participants, consisting of 2 senders and 3 receivers, aged 23 to 49 ($mean$ = 33.2, sd = 12.7, 1 male and 4 female). The senders provided the data, by recording messages for their loved ones. The receivers listened to the messages and the biomusic of their loved ones, after which they could share their experiences.

4.1.2 Measurements

For the user test, we used a combination of questionnaires and interviews to gather feedback about the effect of adding biomusic to the messages on perceived empathy and social connectedness. We used Qualtrics[23] to create the online surveys, and the questions and protocols of the initial protocol can be found in Appendix C.1.

Demographical Characteristics To get an impression of our participants, we asked about the basic characteristics of age and gender, but also the content and frequency of use of voice messages. In addition, the participants indicated the type and duration of their relationship with their loved one, and their common way of communication when not being physically present to gain an impression of the relationship and communication habits.

[23]https://www.qualtrics.com

Measuring Baseline Empathy Since the receiver answers questions regarding the perceived empathy towards the loved one, we added a baseline empathy measurement, by using the Brief Interpersonal Reactivity Index (B-IRI) [48]. This validated, shorter version of the IRI allowed us to measure the baseline empathy of the receiver, to check for potential deviations, which could affect people's ability to empathize. The B-IRI was added to the demographics questionnaire of the receiver.

Measuring Empathy and Social Connectedness In previous research, empathy and social connectedness were measured in different ways (see sections 2.2.1 and 2.3.1). Although scales such as the IRI [22] and EQ [6] have been widely used for measuring empathy, these scales focus on measuring individual empathy. During our study, we were interested in measuring empathy between people, specifically loved ones. Some questionnaires measure empathy between loved ones, for example, an alteration to the IRI: the Interpersonal Reactivity Index for Couples [92], or the Self Dyadic Perspective-Taking Scale [71]. However, such scales focus on the general feeling of empathy in relationships, while in our study we wanted to measure the effect of biomusic on the perceived empathy towards a loved one during an asynchronous conversation. For that, questions towards the feelings and current state of the other are needed. Therefore, we used the validated cognitive and identification empathy categories of the Consumer Empathic Response to Advertising Scale (CERA) [102, 122], of which we replaced their person indication of "The character" with "My loved one". The CERA included questions such as "I understand how the character is feeling", thus focusing on empathy towards someone during a specific moment.

Adding to that, we used the Inclusion of the Other in the Self Scale (IOS) [5] to measure social connectedness between people, since this is the most commonly used scale, being validated and standardised, and applicable to our study.

Interview In addition to these quantitative scales, we used semi-structured interviews to gain more insights into the experiences and feelings of the sender and the receiver, aiming to understand the reasoning behind the answers to the questionnaire.

The interview questions of the sender focused on the overall impression of using biomusic in communication, the ease of recording and the attitude towards sending and receiving biomusic, thus sharing biofeedback. The interview with the receiver was slightly extended, including questions regarding the effect of and feelings towards the biomusic that was added to the conversation, and comparing the conditions, as can be read in Appendix C.1.

4.1.3 Procedure

After recruiting the dyads, those were split into a sender and a receiver. The setup of the user test has been visualised in Figure 8, and consisted of four parts: preparing, recording, converting and listening. The protocols of the initial user test can be read in Appendix C.2

Preparing As explained in the Creation Chapter 3, biomusic was generated based on the biofeedback of the participants. When having consistent biofeedback, not much variation will occur in the music. In addition, the need for non-verbal cues and more information about a partner during remote emotional conversations is higher than for day-to-day

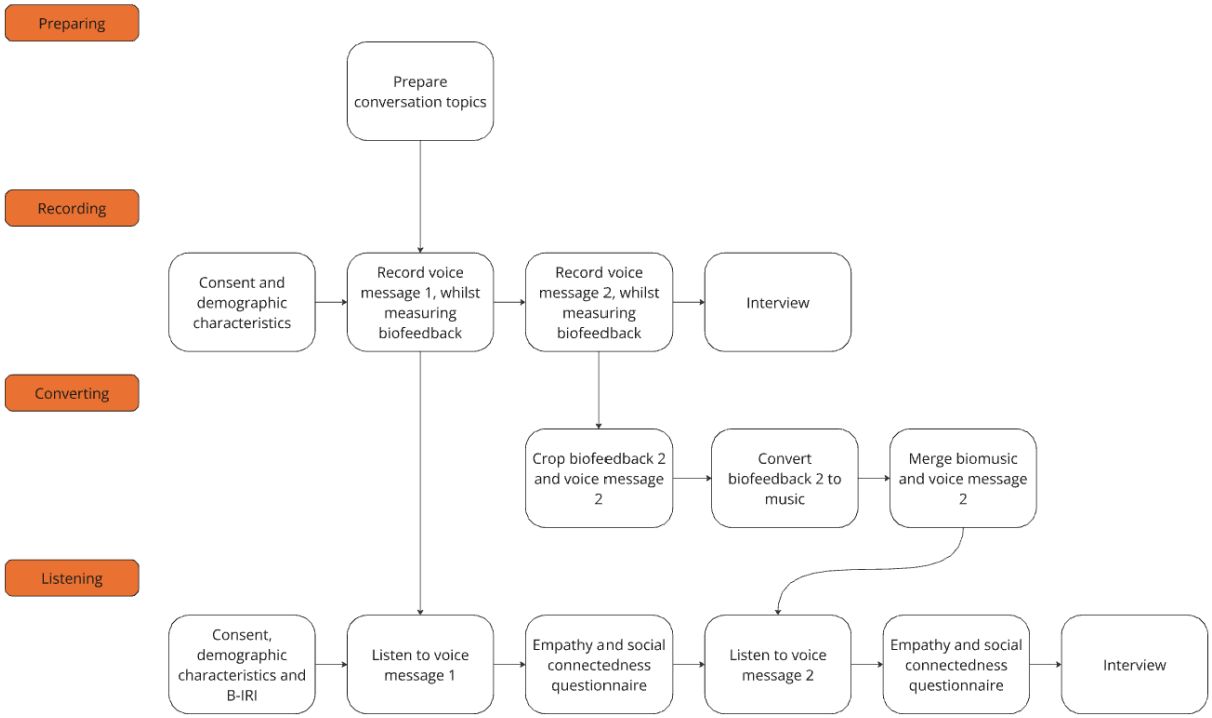


Figure 8. *Flow diagram visualising the protocol of the pilot test.*

conversations. Therefore, we intended the voice messages in the experiment to contain a certain emotion. We gained inspiration from the method of Cohen et al. [17] and Rojas et al. [94], both researching empathy between close relationships based on emotional conversations. Following their approaches, we asked the sender to prepare one or two conversation topics that could be used as input for the voice messages. The senders were told that the topic should be conversation-like, involving emotion or feeling, meaning that it should not be practical statements such as "I'll be home at 3 and pick up the groceries", but rather sharing emotions and feelings in a conversation-like setup. To gain inspiration, the senders were given a list of example topics, as can be found in Appendix C.3.

Recording After explaining the research setup, the sender started by giving consent and providing demographic characteristics, after which the Empatica was attached to their non-dominant wrist, following the Empatica guidelines. Following, the sender was asked to record two voice messages containing the same type of emotion, e.g. two enthusiastic messages, aiming to give the receiver a similar listening experience and limiting the influence of the content of the message. After starting the Empatica recording and voice recording, the researcher left to let the sender record each voice message in private. Finally, the session closed by asking interview questions. The setup of the sender user test can be seen in Figure 9.

Converting Following, the researchers cropped the second voice message and the corresponding biofeedback, and used the final mapping to convert the biofeedback into biomusic. This biomusic was merged with the second voice message, resulting in the first voice message containing only voice, and the second voice message containing both the voice and the biomusic. We decided to keep this order for all participants, following the work of Chou-Ren et al. [15], which argued that their pilot studies indicated that the participants



Figure 9. *Image showing the setup of the user test.*

did not treat the condition without biomusic seriously when coming after the biomusic condition, since they guessed it to be a "control" condition.

Listening Lastly, after explaining the research setup, the receiver started by giving consent and providing demographic characteristics. Following, they were left alone to listen to the first voice message and fill in a questionnaire regarding empathy and social connectedness. This process was repeated for the second voice message, after which the session closed by asking interview questions.

4.1.4 Results

After performing the user test with three dyads, we noticed that we were not measuring what we should measure. We observed during the interviews that three out of three receivers indicated that they mainly answered the empathy and social connectedness questions in the questionnaire based on the content of the voice message, instead of the addition of the biomusic, with Receiver PL_R3 indicating *"I feel now that my answers did not represent kind of what I experienced."*. Therefore, we decided to alter the protocol setup, aiming to measure the effect of adding biomusic to a message, instead of measuring the difference in content.

4.2 Alterations

Content and type of the message To avoid the content of the message influencing the perceived empathy and social connection, we decided to use the same voice message twice: with and without biomusic. Furthermore, we decided to focus on the qualitative data and the experiences of the receivers regarding adding biomusic to communication, since this provided more information regarding participants' attitudes towards using biomusic in communication, rather than trying to capture a difference in empathy using scales. To gain more understanding of the participants' attitudes towards using biomusic in

communication, we added another communication type: text message. Namely, sending text messages is one of the most often used ways of asynchronous communication, but, in contrast to voice messages, does not include biological information such as the intonation of a voice. Therefore, we were curious about the attitudes towards and potential difference between adding biomusic to both text and voice messages.

Selecting a photo Since we noticed that recording a voice message during the experiment was difficult for the senders, we decided to let the participants select a photo, containing a memory of their loved one, or showing something recognizable, about which they would record a voice message and write a text message. The photo also ensured a similar kind of content and emotion between both voice and text messages.

Balancing the conditions We showed the voice and text message to the receiver, with and without biomusic, but this time counterbalancing the conditions: half of the participants received the biomusic condition first, the other half received the 'normal' message without biomusic first. We decided to balance this since, in contrast with the pilot test, the content of the messages was the same, meaning that listening or reading the same message again could influence the experience and thus the results.

Altering questions Lastly, we extended the interview questions and added survey questions by directly asking about their general feeling towards the biomusic being added and its effect on empathy and social connection. This enabled us to focus on the reasoning behind participants' answers and to gain quantitative data regarding the effect of biomusic on empathy and social connectedness.

4.3 Reviewed Protocol

Implementing these alterations resulted in the reviewed protocol, as visualized in Figure 10. In short, the participants were split into a sender and a receiver, after which the receiver selected a photo. Based on this photo, the sender recorded a voice message and a text message, during which their biofeedback was measured. The experience of the sender was captured in the interview, after which the data were converted into music and added to the messages. The receiver listened to the voice message and read the text message with and without biomusic while looking at the photo, and answered a questionnaire regarding empathy and social connection after each condition. Finally, we questioned the experience of the receiver in the final interview. The consent forms and protocols for sending and receiving, including interview questions can be found in Appendix D.1, Appendix D.2, Appendix D.3 and Appendix D.4. The interview questions, the protocol for converting biofeedback into biomusic and the slides for the sender and receiver can be found in Appendix D.5, Appendix D.6, Appendix D.7 and Appendix D.8 respectively.

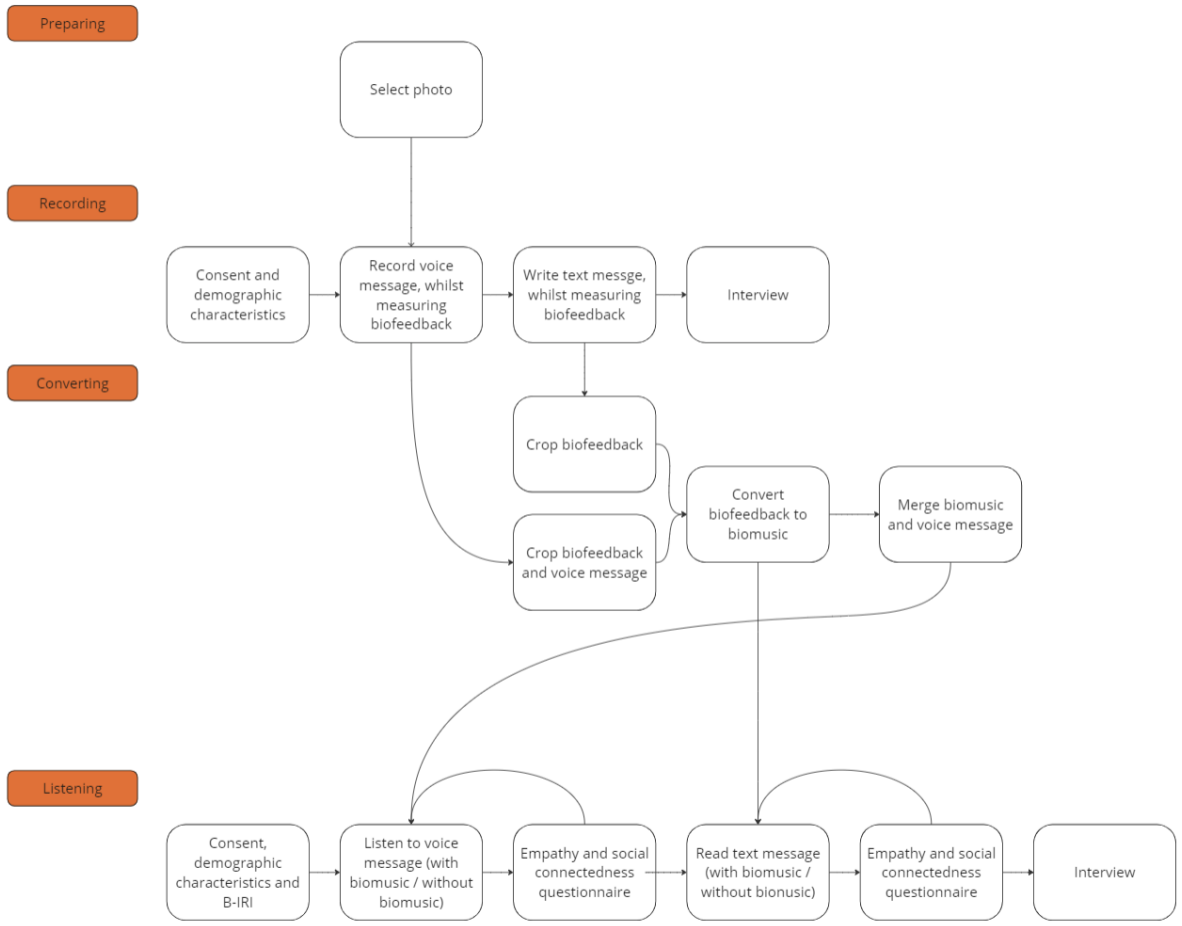


Figure 10. *Flow diagram visualising the reviewed protocol of the user test.*

4.3.1 Particpants

After altering the protocol, we performed the reviewed user test and recruited 17 dyads, consisting of 9 senders and 17 receivers, aged 18 to 49 ($mean = 28.9$ years, $sd = 9.2$, 13 male and 13 female) For analyzing the interviews, we decided to include the 3 pilot study dyads, since these contained similar questions, diving into the feelings and opinions of the participants towards the sound and addition of biomusic. This resulted in the following dyads being used for the analysis: Table 3.

Half of the dyads indicated being close relationships, four were romantic relationships and six were family bonds. The duration of the relationships ranged from 0.5 years to 45 years, with a $mean = 12.7$ and $median = 5.5$. The dyads indicated sending and receiving text messages very frequently, while for voice messages, this was more varied. Twenty per cent indicated never sending voice messages, and half of the participants rarely received a voice message, as can be seen in Figure 11. The voice messages and text messages were almost equally divided regarding content type, containing practical statements, sharing experiences and having conversations.

4.3.2 Data Analysis Plan

After performing the experiments, we analysed the qualitative and quantitative data in the following manner.

Sender	Receiver	Relationship	Duration
PL_S1	PL_R1	Family bond	45 years
S1	R2	Family bond	29 years
S2	R3	Close friendship	4,5 years
PL_S2	PL_R4	Close friendship	4 years
PL_S2	PL_R5	Close friendship	4,5 years
S2	R6	Close friendship	4,5 years
S1	R7	Romantic relationship	28 years
S3	R8	Close friendship	4,5 years
S3	R9	Family bond	21 years
S4	R10	Romantic relationship	6 years
S4	R11	Close friendship	6 years
S5	R12	Close friendship	5 years
S5	R13	Family bond	23 years
S5	R14	Family bond	21 years
S6	R15	Romantic relationship	4 years
S7	R16	Romantic relationship	30 years
S7	R17	Family bond	18 years
S8	R18	Close friendship	1 year
S8	R19	Close friendship	1 year
S9	R20	Close friendship	0,5 year

Table 3. *Table showing an overview of the participant dyads, including the ID's, the relationship type and duration. The pilot study dyads are indicated with PL_ in front of their ID.*

Empathy and social connectedness questionnaires For each receiver, we gathered data regarding the perceived empathy and social connection for each condition, using the CERA and the IOS scales. We tested the effect of the independent variables MessageType (voice message and text message) and Biomusic (with and without) and their interaction on the three separate dependent variables Cognitive empathy, Identification empathy and Social connectedness. In addition, we visualised and compared the answers to the direct empathy, social connectedness and liking questions.

Interview senders and receivers Following, we transcribed the interviews with the senders and receivers and translated them into English when needed. Since the experience and content of the user test were different, we decided to analyze these separately. We performed a thematic analysis following the work of Braun and Clarke [12], by coding each transcript to identify the topic of conversation. Following, we grouped the codes and identified (dis)similarities and themes, which we used to write the interview results. Ideally, qualitative analysis is performed by multiple researchers to increase the validity and reliability [18]. Unfortunately, this was not possible within the scope of this research, which resulted in the interviews being coded by one researcher.

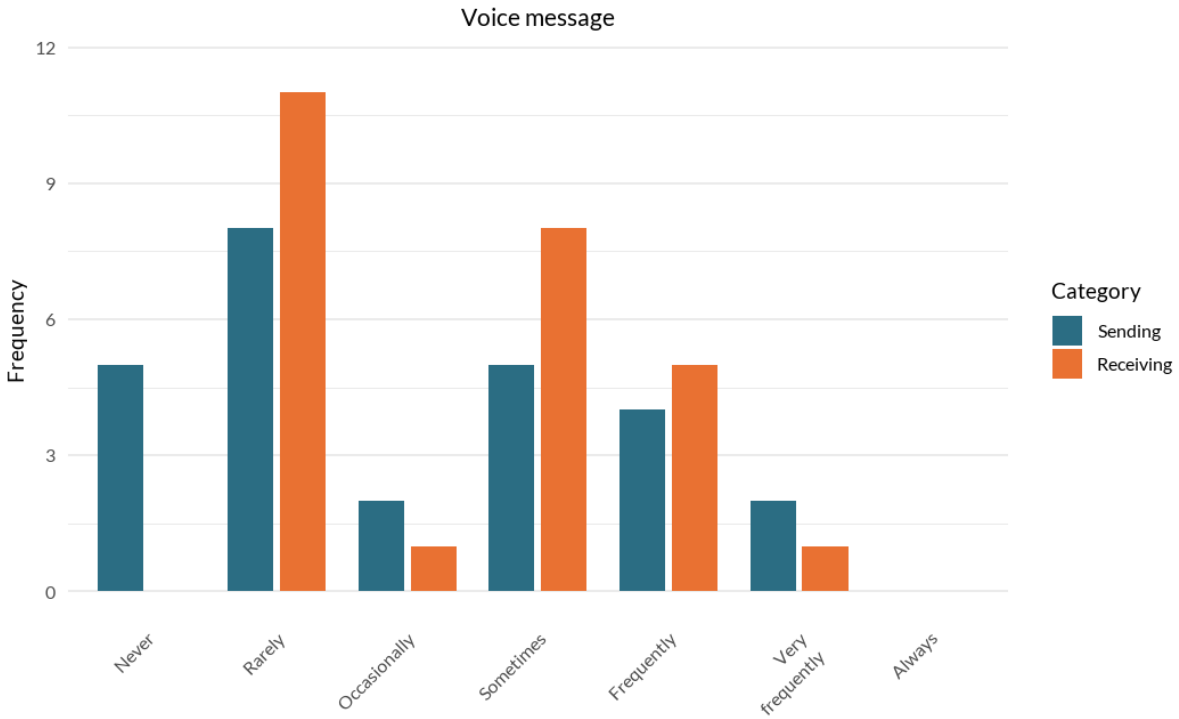


Figure 11. *Bar chart visualising the frequency of sending and receiving voice messages for all participants.*

5 Results

We used the quantitative data of the receivers to test for a difference in empathy and social connectedness and analyzed the interviews of the senders and receivers separately. Namely, these address a slightly different perspective: the receivers experienced the use of biomusic in two types of communication, whereas the senders expressed their feelings towards recording biomusic and their expectations regarding the use of biomusic.

5.1 Empathy and Social Connectedness Scales

The receivers answered the CERA and IOS questionnaires after each of the four conditions and indicated their attitude towards the biomusic being added to the message. The Shapiro-Wilk test showed normally distributed data for cognitive empathy and identification empathy ($p > 0.05$), and non-normally distributed data for social connectedness ($p < 0.05$). Levene tests showed a homogeneity of variance for cognitive empathy and identification empathy ($p > 0.05$). Therefore, we performed a two-way repeated measures ANOVA for cognitive empathy and identification empathy, and a non-parametric alternative for the social connectedness: the Aligned Rank Transforms (ART) [118]. The results of the ANOVA and the ART are shown in Table 4 and Table 5. The results of the cognitive empathy ANOVA showed no statistically significant effect of either MessageType, Biomusic and their interaction on cognitive empathy ($p > 0.05$). The results of the identification empathy ANOVA indicated that the main effect of messageType on identification empathy was statistically significant ($p < 0.01$). The results of the pairwise Bonferroni-Holm correction for MessageType on identification empathy showed that text messages resulted in significantly lower identification empathy scores than voice messages ($estimate = -0.368$, $SE = 0.111$, $t(16) = -3.309$, $p = 0.0044$). The Biomusic and interaction between MessageType and Biomusic did not significantly affect identification empathy ($p > 0.05$). Lastly, the results of the social connectedness ART indicated no statistically significant effect of either MessageType, Biomusic and their interaction on social connectedness ($p > 0.05$). To give an insight into the distribution of the dependent variables, those have been visualised using boxplots, as can be seen in Figure 12, Figure 13 and Figure 14.

	Factor	**Df**	**Sum Sq**	**Mean Sq**	**F**	p	
Cognitive Empathy	MessageType	1	0.2980	0.2978	1.368	0.259	
	Biomusic	1	0.2978	0.2978	1.704	0.210	
	MessageType:Biomusic	1	0.0331	0.0331	0.772	0.393	
Identification Empathy	MessageType	1	2.2980	2.2978	10.950	0.004	**
	Biomusic	1	0.7210	0.7206	2.755	0.116	
	MessageType:Biomusic	1	0.0919	0.0919	1.175	0.294	

Table 4. *Table showing the two-way repeated measures ANOVA results, indicating the effects of MessageType, Biomusic and their interaction on cognitive empathy and identification empathy. ** indicates a significant result where $p < 0.01$.*

Factor	Df	Df.res	F	Partial η^2	p
MessageType	1	48	2.103	0.04	0.154
Biomusic	1	48	1.894	0.04	0.175
MessageType:Biomusic	1	48	0.161	0.00	0.690

Table 5. *Table showing the Aligned Rank Transforms results, indicating the effects of MessageType, Biomusic and their interaction on social connectedness.*

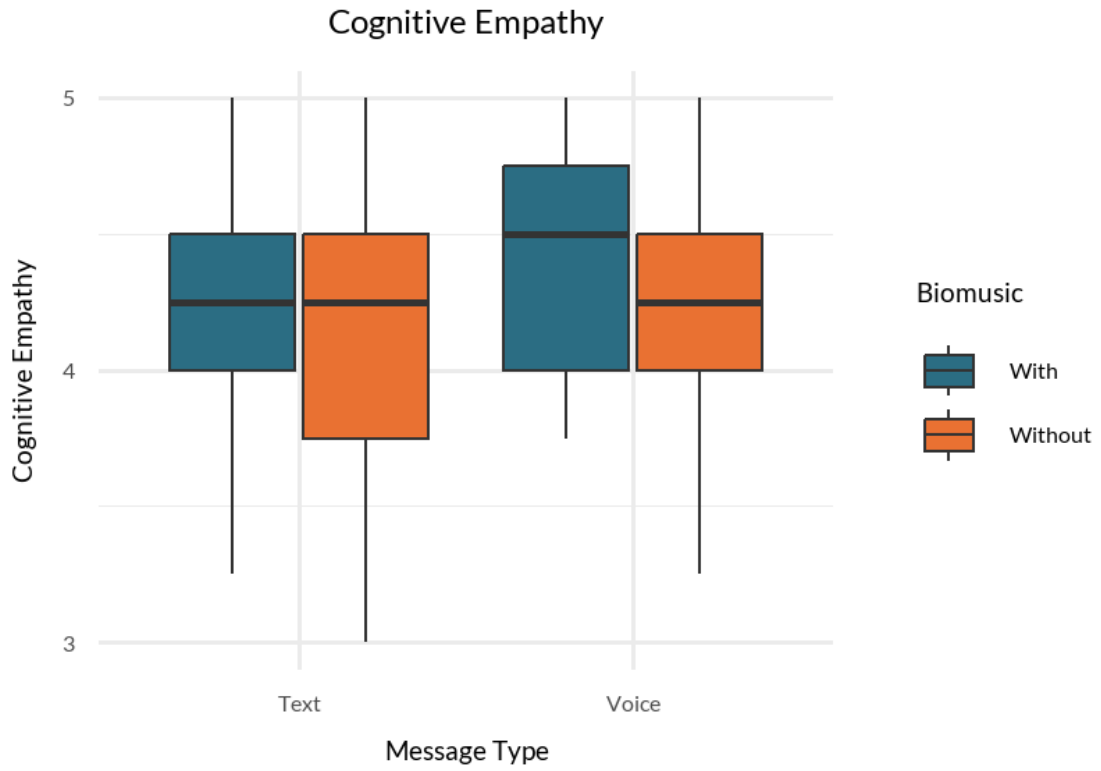


Figure 12. *Boxplot showing the distribution of cognitive empathy for each group, on a scale of 1-5.*

5.2 Direct Questions

In addition to the validated questionnaires, the receivers were asked to directly compare the text and voice message with and without biomusic and indicate whether they liked adding the biomusic (Figure 15) and whether the biomusic made them feel more or less emphatic (Figure 16) and connected (Figure 17).

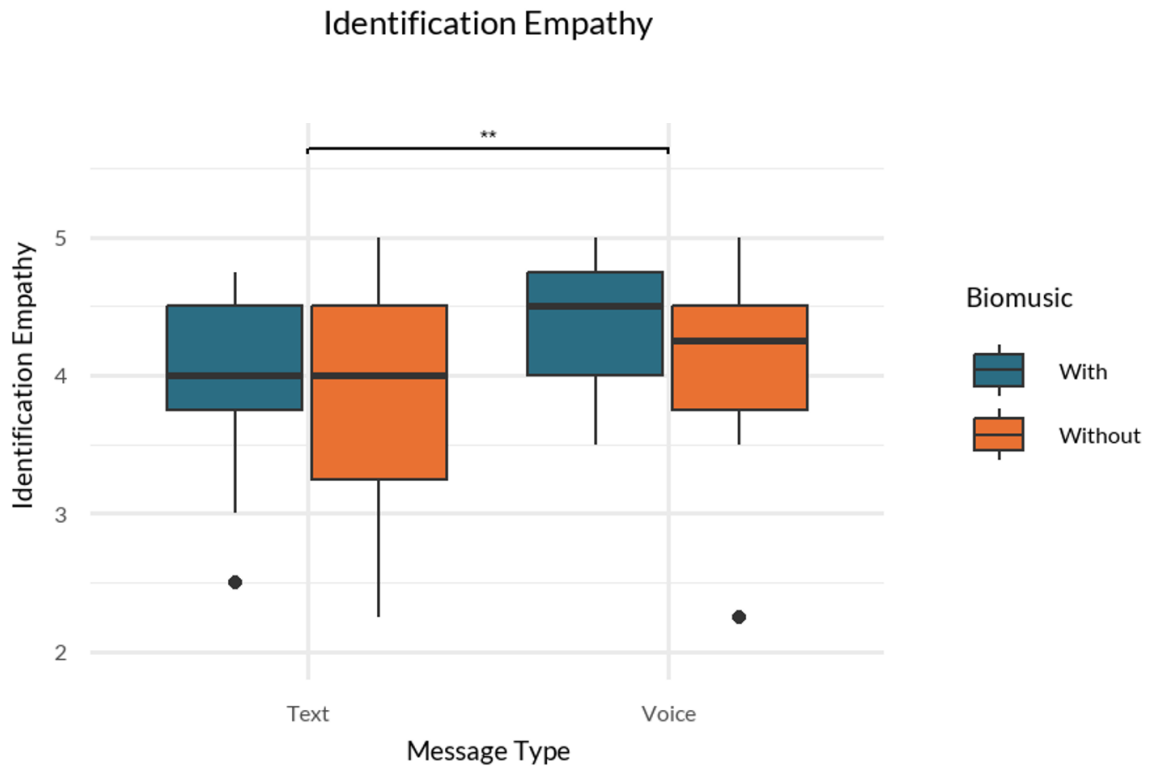


Figure 13. *Boxplot showing the distribution of identification empathy for each group, on a scale of 1-5.*

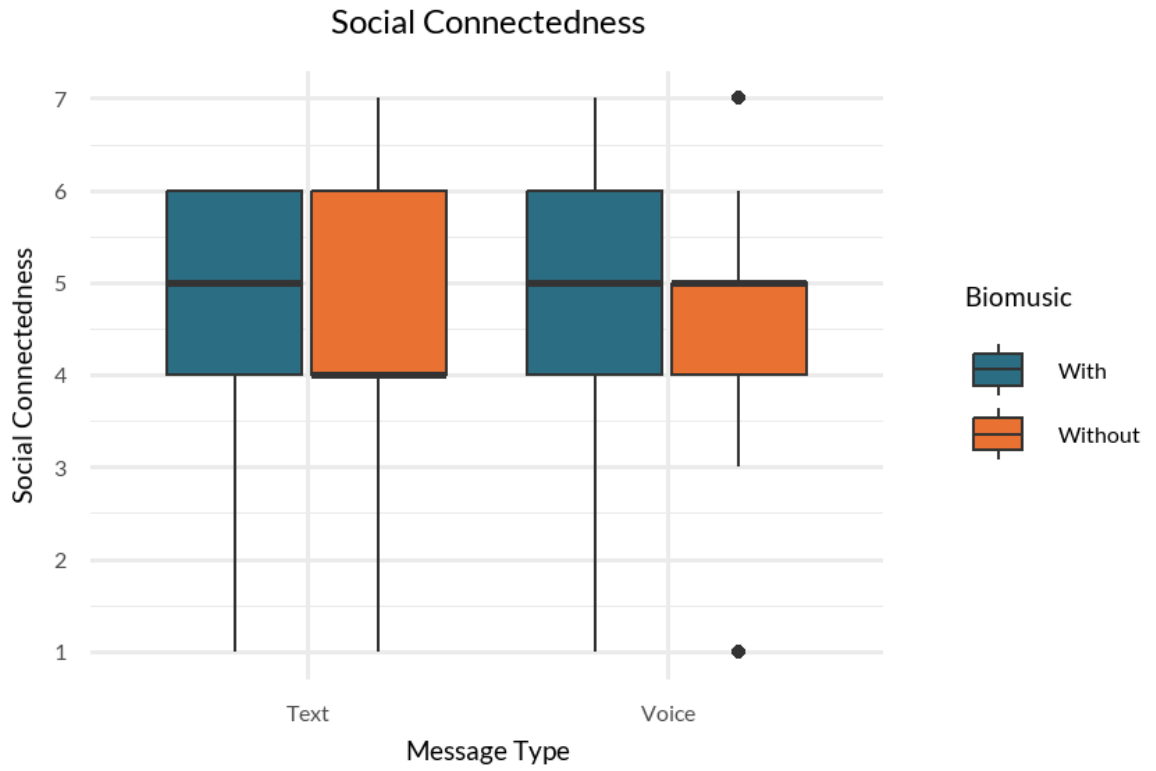


Figure 14. *Boxplot showing the distribution of social connectedness for each group, on a scale of 1-7.*

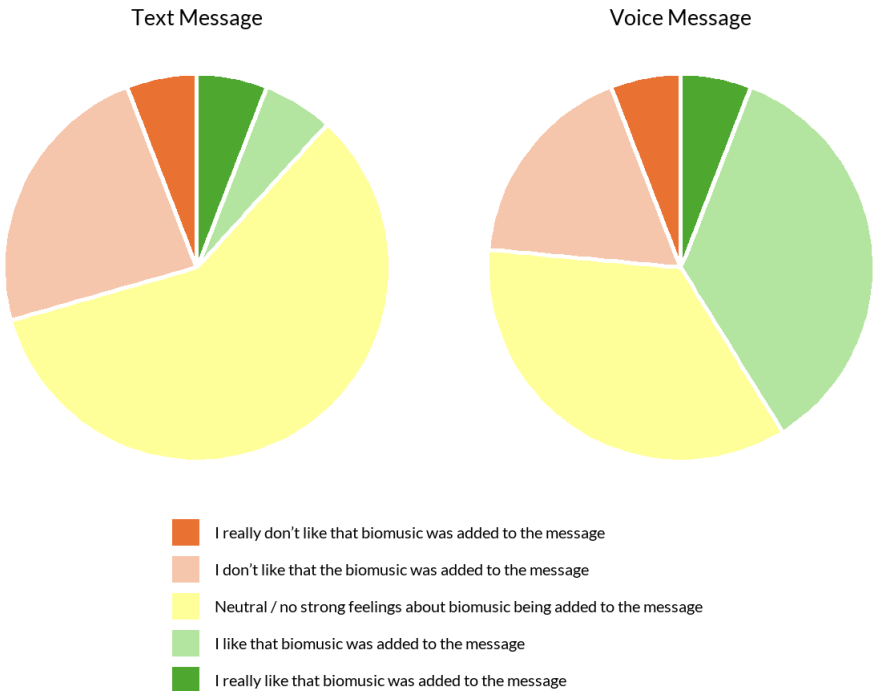


Figure 15. *Pie charts showing the distribution of the answers to the direct liking question, for both the text and the voice message.*

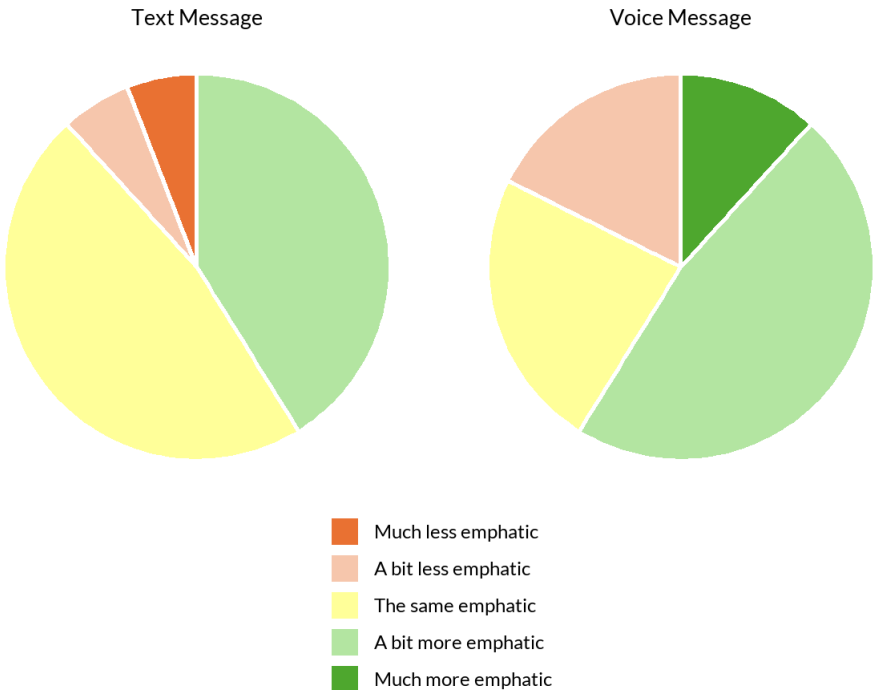


Figure 16. *Pie charts showing the distribution of the answers to the direct empathy question, for both the text and the voice message.*

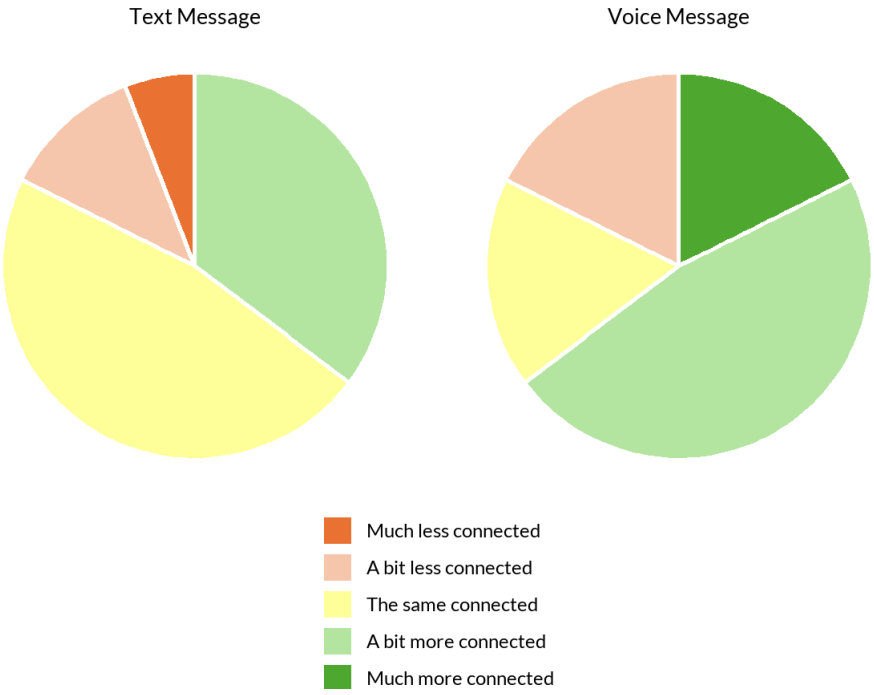


Figure 17. *Pie charts showing the distribution of the answers to the direct connectedness question, for both the text and the voice message.*

5.3 Interviews Senders

More than half of the senders expressed their curiosity towards the reaction of the receiver, with sender PL_S2 stating *"I think it's gonna be quite interesting. I'm very curious about what the receiver thinks of it, and if it has any effects."*. Still, imagining how it would be to use biomusic in communication appeared to be difficult. Overall, senders were positive towards the idea of using biomusic in communication, *"I think it's really cool that this exists."* (PL_S1), but one sender already focused on long-term disadvantages such as costing storage phone memory. The senders deemed recording the biomusic using a bracelet or smartwatch very easy, being a realistic possibility in the future for people who wear a smartwatch anyway. Having to purchase new hardware or wear another device would decrease the likeliness of using biomusic.

5.3.1 Using Biomusic to Convey Emotions

The senders were positive towards using biomusic in communication, but the majority specifically indicated that they would not use biomusic in every message. For example, sender S3 indicated wanting to use biomusic for special occasions instead of for each message, because using biomusic would become distracting (PL_S2). The moments in which the senders valued biomusic in communication all concerned emotional messages, thus not applying it to practical conversations (S6). For example, they would use biomusic in a special letter, difficult conversation, stressful situation or when talking *"heart to heart"* (S7). The main reason mentioned was that biomusic could be used to express or highlight certain feelings or be an option to show how much you care for someone (S3). Sender S7 suggested that biomusic could be used in emotional situations such as a funeral.

In addition, (bio)music is deemed to convey emotions: *"if you have fitting music*

that suits your mood, than it can convey something, than it can hit more" (S7). Biomusic converts numerical values into music, being easier to interpret (S5) and communicate emotions (S3). A downside to conveying emotions through biomusic was indicated by sender PL_S2: *"I think it gets more tricky because you can't really hide your emotions, it's just as if they can see into your brain."*. Similarly, sender S3 added that when using biomusic, you cannot hide things anymore. Therefore, the interaction partner should be carefully considered.

5.3.2 Interaction Partner

The senders had different interaction partner preferences for sharing and receiving biomusic. Two senders indicated that they solely wanted to receive biomusic from people they knew, but more than half of the senders indicated being comfortable receiving biomusic from anyone. However, receiving biomusic from close relationships or people they know would be way more interesting. On the contrary, the senders were less willing to share their biomusic with anyone, most preferring close relationships, due to the intimacy (S4). This difference in willingness to send and receive biomusic was summarized by sender S8 by stating *"I would be willing to, but I would prefer more where I will get the information from the other person."*.

Interestingly, sender S6 indicated wanting to share biomusic with direct colleagues because *"you are like a team, you work very much together. And with men mutually, it's not always very easy to understand each other, then it could be very helpful, I think."*. Other senders were a bit more hesitant to share their biomusic, preferring people they know (S4), close relationships (PL_S2, S3, S6), or people that they don't know at all: *"because they don't have any, like, it doesn't really matter what they know about me."* (S3). Similarly, three other senders did not feel sensitivity towards the music and indicated wanting to share biomusic with anyone, with sender PL_S1 indicating that it isn't a sensitive privacy issue. In addition, sender S9 indicated being willing to share biomusic with anyone, but *"it makes more sense to do it with people you know"*.

Senders S7 and S8 both did not base their willingness to share biomusic on the closeness of the interaction partner, but focused on the topic of the conversation, meaning that they would want to share and receive the biomusic while sharing something emotional (S7) or having difficult or stressful conversations (S8). Sender S5 had a similar opinion, being willing to share biomusic when feeling comfortable, and defines the current biomusic as not sensitive since it is still quite undeveloped.

5.3.3 Contexts to Use Biomusic

In addition to the interaction partner, the senders had different ideas about the use of biomusic in different contexts of communication. Sender S9 indicated having had a long-distance relationship, with which it could be valuable, *"especially there, because of course you only see each other and if you can add a certain layer to your messages using biomusic, I think your partner might then understand your feelings even more"*. Sender S5 also has long-distance relationships but indicated not being sure how biomusic could be applied, since the biggest obstacle in long distance is to make time for each other. However, sender S5 indicated that biomusic could definitely add to the closeness towards a loved one, despite the long distance. Furthermore, sender S4 suggested that biomusic could give a certain connection when communicating with a person you are not speaking that often.

5.3.4 Communication Type

When discussing the communication type in which biomusic could be used, some senders gave opposite answers: *"I feel like with phone call it's maybe less impactful because you can already interpret the other person's state of being a little bit from their voice."* (S5) versus *"So I would certainly apply it there, especially when calling, it is sometimes difficult to make that connection, because you cannot see each other's facial expressions, and then this might be a nice helpful addition."* (S6). Multiple senders also indicated being interested in using biomusic when calling, or sending voice messages. This preference for audio conversation was for some senders due to the lack of vision (PL_S1) and text messages being more often used for practical issues (S6). In addition, biomusic could be used in audio communication as a way to determine the feelings behind someone's words, as sender S3 indicated: *"sometimes someone says something but the tone of their voice doesn't actually resonate with what they feel. So biomusic would probably help it."*.

On the other hand, several other senders indicated that biomusic would be interesting to use in written communication, due to miscommunication that could arise when communicating via text. *"I think would be most valuable in text messages because people can interpret better probably what you mean."* (S3), with sender S5 indicating that adding biomusic to text messages would be the most functional. Where sender S9 indicated that both face-to-face and online communication could be positively influenced by biomusic, sender PL_S2 indicated that adding biomusic to live conversation would be overstimulating, redundant and *"probably just annoying after a while"*. Alternatively, sender PL_S1 liked the idea of just listening to the biomusic of a loved one when not having a conversation, for example, if you miss someone.

5.3.5 Music Taste

The use of the biomusic also depends on the sound, which should, according to senders S3, S7 and S8, be based on the emotion of the message. For example, some instruments represent happy sounds and others are sad (S3), and the sound and emotion of the biomusic should thus match the emotion of the message. In addition, as sender S5 highlighted, people have very different tastes in music, and what one might enjoy, someone else might not enjoy. Therefore, the sound of the music could influence the experience of the listener, resulting in several senders suggesting personalising the sound of the music so that it matches their musical preference.

Overall, the senders liked the current sound of the biomusic, being quite calm, which is good since the biomusic serves as background music, which should not be too distracting (S5). Furthermore, senders S4 and S9 suggested experimenting with different and multiple instruments and senders S5 and S6 indicated that they would change the twinkle sound.

5.3.6 Using Biomusic in the Future

For the biomusic to be valuable, some senders indicated that it would take some getting used to, being able to recognize patterns and interpret the meaning behind the biomusic. But if the biomusic would improve communication, *"Then I definitely want to use it, [...], I think communication is one of the most important things in a human life, if you can improve that through such a relatively simple step, then we should just do that, I think."* (S6).

5.4 Interview Receivers

Whereas the senders could only guess what it would be like to use biomusic in communication, the receivers experienced this in two formats: receiving biomusic with a voice message and a text message.

Overall, receivers reacted positively to the biomusic: they thought it was cool (PL_R5), funny (R16) and made them really happy (R20). However, for some receivers *"it was a bit weird"* (R10), because of the novelty, the sound effects (R12) or repetitiveness (R8). In general, the opinions of the receivers varied widely, with some having completely opposite opinions and arguments: *"I don't think it adds anything"* (R7), versus *"I think so it will be really, really useful"* (R18). In the following sections, we discussed the main takeaways from the receivers.

5.4.1 Empathy

Regarding the effect of biomusic on empathy towards their loved one, eight of the receivers indicated that the biomusic increased their empathy, eight indicated it had no effect and one indicated feeling less empathy towards their loved one. Receivers R3, R10 and R15 argued that the biomusic had no effect since they already felt much empathy for the sender, and because of the asynchrony of reading and listening (R15). Receiver R9 felt more empathy when there was no biomusic added to the voice message because without the biomusic they could hear their loved one's voice better. Being distracted by the biomusic was also one of the reasons receiver R11 felt less empathy when the biomusic was added, together with the music not suiting the personality of the sender.

In contrast, receiver R2 felt much more emotional and empathetic with the biomusic, just like receiver R8. receiver R6 also felt more empathetic when the biomusic was added, especially with the voice message, since this felt sweeter, while the normal voice message sounded more monotone. Three other receivers also felt more empathy with the voice message, with R20 arguing *"in voice messages, you don't really get to see someone's face, so you miss out on a lot of emotional cues that way, which might be replaced a little bit by their biomusic."*. Receiver R18 indicated feeling a huge difference in empathy, with the biomusic adding an extra layer. Receiver PL_R5 indicated that the biomusic resonated with the words of their loved one: *"it felt kind of like a truth behind the words. Yeah, that he really meant what he was saying."*.

Whereas some receivers felt more empathy with the biomusic added to the voice message, for receivers R9 and R14, the biomusic affected empathy while being added to the text message since this enabled them to relate more (R9). Namely, with a voice message, you already hear the voice, but a text message is more static (R14). Therefore, receiver R14 preferred the text message; not specifically because of the biomusic's current sound, but because music was added based on their loved one's biofeedback.

5.4.2 (Not) Distracted by the Biomusic

The difference in empathy for text and voice messages was influenced by the biomusic being distracting for some receivers, for example, because of the tempo of the biomusic or the twinkle sound when an EDA peak occurred, especially when there were a lot of them (R12).

Not unexpectedly, half of the receivers discussed the asynchrony of reading the text message in a few seconds, after which they had to listen for several minutes to the rest

of the music (R20). Receiver R9 expressed their frustration: *"I already read the message like ten times and I was like, when is your music gonna be done? How long did you take to write this message?"*. Therefore, the biomusic felt a bit redundant (R10) and less interesting (R7). In addition, receiver R15 indicated that it was difficult to link the biomusic to the message since, in contrast with the voice message, you don't know exactly where someone is in their story. For multiple receivers, this asynchrony led to the biomusic being distracting when added to the text message.

On the contrary, for five receivers, the biomusic was distracting while listening to the voice message, mainly because focusing both on the biomusic and the voice was difficult, with the music being a second thing you need to pay attention to (R7). That each individual has different preferences became clear when receiver R13 stated over the voice message: *"it helped me focus on what [Loved one] was saying, helped me to not be distracted as easily"*. Similarly, multiple receivers indicated that the biomusic was not distracting specifically while listening to the voice message, because they are both audio, and for receivers R6, R8 and R18 it was not distracting at all.

5.4.3 Social connectedness

The distraction of the biomusic caused receiver R11 to feel less connected. Furthermore, multiple receivers indicated that the biomusic did not have any effect on the connectedness they felt towards their loved one, with receiver R9 arguing that they already felt so connected with their loved one, that nothing could change that whereas with a friend, the biomusic may have had another effect on the connectedness. A lack of change in the biomusic made receiver R19 not feel a change in connectedness.

In contrast with empathy, more than half of the participants indicated that the biomusic increased the social connection they felt towards their loved ones. Receiver R8 indicated feeling more connected with the biomusic added to the text message because with a text message, you don't know someone's intentions or feelings. Most of the receivers indicated feeling more connected with the biomusic added to the voice message: *"the words come in even more"* (R15), *"because I know it was his heart rate"* (R3). The biomusic confirmed (R10) and emphasized (R16) the emotion, and receivers R2 and R18 also experienced more emotion when the biomusic was added to the messages, with receiver R18 highlighting that the biomusic added a layer of emotion while usually, their loved one's expression is quite blank.

5.4.4 Type of Communication

Based on the effectiveness and the experience with the biomusic added to the text and voice message, the majority of the receivers preferred adding biomusic to audio conversation. In addition to voice messages, some receivers expected that adding biomusic could also be interesting for synchronous conversation, such as calling or just listening to someone's biomusic without having a conversation, whereas others preferred asynchronous communication, for example through using text messages. One thing all receivers did agree on was: *"I don't think I would want it all the time"* (R6). They preferred having the possibility to turn the biomusic on or off, and would especially not add it to practical conversations.

Some receivers indicated specific situations or communication in which they would value adding biomusic, for example for reliving past experiences (R13), on radio or television (R20), in church when someone is preaching (R2) or for dating or making new

friends (R18). In addition, receiver R18 was very enthusiastic about using biomusic in their long-distance relationships: *"it's not the replacement of a real hug or a kiss, but it still adds something way more than just an audio note"*. Similarly, several receivers valued biomusic in long-distance relationships they have or imagined having. In addition, receivers R3 and PL_R5 indicated that they would use biomusic in communication with loved ones they do not see often.

Following, multiple receivers suggested that biomusic could be valuable in situations where communication is poor (R8), for people having difficulty experiencing empathy (R9) or expressing themselves (R14). In addition to communication for people with intellectual difficulties, biomusic could also be used in medical situations or with physical injuries, such as for blind people. In addition, receiver PL_R1 suggested using biomusic in communication with people with aphasia or dementia, since they can have trouble talking and expressing feelings, where biomusic can provide information. Similarly, receiver R18 valued the use of biomusic for people who are going to pass away to communicate with their loved ones or *"maybe recording the last moments of their biosignals and giving that audio recording, turning into a something symphony to their loved ones. It might give them relief."*

5.4.5 Emotional conversations

Furthermore, receivers indicated that the biomusic confirmed the emotion that was conveyed through the message (R10, R17), added feeling (PL_R5), and was an understatement (R18). For receiver R15, the biomusic made the message more romantic, reinforcing the feeling and the message. Therefore, multiple receivers suggested using biomusic in emotional conversations, since it can provide more context (R12) and help improve communication (R17). The biomusic could help to understand the emotions of the sender (R6, R15), especially in situations where the emotions and the words that are spoken are not the same (R8, R12), for example, when being sarcastic or not truthful (R8), when the person is not that expressive (PL_R5, R18) or when they are pretending that no emotions are involved (R15).

Receivers did not agree on the type of emotion with which biomusic could be used. All messages in the experiment contained happy emotions, making it hard for some participants to imagine how it would be like to have biomusic added to different emotional conversations. Receiver R9 would find it helpful to use biomusic in sad messages, for example when responding or sharing something difficult, in situations where they don't know what to say. Receiver PL_R5 shared the interest in using biomusic in serious messages,*"but on the other side, maybe it would be a little bit too much, too intimate"*, which agrees with the feelings of receiver R17. The latter is also the reason that receivers R14, R15 and R20 did not like to include biomusic in sad or angry messages, *"you would probably want to get a message which is full of happiness or love or whatever emotion and then you would actually like to emphasise that using biomusic. But when somebody's angry, you probably already get the point. You're like, let's turn this biomusic off as quickly as possible"* (R10).

5.4.6 Interaction partner

In addition to the topic and type of communication, the interaction partner influenced the preferred use and applicability of the biomusic in communication. As discussed in the previous section, the biomusic was deemed sensitive by several receivers: *"someone gets*

really an insight on what's going on with you. So in that way, it's kind of vulnerable" (R9), and you don't always want to share how you are feeling (R14). Receiver R20 and PL_R1 noted that the current biomusic is auralizing information that is usually not visible, which also brings an aspect of privacy and sensitivity. Using biomusic is especially vulnerable since you cannot alter or hide your emotions (R10), making receiver PL_R1 reconsider using it. The sensitivity, intimacy and vulnerability involved when using biomusic in communication made twelve receivers prefer to share biomusic only with close relationships, of which some specified only with very close (R19), the intimates (PL_R1) or family (R13). Alternatively, receiver R4 would not share biomusic at all, and five receivers would not send it themselves, *"but if they want me to do it, then I wouldn't mind, if they are close to me."* (R3).

However, not all receivers preferred using biomusic (solely) in close relationships: others indicated that they would not mind sending their biomusic to non-close relationships (PL_R5) or just anyone who wanted to listen to it (R8). Receiver R9 indicated that sharing biomusic is vulnerable, being a reason to send it to people close, but *"at the same time, I'm thinking about the people who are close to me, don't need that 'cause they know me"*. This is in line with receiver R11, being interested in using biomusic with for example colleagues. This is exactly the opposite of receivers PL_R1, R7, R10, and R14 who indicated not wanting to share biomusic in work situations: *"I can't even bear the thought"* (PL_R1). However, there appeared to be a difference in willingness to share and receive biomusic, with receiver R10 stating *"Like, I would never send that to my boss, you know, but like to see through this thick wall, you know, of non-emotions. It would be great, right? But the other way around? No, no way."*. That difference in sharing and receiving biomusic also applied to receivers PL_R5, R6 and R20, who would want to receive biomusic from more people than they would want to share it with, such as people further away or strangers, to understand their intentions and emotions more (R6). Several receivers indicated not being interested in receiving biomusic, meaning that receiver R9 was the only receiver more willing to share than to receive biomusic.

5.4.7 Sound of the music

Overall, the receivers were positive about the sound of the biomusic, with some suggesting small changes such as lowering the volume or making the end of the music a bit less abrupt. The most frequently named element was the twinkle sound for the EDA peak. Six receivers suggested changing this, for various reasons, for example because it was too present and distracting, disrupting the sound, being distracting because of the frequency or because it was associated with cuteness and happiness. Receivers R5 and R12 suggested adding more variation in the chords and receiver R9 proposed a less present way of playing the chords, while on the contrary, receivers PL_R1, R11 and R15 indicated that the current biomusic sounded calm and neutral. Changing the guitar to some other calm-sounding instrument such as a piano or a flute was suggested, but most of all, seven receivers indicated that the sound of the biomusic should match the emotion of the message. In addition, the biomusic could be changed to match the music taste of the receiver (PL_R1, R16) or the personality of the sender (PL_R5, R11). One receiver indicated getting nervous because of the beat (R3) and scared of the biomusic being added (PL_R4), while others indicated that they could not really distinguish change. In addition to those receivers suggesting changes, seven receivers indicated that they liked the current biomusic and would not change anything.

5.4.8 Using Biomusic in the Future

When discussing the future use of biomusic, receiver R18 suggested combining the biomusic with some visualisations, and receivers R15 and R20 indicated that when using biomusic in communication more often, we would get used and it would coincide with our communication (R15); we would be able to interpret the meaning of the sound better, making it super interesting to use (R11), and receivers R10 and PL_R5 highlighted the potential of the biomusic because of the ease of recording and implementation.

Seven receivers indicated that they would not use biomusic in communication, since it did not add anything (R7) or felt unnecessary since the tone of their voice already told quite a lot (R9). Receiver R14 indicated getting bored or annoyed by it pretty soon, receiver PL_R4 indicated getting scared because of the sound and for R11 it felt like romanticising and in that way manipulating reality. Receivers R2 and R8 specified not using biomusic for daily conversations, but maybe in conversations in which you would want to convey or recognize an emotion. Where receiver R12 was still doubting the use of biomusic in communication, other participants valued the biomusic and were enthusiastic about its use in general and specific types of communication, as discussed above; *"I think so it will be really, really useful"* (R18).

6 Discussion

As shown in the results section, the opinions towards using biomusic in communication differed widely. Statistically, no significant effect of the biomusic was found regarding empathy and social connectedness. We did find that receivers felt more identification empathy with the voice message compared to the text message, which is not surprising since the voice message already contains more information such as intonation and voice. However, this significant difference could also be due to a novelty effect of the voice message, since we see in Figure 11 that most of the participants rarely receive a voice message, which could have caused more empathy when they listened to a voice message of their loved one during the experiment.

Interestingly, the answers to the direct questions showed that the majority of the receivers were not that enthusiastic towards adding biomusic to text messages, but were more positive about adding biomusic to voice messages. Remarkable is that a relatively big part of the senders imagined adding biomusic to text messages as valuable since this could improve interpretation and help conveying emotions. However, the majority of the receivers highlighted the asynchrony of the biomusic with the text message: reading the message in several seconds while the biomusic lasted a few minutes, resulting in them disliking the biomusic being added to the text message.

By answering the direct questions, the majority of the receivers indicated feeling more emphatic when the biomusic was added to the voice message, in contrast to what was measured using the CERA questionnaire. Adding biomusic to a text message was deemed less effective regarding empathy, and connectedness. Again, the majority of the receivers indicated feeling more connected when the biomusic was added to the voice message, in contrast to what was measured using the IOS questionnaire. The results of the direct questions matched the interview results and showed that the majority of the receivers preferred adding biomusic to audio communication and indicated that it increased their empathy and social connectedness, mainly for the voice message. However, for several other receivers, the biomusic did not really affect empathy and social connectedness or even decreased those feelings. This was partly due to the biomusic being distracting for some receivers, mainly during the text message but for others with the voice message.

In addition to the message type, the interaction partner influenced the preferred use and effect of biomusic in communication. As expected, the majority of the participants indicated wanting to use biomusic with close relationships since they deemed the information and biomusic quite personal. However, some participants valued the use of biomusic with people further away, for example, to gain an understanding of their intentions. Thus, biomusic could be used to express emotions and feelings and share intimate information, which made several participants suggest using biomusic in long-distance relationships or with people with intellectual difficulties.

The main takeaway of the interviews was that participants deemed biomusic interesting to use on special occasions in asynchronous communication, such as emotional conversations. It could enhance the feelings of social connection, empathy and understanding, but would not be interesting to use in every day (practical) conversations. These are however only expectations, participants indicated not being able to fully imagine what it would be like to use biomusic in communication, so that they would like to experience that first.

6.1 Answering the Research Question

The question we aimed to answer through this research is the following:

How do loved ones experience using biomusic in communication and how does this affect their empathy and social connectedness?

Based on the results of the questionnaires and interviews, we can conclude that there is a wide variety of opinions towards using biomusic in communication. Whereas one feels like biomusic does not add anything and only distracts from the message, the other is very enthusiastic. Overall, the participants were positive towards the sound and application of biomusic in communication. They indicated feeling a bit more empathy towards and socially connected with their loved one because of the biomusic being added to the voice message. On the contrary, the biomusic was deemed less valuable in written communication, where it impacted empathy and social connectedness less between the dyads. The participants indicated being curious towards using biomusic with loved ones on special occasions and emotional conversations and suggested broadening the application to include other types of communication and relationships.

6.2 Contribution and Comparison with Literature

After answering the research question based on our study, we compared these results with the findings in the literature, as described in Chapter 2.

Sensitivity Firstly, the participants highlighted the sensitivity of (sharing) the biomusic, with the majority indicating solely wanting to share biomusic with close relationships, also indicating that this would be the most meaningful. This aligned with the findings in the literature ([52, 66, 84]), being the main reason to focus on the communication between loved ones in our study. Alternatively, several participants valued sharing biomusic with people further away, or for example in work-related situations.

Empathy and social connectedness Furthermore, our results showed that participants indicated feeling a bit more emphatic and socially connected because of the biomusic and suggested using the biomusic in emotional conversations to gain more understanding of each other's feelings and emotions. This is in line with the findings of multiple studies towards sharing biofeedback amongst close relationships through remote communication using physical devices ([32, 94]) or online communication ([41, 67–69]). Namely, those showed that sharing biofeedback stimulated empathy and social connectedness, increased awareness and increased emotional perspective-taking. However, our results did not show statistically significant effects between cognitive empathy, identification empathy and social connectedness levels, and for several participants, the biomusic did not add anything at all.

Biomusic The most direct comparison we could make with literature was with the three studies researching the effect of biomusic in communication, despite those having a slightly different focus. Blain-Moraes et al. [11] and Cheung et al. [14] researched the effect of biomusic on communication between people having intellectual disabilities and their caregivers. Both created the music in a similar way as our research, using multiple biofeedback elements and connecting those to musical, melodic elements. Their results

showed that the biomusic positively impacted communication, causing an improvement in their interaction and perceptions of the person. In addition, they were able to accurately distinguish emotions based on hearing the biomusic. These results align with the results of our study, despite the difference in study setup regarding interaction type: they solely included hearing the biomusic, without including spoken or written text.

Chou-Ren et al. [15] were the first to research (non-melodic) biomusic during a conversation and showed that listening to both real and synthetic biomusic increased empathy and closeness between the participants. Fake biomusic having the same effect as real biomusic could imply that measuring biofeedback is not needed. However, the participants were not aware of the biomusic being fake, which is not a realistic setting and implementation for possible future applications of biomusic in communication. Therefore, we researched the effect of real melodic biomusic on remote communication between loved ones. We gained insights from both the sending and receiving perspectives of using biomusic in communication for two different types of communication: text messages and voice messages. Therefore, our study related to and extended existing literature and provided new insights into the use of biomusic in communication.

6.3 Limitations

The limitations of the described creation of the biomusic and user evaluation must be considered.

6.3.1 Creation of the Biomusic

The results of this study regard the effect of our type and sound of biomusic, which we created based on trial and error, expert feedback and a workshop. For the expert feedback and workshop, we used purposive sampling, which is based on the researcher's subjective judgement. In addition to this bringing observer bias, all participants can be categorized as WEIRD: being from Western, Educated, Industrialized, Rich, and Democratic societies [43]. Based on this cultural background, they gave feedback and suggestions, based on which we created the music. However, music taste differs per person, country and culture [99], meaning that if we had gathered feedback from another or more diverse sample, this would have resulted in different feedback and thus a different type and sound of biomusic.

In addition, we chose to use two biofeedback elements, namely heart rate and EDA. However, biomusic could have been created using multiple or different biofeedback elements, such as respiration or temperature, which would have resulted in another type of biomusic. In addition, other musical elements could have been used, such as other instruments, sound effects and tempo identification. All decisions regarding biofeedback and musical elements led to the final mapping, which was used during the user evaluation. However, other decisions and another type of biomusic could have resulted in a different experience of its use in communication and another effect on empathy and social connectedness, meaning that the results of this study are not generalizable for all types of biomusic.

In addition, the technical way of creating the biomusic can be debated. We used the Empatica E4 for physiological data sensing, however, as stated before, other sensors appeared to be more reliable for sensing EDA. Therefore, the inaccuracy of measuring biofeedback could have influenced the sound of the biomusic, and thus possibly conveyed an inaccurate change in the biofeedback of the sender, which could have influenced the

experience of the receiver. Therefore, we recommend to verify the results by performing additional studies using other sensors.

When processing the biofeedback for creating the music, we updated the biomusic every bar and averaged the values to limit the influence of fluctuating data. In addition, we indicated the tempo of the music at 75% of the heart rate to avoid a stress-evoking feeling. However, these decisions lead to the biomusic being not one-on-one representing the physiological data of the participants. Furthermore, the functions we wrote and ranges we set for changing the chords influenced the eventual sound of the biomusic. Therefore, we recommend experimenting with the update frequency, EDA ranges and heart rate tempo, and gathering user feedback, aiming to find a balance between accurately representing the biofeedback and creating a nice-sounding biomusic.

By playing the biomusic to the receiver, we aimed to convey a change in the physiological state based on emotion from the sender. However, we could not distinguish different kinds of emotions, such as the sender being sad or happy. Therefore, the biomusic conveyed different changes in emotion in a similar way, making the interpretation of the biomusic more difficult for the participants. Therefore, identifying emotions based on biofeedback could be explored in future studies, together with a corresponding sound of biomusic.

6.3.2 Evaluation of the Biomusic

Our sample consisted of 29 participants, of which 20 receivers indicated their perceived empathy and social connectedness. Since this sample is relatively small, the results of the statistical tests could be debatable. In addition, we used convenience and snowball sampling methods for recruiting participants, which led to a non-diverse sample regarding for example social norms, ethnicity, culture and educational level. Similar to the participants of the expert feedback and workshop, almost all senders and receivers can be categorized as WEIRD [43]. Their background influenced their opinion towards the sound of the music, and possibly towards the use of biomusic in communication, together with the perceived empathy and social connectedness. The results of this study therefore cannot be generalized to other populations.

Within the sample, the type of relationships of the dyads differed, with half of the dyads defining their relationship as a close friendship and only four being romantic relationships. Since the participants highlighted the sensitivity of sharing the biomusic, the results of the biomusic on empathy and social connectedness may differ per relationship type.

During the converting process, we faced some technical challenges using the Empatica E4, sometimes measuring zeros in EDA. Since the EDA values were generally very low, we could not determine whether those were missing or incorrect values, thus we kept them as if. However, these values influenced the chords that were played in the biomusic, possibly not accurately representing the sender and influencing the feelings of the receiver.

While testing with the receiver, we measured empathy and social connectedness by using the CERA and IOS scale. Since keeping the scale intact was deemed important, the formulation and questions of these scales were not fully applicable in the user test setup, thus possibly not representing the actual feelings of empathy and social connectedness of the receivers. In addition, we asked the receivers to indicate whether the biomusic made them feel more or less emphatic and socially connected with their loved ones. However, the concepts of empathy and social connectedness could have been perceived differently

amongst the participants, introducing subjectivity in the answers.

Lastly, we did not limit the senders in selecting a photo and conversation topic, resulting in all senders choosing a happy memory or emotion. Therefore, all receivers experienced receiving biomusic in communication with a happy emotion, meaning that we could not get an accurate understanding of the effect of biomusic in conversations with another emotion, making the results less generalizable. Furthermore, we tested solely with two messages in a controlled setting, while this may not provide the most representative results of using biomusic in communication.

6.4 Future Work

Following the results and limitations of our research, we suggest further researching biomusic in communication. Specifically, researching biomusic between loved ones with different types of emotions, for example by letting them recall a sad memory. This would give more insights into the effect of biomusic on tense communication, resulting in a deeper understanding of users in different communication situations.

In addition, we recommend experimenting with the sound and creation of the biomusic by using different sounds, biofeedback and musical elements. This would enable researching the effect of all separate elements, providing insights into the design process, and setting up requirements for the creation of biomusic. We recommend gathering feedback from a diverse sample, for example including people from different countries and cultures. Since all users are unique and have different preferences, finding one suitable type of biomusic for everyone seems unrealistic. Therefore, there could be experimented with personalizing the sound of the biomusic, for example, to match the musical taste of the receiver or the personality of the sender. This would enable the application of biomusic in communication for a variety of different users.

Furthermore, we recommend researching biomusic in synchronous communication, both physically and remotely, to test in which communication type biomusic could be most valuable. Ideally, the use of biomusic in remote communication could be researched in a longitudinal study, instead of focusing on one message, to test the reactions of participants over a longer period. This would enable the participants to get familiar with the biomusic and interpret the sound, potentially giving more insights into the feelings of their loved one. In addition, it would enable investigating which type of messages and with what frequency participants would value adding biomusic to communication. This would provide more insights into the preferred design of the system and potential future implementations.

Besides the use of biomusic in communication between loved ones, applying biomusic in healthcare could also be valuable. Since biomusic aims to convey information, it can be used in situations where a person is limited in communication, for example providing information to a caregiver or family member. Similarly, it possibly can add to the communication of visually impaired people, since they lack visual cues, whereas biomusic can provide information. Therefore, we recommend researching the possible applications of biomusic, and thus mapping valuable future applications.

We acknowledge that the current biomusic is a first step in the investigation of biomusic in communication, but our results showed positive reactions towards using biomusic in communication between loved ones, suggesting valuable future applications. Therefore, we see lots of potential for using biomusic in communication and recommend extending our research in future work.

7 Conclusion

This study aimed to research the use of biomusic in communication between loved ones, and its effect on empathy and social connectedness. We used heart rate and EDA values and performed three design iterations to map those biofeedback elements to musical elements. We controlled Ableton Live 12 using `python-rtmidi`, enabling us to generate music based on biofeedback: **biomusic**.

The biomusic consisted of a tempo based on heart rate, a chord played in the background based on EDA values and a sound effect when an EDA peak occurred. Using this mapping, we performed evaluations with twenty dyads of loved ones, consisting of nine senders and twenty receivers. We let the sender record one voice message and write one text message for their loved one while their biofeedback was being recorded and converted this biofeedback into biomusic. Following, we added the biomusic to the messages and let the receiver listen to the voice message and read the text message, with and without biomusic. After each of the four conditions, we asked the receivers to indicate their perceived empathy and social connectedness, using the CERA scale, IOS scale and direct questions and we closed with an interview to gather insights into the reasoning behind the answers.

The results of the CERA and IOS scales did not show a statistically significant effect of the biomusic on empathy and social connectedness. However, in the direct questions and during the interview, the majority of the participants indicated feeling a bit more emphatic towards and socially connected with their loved one when the biomusic was added to the voice message. Adding biomusic to textual communication was deemed less interesting, due to the asynchrony of the music and the text. The opinions and experiences of the participants regarding the use of biomusic in communication differed widely, with some participants indicating that the biomusic did not add anything, whilst others were very enthusiastic. Participants indicated wanting to use biomusic in special types of communication, for example in emotional conversations or with difficult messages, rather than in day-to-day communication. In addition, the preferred interaction partner differed, but in general, the participants preferred using biomusic in communication with close relationships due to the sensitivity of the data and found sharing biomusic with close relationships more interesting. This research raised new questions and potential opportunities for using biomusic in communication. Therefore, we suggest extending this research, including different target groups and communication means. In addition, we recommend experimenting with the sound and creation of the biomusic by using different sounds, biofeedback and musical elements.

In conclusion, the current research showed that biomusic had varying effects on social connection, providing new insights into the use of melodic biomusic in communication, focusing on asynchronous communication between loved ones.

References

[1] F. Alam, M. Danieli, and G. Riccardi. "Annotating and modeling empathy in spoken conversations". In: *Computer Speech Language* 50 (2018), pp. 40–61.

[2] D. Aldridge. "An overview of music therapy research". In: *Complementary Therapies in Medicine* 2.4 (1994), pp. 204–216.

[3] C. R. Angel. "Creating Interactive Multimedia Works with Bio-data." In: *Proceedings of the International Conference on New Interfaces for Musical Expression* (2011), pp. 421–424.

[4] C. Ardito, T. Colafiglio, T. Di Noia, and E. Di Sciascio. "A Biofeedback System to Compose Your Own Music While Dancing". In: *IFIP Conference on Human-Computer Interaction* (2021), pp. 309–312.

[5] A. Aron, E. N. Aron, and D. Smollan. "Inclusion of other in the self scale and the structure of interpersonal closeness." In: *Journal of personality and social psychology* 63.4 (1992), pp. 596–612.

[6] S. Baron-Cohen and S. Wheelwright. "The empathy quotient: an investigation of adults with Asperger syndrome or high functioning autism, and normal sex differences". In: *Journal of autism and developmental disorders* 34 (2004), pp. 163–175.

[7] C. D. Batson. *The altruism question: Toward a social-psychological answer.* Lawrence Erlbaum Associates, Inc, 1991.

[8] I. Bergstrom, S. Seinfeld, J. Arroyo-Palacios, M. Slater, and M. V. Sanchez-Vives. "Using music as a signal for biofeedback". In: *International Journal of Psychophysiology* 93.1 (2014), pp. 140–149.

[9] L. Bernardi, C. Porta, G. Casucci, R. Balsamo, N. F. Bernardi, R. Fogari, and P. Sleight. "Dynamic Interactions Between Musical, Cardiovascular, and Cerebral Rhythms in Humans". In: *Circulation* 119.25 (2009), pp. 3171–3180.

[10] R. Bhandari, A. Parnandi, E. Shipp, B. Ahmed, and R. Gutierrez-Osuna. "Music-based respiratory biofeedback in visually-demanding tasks." In: *Proceedings of the International Conference on New Interfaces for Musical Expression* (2015), pp. 78–82.

[11] S. Blain-Moraes, S. Chesser, S. Kingsnorth, P. McKeever, and E. Biddiss. "Biomusic: A novel technology for revealing the personhood of people with profound multiple disabilities". In: *Augmentative and Alternative Communication* 29.2 (2013), pp. 159–173.

[12] V. Braun and V. Clarke. "Thematic analysis". In: *APA handbook of research methods in psychology, Vol. 2. Research designs: Quantitative, qualitative, neuropsychological, and biological.* Ed. by H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, and K. J. Sher. Washington, DC: American Psychological Association, 2012, pp. 57–71.

[13] D. Buschek, M. Hassib, and F. Alt. "Personal Mobile Messaging in Context: Chat Augmentations for Expressiveness and Awareness". In: *ACM Transactions on Computer-Human Interaction* 25.4 (2018).

[14] S. Cheung, E. Han, A. Kushki, E. Anagnostou, and E. Biddiss. "Biomusic: An auditory interface for detecting physiological indicators of anxiety in children". In: *Frontiers in neuroscience* 10 (2016).

[15] D. Chou-Ren, M. Winters, J. Hernandez, D. McDuff, J. Suh, V. Rodriguez, G. Romos, and M. Czerwinski. "Do You Even Need Sensors?: Synthetic Biomusic as an Empathic Technology". In: *2023 11th International Conference on Affective Computing and Intelligent Interaction (ACII)* (2023), pp. 1–8.

[16] K. R. Christopher, A. Kapur, D. A. Carnegie, and G. M. Grimshaw. "A history of emerging paradigms in EEG for music". In: *Proceedings of the 2014 International Computer Music Conference* (2014).

[17] S. Cohen, M. S. Schulz, E. Weiss, and R. J. Waldinger. "Eye of the beholder: the individual and dyadic contributions of empathic accuracy and perceived empathic effort to relationship satisfaction." In: *Journal of Family Psychology* 26.2 (2012), pp. 236–245.

[18] J. W. Creswell and C. N. Poth. *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications, 2016.

[19] B. M. Cuff, S. J. Brown, L. Taylor, and D. J. Howat. "Empathy: A review of the concept". In: *Emotion review* 8.2 (2016), pp. 144–153.

[20] A. I. Dailly, R. Sigrist, Y. Kim, P. Wolf, H. Erckens, J. Cerny, A. Luft, R. Gassert, and J. Sulzer. "Can simple error sonification in combination with music help improve accuracy in upper limb movements?" In: *2012 4th IEEE RAS & EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob)* (2012), pp. 1423–1427.

[21] F. S. Dam. "The effect of feedback on the similarity of biosignals on social connectedness and empathy". MSc thesis. Eindhoven University of Technology. 2021.

[22] M. H. Davis. "Measuring individual differences in empathy: Evidence for a multidimensional approach." In: *Journal of personality and social psychology* 44.1 (1983), pp. 113–126.

[23] R. Derie, P. Van den Berghe, J. Gerlo, S. Bonnaerens, I. V. Caekenberghe, P. Fiers, D. De Clercq, and V. Segers. "Biomechanical adaptations following a music-based biofeedback gait retraining program to reduce peak tibial accelerations". In: *Scandinavian Journal of Medicine & Science in Sports* 32.7 (2022), pp. 1142–1152.

[24] J. Desnoyers-Stewart, E. R. Stepanova, P. Pasquier, and B. E. Riecke. "JeL: Connecting Through Breath in Virtual Reality". In: *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (2019), pp. 1–6.

[25] T. A. Deuel, J. Pampin, J. Sundstrom, and F. Darvas. "The Encephalophone: A novel musical biofeedback device using conscious control of electroencephalogram (EEG)". In: *Frontiers in human neuroscience* 11 (2017).

[26] Q. Dong, Y. Li, B. Hu, Q. Liu, X. Li, and L. Liu. "A solution on ubiquitous EEG-based biofeedback music therapy". In: *5th International Conference on Pervasive Computing and Applications* (2010), pp. 32–37.

[27] S. K. Ehrlich, K. R. Agres, C. Guan, and G. Cheng. "A closed-loop, music-based brain-computer interface for emotion mediation". In: *PloS one* 14.3 (2019).

[28] A. El Ali, E. R. Stepanova, S. Palande, A. Mader, P. Cesar, and K. Jansen. "BreatheWithMe: Exploring Visual and Vibrotactile Displays for Social Breath Awareness during Colocated, Collaborative Tasks". In: *Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems* (2023).

[29] M. Escalona, R. Laxamana, K. Pagtakhan, M. T. Suarez, E. Tighe, and R. Trogo. "RHIA: Building a Music Provision System for College Students Based on Stress Levels". In: *Proceedings of the 14th Philippine Computing Science Congress* (2014), pp. 159–167.

[30] M. A. Feijt, Y. de Kort, J. Westerink, S. Okel, and W. A. IJsselsteijn. "The effect of simulated feedback about psychophysiological synchronization on perceived empathy and connectedness". In: *Annual Review of Cybertherapy and Telemedicine* 117 (2020).

[31] A. Ferguson, C. Castellanos, and P. Pasquier. "Digital music interventions for stress with bio-sensing: a survey". In: *Frontiers in Computer Science* 5 (2023).

[32] J. Frey, M. Grabli, R. Slyper, and J. R. Cauchard. "Breeze: Sharing Biofeedback through Wearable Technologies". In: *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (2018), pp. 1–12.

[33] S. Gächter, C. Starmer, and F. Tufano. "Measuring the closeness of relationships: a comprehensive evaluation of the'inclusion of the other in the self'scale". In: *PloS one* 10.6 (2015).

[34] I. V. Gartha. "What is biofeedback?" In: *Canadian Family Physician* 22 (1976), pp. 105–106.

[35] I. Godt. "Music: A practical definition". In: *The Musical Times* 146.1890 (2005), pp. 83–88.

[36] L. J. Hadjileontiadis. "Conceptual blending in biomusic composition space: The "brainswarm" paradigm". In: *Proceedings of the 2014 International Computer Music Conference* (2014).

[37] B. M. Hagerty, J. Lynch-Sauer, K. L. Patusky, and M. Bouwsema. "An emerging theory of human relatedness". In: *Image: The Journal of Nursing Scholarship* 25.4 (1993), pp. 291–296.

[38] J. A. Hall and R. Schwartz. "Empathy present and future". In: *The Journal of Social Psychology* 159.3 (2019), pp. 225–243.

[39] S. Hallam, I. Cross, and M. Thaut. *Emotional responses to music*. Oxford University Press, 2009.

[40] C. Haslam, T. Cruwys, S. A. Haslam, and J. Jetten. "Social connectedness and health". In: *Encyclopedia of geropsychology* 46.1 (2015), pp. 1–10.

[41] M. Hassib, D. Buschek, P. W. Wozniak, and F. Alt. "HeartChat: Heart Rate Augmented Mobile Chat to Support Empathy and Awareness". In: *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (2017), pp. 2239–2251.

[42] D. J. Hemmerling, M. Stroinski, K. Kwarciak, K. Trusiak, M. Szymkowski, W. Celniak, W. Frier, O. Georgiou, and M. Maksymenko. "Touchless Touch with Biosignal Transfer for Online Communication". In: *Proceedings of the 2022 International Conference on Multimodal Interaction* (2022), pp. 579–590.

[43] J. Henrich, S. J. Heine, and A. Norenzayan. “The weirdest people in the world?” In: *Behavioral and Brain Sciences* 33.2—3 (2010), pp. 61–83.

[44] T. Hinterberger and G. Baier. “Parametric orchestral sonification of EEG in real time”. In: *IEEE MultiMedia* 12.2 (2005), pp. 70–79.

[45] L. Hirsch, F. Müller, F. Chiossi, T. Benga, and A. M. Butz. “My Heart Will Go On: Implicitly Increasing Social Connectedness by Visualizing Asynchronous Players’ Heartbeats in VR Games”. In: *Proceedings of the ACM on Human-Computer Interaction* 7 (2023).

[46] T. C. T. Ho and X. Chen. “iHeartLift: A closed loop system with bio-feedback that uses music tempo variability to improve heart rate variability”. In: *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (2011), pp. 1181–1184.

[47] N. Howell, L. Devendorf, R. K. Tian, T. Vega Galvez, N.-W. Gong, I. Poupyrev, E. Paulos, and K. Ryokai. “Biosignals as Social Cues: Ambiguity and Emotional Interpretation in Social Displays of Skin Conductance”. In: *Proceedings of the 2016 ACM Conference on Designing Interactive Systems* (2016), pp. 865–870.

[48] S. Ingoglia, A. Lo Coco, and P. Albiero. “Development of a brief form of the Interpersonal Reactivity Index (B-IRI)”. In: *Journal of Personality Assessment* 98.5 (2016), pp. 461–471.

[49] J. H. Janssen, J. N. Bailenson, W. A. IJsselsteijn, and J. H. D. M. Westerink. “Intimate heartbeats: Opportunities for affective communication technology”. In: *IEEE Transactions on Affective Computing* 1.2 (2010), pp. 72–80.

[50] S. Järvelä, B. Cowley, M. Salminen, G. Jacucci, J. Hamari, and N. Ravaja. “Augmented Virtual Reality Meditation: Shared Dyadic Biofeedback Increases Social Presence Via Respiratory Synchrony”. In: *ACM Transactions on Social Computing* 4.2 (2021).

[51] S. Järvelä, M. Salminen, A. Ruonala, J. Timonen, K. Mannermaa, N. Ravaja, and G. Jacucci. “DYNECOM: Augmenting empathy in VR with dyadic synchrony neurofeedback”. In: *Proceedings of the 52nd Hawaii International Conference on System Sciences* (2019).

[52] Y. Jiang, X. Ding, X. Ma, Z. Sun, and N. Gu. “IntimaSea: Exploring Shared Stress Display in Close Relationships”. In: *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (2023), pp. 1–19.

[53] B. W. Joseph. “Biomusic”. In: *Grey Room* 45 (2011), pp. 128–150.

[54] R. S. Kayne. “Connectedness”. In: *Linguistic inquiry* 14.2 (1983), pp. 223–249.

[55] G. Kramer, B. Walker, T. Bonebright, P. Cook, J. H. Flowers, N. Miner, and J. Neuhoff. “Sonification report: Status of the field and research agenda”. In: *Faculty Publications, Department of Psychology* (2010), p. 444.

[56] S. D. Kreibig. “Autonomic nervous system activity in emotion: A review”. In: *Biological Psychology* 84.3 (2010), pp. 394–421.

[57] M. S. Kurdi and V. D. Gasti. “Music and Health”. In: *Journal of Applied and Advanced Research* 2.2 (2017), pp. 95–102.

[58] M. Lee, K. Kim, H. Rho, and S. J. Kim. "Empa Talk: A Physiological Data Incorporated Human-Computer Interactions". In: *CHI '14 Extended Abstracts on Human Factors in Computing Systems* (2014), pp. 1897–1902.

[59] R. M. Lee, M. Draper, and S. Lee. "Social connectedness, dysfunctional interpersonal behaviors, and psychological distress: Testing a mediator model." In: *Journal of counseling psychology* 48.3 (2001), pp. 310–318.

[60] R. M. Lee and S. B. Robbins. "Measuring belongingness: The social connectedness and the social assurance scales." In: *Journal of counseling psychology* 42.2 (1995), pp. 232–241.

[61] G. Leslie. "Inner rhythms: vessels as a sustained brain-body performance practice". In: *Leonardo* 54.3 (2021), pp. 325–328.

[62] G. Leslie. *Composing at the Border of Experimental Music and Music Experiment*. 2023.

[63] F. F. de Lima and F. de Lima Osório. "Empathy: Assessment Instruments and Psychometric Quality – A Systematic Literature Review With a Meta-Analysis of the Past Ten Years". In: *Frontiers in Psychology* 12 (2021).

[64] F. Liu. "Fostering Social Connection through Expressive Biosignals". PhD thesis. Microsoft Research, 2020.

[65] F. Liu, L. Dabbish, and G. Kaufman. "Can Biosignals Be Expressive? How Visualizations Affect Impression Formation from Shared Brain Activity". In: *Proceedings of the ACM on Human-Computer Interaction* 1 (2017).

[66] F. Liu, L. Dabbish, and G. Kaufman. "Supporting Social Interactions with an Expressive Heart Rate Sharing Application". In: *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 1.3 (2017).

[67] F. Liu, M. Esparza, M. Pavlovskaia, G. Kaufman, L. Dabbish, and A. Monroy-Hernández. "Animo: Sharing Biosignals on a Smartwatch for Lightweight Social Connection". In: *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* (2019).

[68] F. Liu, G. Kaufman, and L. Dabbish. "The Effect of Expressive Biosignals on Empathy and Closeness for a Stigmatized Group Member". In: *Proceedings of the ACM on Human-Computer Interaction* 3 (2019).

[69] F. Liu, C. Park, Y. J. Tham, T.-Y. Tsai, L. Dabbish, G. Kaufman, and A. Monroy-Hernández. "Significant otter: Understanding the role of biosignals in communication". In: *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (2021), pp. 1–15.

[70] H. Liu, J. Hu, and M. Rauterberg. "Software architecture support for biofeedback based in-flight music systems". In: *2009 2nd IEEE International Conference on Computer Science and Information Technology* (2009), pp. 580–584.

[71] E. C. J. Long. "Measuring dyadic perspective-taking: Two scales for assessing perspective-taking in marriage and similar dyads". In: *Educational and psychological measurement* 50.1 (1990), pp. 91–103.

[72] V. Lorenzoni, P.-J. Maes, P. Van den Berghe, D. De Clercq, T. De Bie, and M. Leman. "A biofeedback music-sonification system for gait retraining". In: *Proceedings of the 5th International Conference on Movement and Computing* (2018), pp. 1–5.

[73] V. Lorenzoni, J. Staley, T. Marchant, K. E. Onderdijk, P.-J. Maes, and M. Leman. "The sonic instructor: a music-based biofeedback system for improving weightlifting technique". In: *Plos one* 14.8 (2019).

[74] V. Lorenzoni, P. Van den Berghe, P.-J. Maes, T. De Bie, D. De Clercq, and M. Leman. "Design and validation of an auditory biofeedback system for modification of running parameters". In: *Journal on Multimodal User Interfaces* 13 (2019), pp. 167–180.

[75] A. Lucier and D. Simon. *Chambers: Scores by Alvin Lucier*. Wesleyan University Press, 2012.

[76] S. Mainka, A. Schroll, E. Warmerdam, F. Gandor, W. Maetzler, and G. Ebersbach. "The Power of Musification: Sensor-Based Music Feedback Improves Arm Swing in Parkinson's Disease". In: *Movement Disorders Clinical Practice* 8.8 (2021), pp. 1240–1247.

[77] D. Makowski, T. Pham, Z. J. Lau, J. C. Brammer, F. Lespinasse, H. Pham, C. Schölzel, and S. H. A. Chen. "NeuroKit2: A Python toolbox for neurophysiological signal processing". In: *Behavior Research Methods* 53.4 (2021), pp. 1689–1696.

[78] M. Mandolfo. "You trust me, and I feel it. Influence of foreign live biofeedback on interpersonal trust-related behaviour". MSc thesis. Politecnico di Milano. 2015.

[79] W. Meijer, B. Verhoeff, H. Verma, and J. Bourgeois. "Fast Drink: Mediating Empathy for Gig Workers". In: *Proceedings of the 2nd Empathy-Centric Design Workshop* (2023).

[80] N. Milstein and I. Gordon. "Validating Measures of Electrodermal Activity and Heart Rate Variability Derived From the Empatica E4 Utilized in Research Settings That Involve Interactive Dyadic States". In: *Frontiers in Behavioral Neuroscience* 14 (2020).

[81] T. Min. "Inducing Empathy Among Strangers Through Biofeedback-Controlled Stimuli". MSc thesis. Georgia Institute of Technology. 2022.

[82] E. R. Miranda and A. Brouse. "Interfacing the brain directly with musical systems: on developing systems for making music with brain signals". In: *Leonardo* 38.4 (2005), pp. 331–336.

[83] E. R. Miranda, A. Brouse, B. Boskamp, and H. Mullaney. "Plymouth brain-computer music interface project: Intelligent assistive technology for music-making". In: *Proceedings of the 2005 International Computer Music Conference* (2005).

[84] C. Moge, K. Wang, and Y. Cho. "Shared User Interfaces of Physiological Data: Systematic Review of Social Biofeedback Systems and Contexts in HCI". In: *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (2022), pp. 1–16.

[85] J. Muñoz, A. Gonçalves, T. Vieira, D. Cró, Y. Chisik, and S. B. i Badia. "Space connection-a multiplayer collaborative biofeedback game to promote empathy in teenagers: A feasibility study". In: *Proceedings of the 3rd International Conference on Physiological Computing Systems* (2016), pp. 88–97.

[86] P. Murali and T. Bickmore. "Sharing Speaker Heart Rate with the Audience Elicits Empathy and Increases Persuasion". In: *Persuasive Technology* (2023). Ed. by A. Meschtscherjakov, C. Midden, and J. Ham, pp. 3–21.

[87] E. Nunez, M. Hirokawa, M. Perusquia-Hernandez, and K. Suzuki. "Effect on Social Connectedness and Stress Levels by Using a Huggable Interface in Remote Communication". In: *8th International Conference on Affective Computing and Intelligent Interaction* (2019), pp. 1–7.

[88] M. Ortiz-Perez, N. Coghlan, J. Jaimovich, and R. B. Knapp. "Biosignal-driven art: Beyond biofeedback". In: *Ideas Sonica/Sonic Ideas* 3.2 (2011).

[89] B. Özcan and V. Sperati. "Lokahi: The Wearable Body Pillow to Foster an Intimate Interaction Between Two Users Through Their Heartbeat Awareness". In: *HCI International 2020 – Late Breaking Posters* (2020). Ed. by C. Stephanidis, M. Antona, and S. Ntoa, pp. 421–429.

[90] B. Özcan, V. Sperati, F. Giocondo, M. Schembri, and G. Baldassarre. "Multi-Sensory Wearable Bio-Feedback Pillow to Enhance Genuine Feeling of Intimate Connection". In: *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (2023).

[91] D. Peeters, C. Ranasinghe, A. Degbelo, and F. Ahmed. "EmoClock: Communicating Real-Time Emotional States Through Data Physicalizations". In: *IFIP Conference on Human-Computer Interaction* (2023), pp. 416–425.

[92] K. Péloquin and M.-F. Lafontaine. "Measuring Empathy in Couples: Validity and Reliability of the Interpersonal Reactivity Index for Couples". In: *Journal of Personality Assessment* 92.2 (2010), pp. 146–157.

[93] S. Peng. "Excitement Projector: Augmenting Excitement-Perception and Arousal through Bio-Signal-Based Haptic Feedback in Remote-Sport Watching". In: *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (2022).

[94] C. Rojas, M. Corral, N. Poulsen, and P. Maes. "Project Us: A Wearable for Enhancing Empathy". In: *Companion Publication of the 2020 ACM Designing Interactive Systems Conference* (2020), pp. 139–144.

[95] C. Rojas, E. Zuccarelli, A. Chin, G. Patekar, D. Esquivel, and P. Maes. "Towards Enhancing Empathy Through Emotion Augmented Remote Communication". In: *Extended Abstracts of the 2022 CHI Conference on Human Factors in Computing Systems* (2022).

[96] O. R. G. Rosello. "HeartBit: mindful control of heart rate using haptic biofeedback". PhD thesis. Massachusetts Institute of Technology, 2020.

[97] M. Salminen, S. Järvelä, A. Ruonala, V. J. Harjunen, J. Hamari, G. Jacucci, and N. Ravaja. "Evoking Physiological Synchrony and Empathy Using Social VR With Biofeedback". In: *IEEE Transactions on Affective Computing* 13.2 (2022), pp. 746–755.

[98] M. Salminen, S. Järvelä, A. Ruonala, J. Timonen, K. Mannermaa, N. Ravaja, and G. Jacucci. "Bio-Adaptive Social VR to Evoke Affective Interdependence: DYNECOM". In: *23rd International Conference on Intelligent User Interfaces* (2018), pp. 73–77.

[99] M. Schedl, F. Lemmerich, B. Ferwerda, M. Skowron, and P. Knees. "Indicators of Country Similarity in Terms of Music Taste, Cultural, and Socio-economic Factors". In: *2017 IEEE International Symposium on Multimedia (ISM)* (2017), pp. 308–311.

[100] F. Schoeller, P. Bertrand, L. J. Gerry, A. Jain, A. H. Horowitz, and F. Zenasni. "Combining Virtual Reality and Biofeedback to Foster Empathic abilities in Humans". In: *Frontiers in Psychology* 9 (2019).

[101] P. Slovák, J. Janssen, and G. Fitzpatrick. "Understanding Heart Rate Sharing: Towards Unpacking Physiosocial Space". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2012), pp. 859–868.

[102] H. Soh. "Measuring consumer empathic response to advertising drama". In: *The Journal of the Korea Contents Association* 14.11 (2014), pp. 133–142.

[103] M. Soufineyestani, D. Dowling, and A. Khan. "Electroencephalography (EEG) technology applications and available devices". In: *Applied Sciences* 10.21 (2020).

[104] V. Straebel and W. Thoben. "Alvin Lucier's Music for Solo Performer: Experimental music beyond sonification". In: *Organised Sound* 19.1 (2014), pp. 17–29.

[105] K. Tahiroğlu, H. Drayson, and C. Erkut. "An Interactive bio-music improvisation system". In: *International Computer Music Conference* (2008).

[106] A. Tanaka. "Sensor-Based Musical Instruments and Interactive Music". In: *The Oxford Handbook of Computer Music*. Oxford University Press, 2011.

[107] W. F. Thompson and B. Robitaille. "Can Composers Express Emotions through Music?" In: *Empirical Studies of the Arts* 10.1 (1992), pp. 79–89.

[108] K. C. Townsend and B. T. McWhirter. "Connectedness: A review of the literature with implications for counseling, assessment, and research". In: *Journal of Counseling & Development* 83.2 (2005), pp. 191–201.

[109] P. Van den Berghe, R. Derie, P. Bauwens, J. Gerlo, V. Segers, M. Leman, and D. De Clercq. "Reducing the peak tibial acceleration of running by music-based biofeedback: a quasi-randomized controlled trial". In: *Scandinavian Journal of Medicine & Science in Sports* 32.4 (2022), pp. 698–709.

[110] P. Van den Berghe, V. Lorenzoni, R. Derie, J. Six, J. Gerlo, M. Leman, and D. De Clercq. "Music-based biofeedback to reduce tibial shock in over-ground running: A proof-of-concept study". In: *Scientific reports* 11.1 (2021), p. 4091.

[111] E. Venter. "Challenges for meaningful interpersonal communication in a digital era". In: *HTS: Theological Studies* 75.1 (2019), pp. 1–6.

[112] P. Vickers and B. Hogg. "Sonification Abstraite/Sonification Concrète: AnÆsthetic Perspective Space'for Classifying Auditory Displays in the Ars Musica Domain". In: *The 12th Meeting of the International Conference on Auditory Display* (2006).

[113] P. Vickers. "Sonification and music, music and sonification". In: *The Routledge Companion to Sounding Art*. Routledge, 2016, pp. 135–144.

[114] T. Wang and X. Feng. "SinkInSync: A Brainwave Synchronization Experience in VR Towards Enhancing Social Connectedness: A Brainwave Synchronization Experience in VR Towards Enhancing Social Connectedness". In: *ACM Special Interest Group on Computer Graphics and Interactive Techniques Conference 2023 Immersive Pavilion* (2023).

[115] J. Werner, R. Wettach, and E. Hornecker. "United-Pulse: Feeling Your Partner's Pulse". In: *Proceedings of the 10th international conference on Human computer interaction with mobile devices and services* (2008), pp. 535–538.

[116] K. West. *Biofeedback*. Infobase Publishing, 2009.

[117] R. M. Winters, B. N. Walker, and G. Leslie. "Can You Hear My Heartbeat?: Hearing an Expressive Biosignal Elicits Empathy". In: *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (2021), pp. 1–11.

[118] J. O. Wobbrock, L. Findlater, D. Gergle, and J. J. Higgins. "The aligned rank transform for nonparametric factorial analyses using only anova procedures". In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. CHI '11 (2011), pp. 143–146.

[119] M. Wright and A. Freed. "Open soundcontrol: A new protocol for communicating with sound synthesizers". In: *International Computer Music Conference (ICMC)* (1997).

[120] D. Wu, C.-Y. Li, and D.-Z. Yao. "Scale-free music of the brain". In: *PloS one* 4.6 (2009).

[121] K. Yokoyama, J.-i. Ushida, Y. Sugiura, M. Mizuno, Y. Mizuno, and K. Takata. "Heart rate indication using musical data". In: *IEEE Transactions on biomedical engineering* 49.7 (2002), pp. 729–733.

[122] S. Yoo and M. Whang. "Vagal Tone Differences in Empathy Level Elicited by Different Emotions and a Co-Viewer". In: *Sensors* 20.11 (2020).

[123] Y. Zheng. "Comparing the effects of biosignal-similarity feedback and personality-similarity feedback on empathy and social connectedness". MSc thesis. Eindhoven University of Technology. 2022.

Appendices

A Workshop

A.1 Consent Form and Questionnaire

CWI Centrum Wiskunde & Informatica

Utrecht University

Consent form for collection and use of your personal data

Thank you for agreeing to participate in the workshop session run by Utrecht University (UU) and Centrum Wiskunde & Informatica (CWI) the national research institute for mathematics and computer science. This study is carried out by Renske Bootsma (renske.bootsma@cwi.nl) as part of my master thesis regarding **Biomusic**, under supervision of Marit Bentvelzen (m.bentvelzen@uu.nl) and Abdallah El Ali (abdallah.el.ali@cwi.nl). We thank you for participating in our workshop session at 10-04-2024 at 14:00, which has a duration of approximately 1 hour.

Information about the research

The goal of my research project is to investigate the effect of sharing biomusic on the perceived empathy and social connectedness between loved ones. For this, the biomusic will be generated based on biofeedback. In this workshop, you will provide opinions about musical mappings concerning the generation of biomusic.

Gathered data in this study

We will analyze your input on the sticky notes, and this will be linked to the basic demographic information you provide. No highly personal data (e.g., your name, nationality, etc.) will be collected. We will audio record and transcribe the session and take photos throughout the whole session, however faces will always be blurred.

Data protection and privacy notice

CWI would like to be able to use your data for academic research. This means that the data may be part of benchmark data study and/or scientific publication and/or presentations available to the scientific community in and outside Europe, where the personal data protection legislation may not offer the same level of protection to you as in the Netherlands and Europe. We assure you that your identity will remain fully confidential and secured at all times and in no way connected to the collected data. Your data will remain in the databases of CWI for 1 year; after this period they will be removed. As your data will be disseminated in the scientific community and integrated in computer models, they may remain in their possession for a longer period. You can exercise your rights according to personal data protection laws by contacting CWI, privacy@cwi.nl

Consent Biomusic workshop

If you are happy to participate please complete and sign the consent form below.

- ☐ I confirm that I have read and accepted the attached information sheet on the above project and have had the opportunity to consider the information and ask questions and had these answered satisfactorily;
- ☐ I understand that personal information collected about me that can identify me (such as name, age and domicile) will not be shared beyond the study team;
- ☐ I understand that my participation in the study is voluntary and that I am free to withdraw at any time without giving a reason. Such withdrawal will only impact the data/images/recording in the databases of CWI; my data/images/video may still be available to those recipients in the scientific community who received it prior to my withdrawal;
- ☐ I understand that my data/images/recording may be used in databases, academic papers or in academic presentations by the researchers. When the data involves people, the person will be blurred in advance;

I agree to take part in the above project.

Name: _____

Date: _____

Signature: _____

CWI Centrum Wiskunde & Informatica

Utrecht University

Participant demographics – Workshop Biomusic

Please answer the questions below.

Question 1: What is your gender?

- ☐ Male
- ☐ Female
- ☐ Non-binary
- ☐ Prefer not to answer
- ☐ Other:

Question 2: What is your age?

_____ years

Question 3: Please describe your affinity and experience with writing code and/or programming.

_____
_____
_____
_____
_____
_____

Question 4: Please describe your affinity and experience with (playing or producing) music.

_____
_____
_____
_____
_____
_____

"I hereby verify that the information provided on this form is correct to the best of my knowledge."

Date: _____ **Signature:** _____

A.2 Protocol

Workshop Biomusic - Protocol

General information

- Goal:
  - Determine what makes something 'music'
  - Gather opinions regarding different mappings of biofeedback to musical elements
- Participants:
  - Adults
  - Have affinity with music (either playing an instrument or online music production)
- Recruitment process:
  - Purposive sampling → asking colleagues at CWI that have affinity with music
- Timeline:
  - Session 1: 14:00-15:00 in M390 at CWI on 10-04-2024
- Language:
  - English
- Materials:
  - Laptop with Ableton Live and the python script
  - Slides with explanations
  - Recording device
  - Timer
  - Information sheets
  - Consent forms
  - Questionnaire regarding demographics and affinity with music
  - 4 different colours of sticky notes
  - Pens
  - Guitar
  - FOOD
- Data to be collected:
  - Recording and transcript of the workshop
  - Photos of the workshop
  - Input on sticky notes
  - Questions regarding affinity with music and demographics

Preparation

- Run all python code, load Ableton file
- Present slide deck
- Position consent forms and information sheets
- Position 4 different colours of sticky notes + pens
- Prepare 2 whiteboards:
  - One with Music in the middle
  - One with 3 categories: Heartbeat, raw EDA values and EDA peak
- Positioning 2 recoding devices + timer

Workshop overview

Introduction (5min)

- Gaining consent + demographics + music related information
- Explaining the goal of the research

Part 1: Brainstorming about the concept of music (5min)

- Indicate the difficulty of defining music
- Ask the participants to write down elements that make something being classified as 'music'
- Organize the elements on the whiteboard

Part 2: Connecting musical elements to biofeedback elements (10 min)

- Indicate the biofeedback elements
- Indicate the requirements of the music
- Let the participants brainstorm about how the biofeedback elements can be turned into musical elements; for each three categories: Heart rate, raw EDA data, EDA peaks

Part 3: Experimenting with different variables (40 min)

- Indicate the functionalities of rtmidi and possibilities in Ableton Live
- Play the initial mapping
- Play the current mapping [**In the thesis referred to as "Second mapping"**]
- Brainstorm per variable about the preferred mapping
    - How to play the chords
    - Which chords to play
    - Instruments to play the chords
    - How to indicate an EDA peak
    - How to indicate the tempo
- Based on the results of these variables, play the corresponding mapping
- Ask for any other suggestions, or possibilities

Detailed workshop description

Introduction (5 min)

Let the participants read the information sheet, sign the consent form and fill in the demographic questions.

As the most of you know, I've been doing research in the context of sharing biofeedback and the effects on empathy and social connectedness. One way of sharing biofeedback is just sharing the raw data, for example displaying the heartbeat of a person with which you are having a conversation, but I'm more interested in using music to convey this biofeedback. Therefore, I try to create biomusic, namely music generated based on someone's biofeedback.

I'm curious about your opinions and thoughts, so we will take a look together to possibilities of creating music. Let's start with the first part.

Part 1 – Brainstorming about the concept of music (5 min)

The first question I faced was the concept music, and the difference between music and sound. Therefore, first, let's think about what makes something 'music' ?

3 min individually. Please write down elements that are important for something to be classified as music (in contrast to something being sound). Use one sticky note to indicate one element.

-Let the participants position their sticky notes on the whiteboard and categorize the elements-

Part 2 – Connecting musical elements to biofeedback elements (10 min)

Based on previous research, I decided to use Heart rate and Electrodermal Activity (EDA) (also known as galvanic skin response, or simply said the sweat level) since both of these appear to change based on emotions. For example, when having an emotional conversation, heartrate can increase, people can start sweating and EDA peaks occur for example when feeling a sudden emotion.

I added a visualisation of two recordings, both being my own data. As you can see, my EDA values range from 0 to 0.5, the first one containing more peaks and the second one more stable. However, people differ in values, for example someone else's data varying from 0 to 0.8.

I want to convey changes in these physiological states by using music. The application will be during a conversation, so the music based on the other participant's data will play in the background. Based on these conditions, I set up some requirements for the music:

- it should not be distracting (it should be played at the background of a conversation)
- it should not be annoying to listen to for e.g. 15 minutes
- it should sound like music

- it should be based on the biofeedback of the other participant
- changes in the biofeedback of the participant should be noticeable

Based on these requirements, I would like to gain ideas of how to indicate (changes in) these biosignals with musical elements

5 min in pairs. Please write down how these biofeedback elements can be turned into musical elements (heart rate, raw EDA values and EDA peaks). Use one sticky note for one element. You can write down similar elements at different categories.

-Let the participants position their sticky notes on the whiteboard in the correct category-

Part 3 – Experimenting with different variables (40 min)

I want to show you what I did so far, and see whether we can together brainstorm about the ideal mapping to use.

I am using a python package rtmidi, that allows me to send MIDI messages to Ableton Live, which is music production software. The possibilities I have are

- Start/stop playing a sound sample → ***play example in Ableton***
- Start/stop playing a specific pitch → ***play example in Ableton***
- Alter the velocity → ***play example in Ableton***

Ableton has a library of sound samples, but I can also download any .wav audio sample and play this.

Using these possibilities, I mapped the heartbeat to the beat of the music, used raw EDA values for melodic background chords and a sound sample when an EDA peak was occurring. This lead to the first mapping → ***play initial mapping***

Question for all: Would you classify this as being music? Why?

However, for me this did not sound like music, but rather background sound. Therefore, I searched for ways of changing the melodic elements so that it sounded more like music, but did not distract, being based on the heartbeat and EDA values. I took my guitar, and thought about how I would play chords in the background. Based on that, I created the following → ***play current mapping***

Question for all: Would you classify this as being music? Why?

There are different types of variables that can be changed. I would love to think together about ideas of changing variables, in order to create a nice mapping that fulfils the requirements.

If you have any ideas, I can try to auralize/implement them immediately

Please write down your ideas.

How to play the chords. As we heard in the initial mapping, we can play static chords, meaning on a guitar, striking the strings all at once, at the beginning of the bar. → ***play chord per 4 and static chords***

Alternatively, we can play broken chords, by strumming the chord, striking one snare at the time, as we heard in the current mapping. → ***play current mapping***

This can of course be changed to another type of strumming, using other snares etc. I'm curious about what you think would be preferred way of playing the chords? → ***evt. play example of different stumming pattern the guitar.*** Are there any other options? (I'm updating this now each bar, but could also extend to 2 bars)

Which chords to play. In the current mapping, I used major chords, changing for every 0.25 range of EDA values. I can also alter this range of course. I started with the E major chord for the first range, and for each higher range, the major chord increased 1. Aternatively, the starting value can be mapped to for example an A, and based on the difference, the chords can be changed.

In addition to the way of mapping, we can also decide to use minor chords, or a combination of major and minor chords. I'm curious about what you would prefer. → ***play EFGABCD and play Em Fm Gm and play E Em F Fm on guitar***

Which instruments to use. At the moment, I chose to use an acoustic guitar instrument in Ableton. However, I can choose to play the chords on a piano → ***play piano chords***. Or I can choose a different synthesizer sound, a electrical guitar or for example a bass → ***play bass chords***. I'm curious about what you prefer and if you have any other ideas?

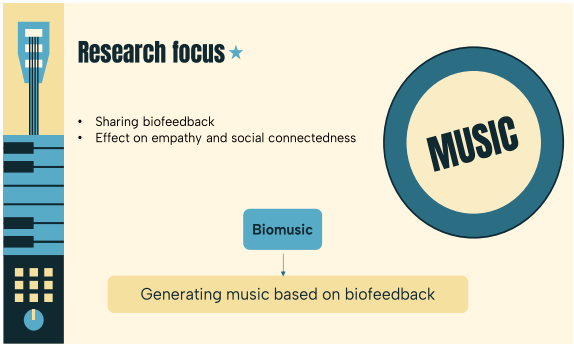
How to indicate the EDA peak. In the initial mapping, I used a chimes sound to indicate an EDA peak → ***play chimes sound***. In the current mapping, I chose to use a whoosh sound → ***play woosh sound***. I can choose any other possible sound; do you have any ideas to indicate the EDA peak in such a way that it does not make the whole overwhelming, but still can be distinguished?

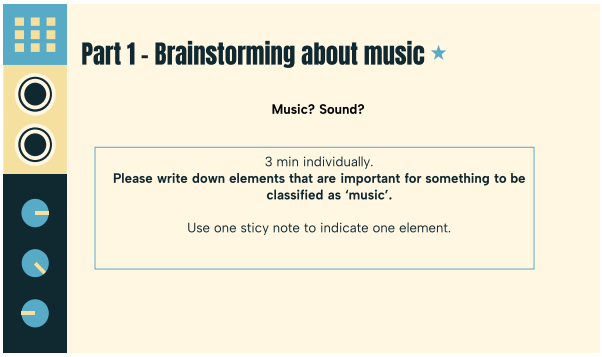
How to indicate tempo. I can use a drum tom sound for indicating every beat, as I did in the current mapping → ***play current mapping***. However, we can also decide to only indicate the first beat of a bar with a drum sound → ***play tom first beat***. Or to add more drum sounds like hi-hats → ***play more drum elements***. Another option, is to play no drum beat at all, and let the tempo solely be indicated by the tempo of the chords playing. I'm curious about your opinions.

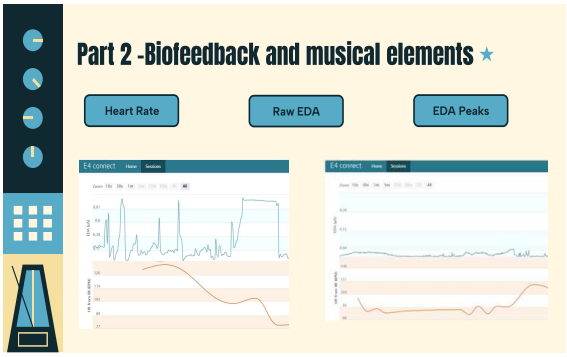
Concluding; *5 min together. Do you have any other suggestions or possible mappings that I can experiment with?*

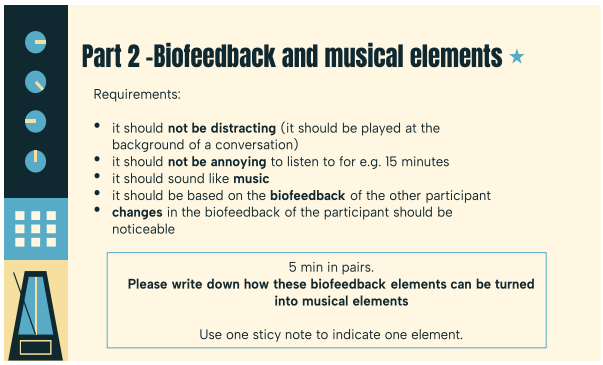
A.3 Slides

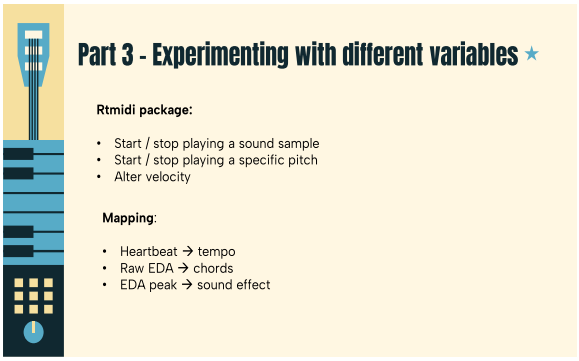

BIOMUSIC
MSc Human Computer Interaction
Renske Bootsma
Research group: Distributed and Interactive Systems, led by Pablo Cesar
Institute: Centrum Wiskunde & Informatica
Supervisors: Marit Bentvelzen & Abdallah El Ali


Research focus
Sharing biofeedback
Effect on empathy and social connectedness
MUSIC
Biomusic
Generating music based on biofeedback


Part 1 - Brainstorming about music
Music? Sound?
3 min individually.
Please write down elements that are important for something to be classified as 'music'.
Use one sticy note to indicate one element.


Part 2 -Biofeedback and musical elements
Heart Rate
Raw EDA
EDA Peaks


Part 2 -Biofeedback and musical elements
Requirements:
it should not be distracting (it should be played at the background of a conversation)
it should not be annoying to listen to for e.g. 15 minutes
it should sound like music
it should be based on the biofeedback of the other participant
changes in the biofeedback of the participant should be noticeable
5 min in pairs.
Please write down how these biofeedback elements can be turned into musical elements
Use one sticy note to indicate one element.


Part 3 - Experimenting with different variables
Rtmidi package:
Start / stop playing a sound sample
Start / stop playing a specific pitch
Alter velocity
Mapping:
Heartbeat → tempo
Raw EDA → chords
EDA peak → sound effect

Part 3 - Experimenting with different variables ★

10 min together.
Discuss what would be the preferred way of playing chords, and why.

How to play the chords

- Static
- Broken, the current mapping
- Broken, but with a different strumming
- Other....

Part 3 - Experimenting with different variables ★

5 min together.
Discuss what would be the preferred chords to play, and why.

Which chords to play

- Major chords, the current mapping
- Combination of major/min/dim/aug chords
- Other...

Range	Chord
0-0,025	E
0,025-0,050	F
0,050-0,075	G
0,075-0,100	A
0,100-0,125	B
0,125-0,150	C

Part 3 - Experimenting with different variables ★

5 min together.
Discuss what would be the preferred instruments to use for playing chords, and why.

Instrument to play the chords

- Acoustic guitar, the current mapping
- Electric guitar
- Piano
- Bass
- Organ
- Other...

Part 3 - Experimenting with different variables ★

5 min together.
Discuss what would be the preferred method of indicating an EDA peak, and why.

Indicating the EDA peak

- Whoosh sound, current mapping
- Chimes sound
- Other...

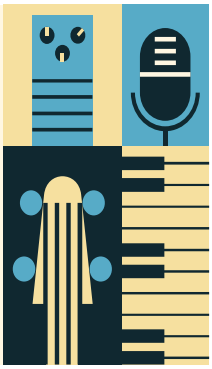
Part 3 - Experimenting with different variables ★

5 min together.
Discuss what would be the preferred way of indicating tempo, and why.

Indicating the tempo

- Using a tom sound every beat current mapping
- Using a tom sound only at the first beat
- Using more drum elements (e.g. combination of tom and hi-hat)
- No drum sound, only chords playing at the right tempo
- Other...

★ Suggestions?



B Quick Scan

Ethics and Privacy Quick Scan (version: 31 July 2023)

Section 1. Research projects involving human participants

		Yes	No
P1	Does your project involve human participants? This includes for example use of observation, (online) surveys, interviews, tests, focus groups, and workshops where human participants provide information or data to inform the research. If you are only using existing data sets or publicly available data (e.g. from Twitter, Reddit) without directly recruiting participants, please answer no.	x	

If no, continue with Section 2; if yes, fill in the following questions.

Recruitment

		Yes	No
P2	Does your project involve participants younger than 18 years of age?		x
P3	Does your project involve participants with learning or communication difficulties of a severity that may impact their ability to provide informed consent?[1]		x
P4	Is your project likely to involve participants engaging in illegal activities?		x
P5	Does your project involve patients?		x
P6	Does your project involve participants belonging to a vulnerable[2] group, other than those listed above?		x

If the answer to all of P2-P6 is no, continue with P8.

As you are dealing with vulnerable participants (yes to one (or more) of P2-P6) a fuller ethical review is required. Please add more detail on your participants here:

[1] For informed consent people need to be able to (1) understand information provided relevant to making the consent decision, (2) retain this information long enough to be able to make a decision, (3) weigh the information, (4) communicate the decision.

[2] Vulnerable people include those who are legally incompetent, who may have difficulty giving or withholding consent, or who may suffer highly adverse consequences if their personal data were to become publicly available or from participating. Examples include irregular immigrants, sex workers, dissidents and traumatized people at risk of re-traumatization.

		Yes	No
P7	Do you intend to be alone with a research participant or have to take sole responsibility for the participants at any point during your research activity?		**x**

If P7 is no continue with P8, otherwise:



As you will be alone with or solely responsible for vulnerable participants (yes to P7) a fuller ethical review is required. You may also need a Certificate of Conduct (Dutch: VOG) from the government. Please add more detail here:

		Yes	No
P8	Does your project involve participants with whom you have, or are likely to have, a working or professional relationship: for instance, staff or students of the university, professional colleagues, or clients?	**x**	

If the answer to P8 is yes, please answer P9, otherwise, continue with PC1.

		Yes	No
P9	Is it made clear to potential participants that not participating will in no way impact them (e.g. it will not directly impact their grade in a class)?	**x**	

If the answer to P9 is yes, then continue with PC1, otherwise:



As participants may think that not participating may harm them (yes to P8 and no to P9), participation may no longer be voluntary. Hence, a fuller ethical review is required. Please provide more information here:

Consent Procedures		**Yes**	**No**	**Not applicable**
PC1	Do you have set procedures that you will use for obtaining *informed* consent from all participants, including (where appropriate) parental consent for children or consent from legally authorized representatives? (See suggestions for information sheets and consent forms on the website[3].)	x		
PC2	Will you tell participants that their participation is voluntary?	x		
PC3	Will you obtain explicit consent for participation?	x		
PC4	Will you obtain explicit consent for any sensor readings, eye tracking, photos, audio, and/or video recordings?	x		
PC5	Will you tell participants that they may withdraw from the research at any time and for any reason?	x		
PC6	Will you give potential participants time to consider participation?	x		
PC7	Will you provide participants with an opportunity to ask questions about the research before consenting to take part (e.g. by providing your contact details)?	x		

If the answer to PC1-PC7 is yes, then continue with PC8, otherwise:

Given your responses to the informed consent questions (a no on any of PC1-PC7), a fuller ethical review is required. Please provide more information regarding the questions that are causing this here:

		Yes	**No**
PC8	Does your project involve concealment[4] or deliberate misleading of participants?		x

[3] uu.nl/en/research/institute-of-information-and-computing-sciences/ethics-and-privacy

[4] This may for example involve concealment of the study aim, of the identity of the researcher, or subliminal messaging during the study.

If the answer to PC8 no, continue with Section 2, otherwise:

 As you plan to use concealment or misleading (yes to PC8), and this may impact participants' rights to informed consent, a fuller ethical review is required. Please provide more information on the concealment/misleading here:

Section 2. Data protection, handling, and storage

The General Data Protection Regulation imposes several obligations for the use of **personal data** (defined as any information relating to an identified or identifiable living person) or including the use of personal data in research.

		Yes	No
D1	Are you gathering or using personal data (defined as any information relating to an identified or identifiable living person[5])?	x	

If the answer to D1 is yes, please answer the following questions; otherwise, continue with Section 3.

High-Risk Data

		Yes	No
DR1	Will you process personal data that would jeopardize the physical health or safety of individuals in the event of a personal data breach?		x
DR2	Will you combine, compare, or match personal data obtained from multiple sources, in a way that exceeds the reasonable expectations of the people whose data it is?[6]		x
DR3	Will you use any personal data of children or vulnerable individuals for marketing, profiling, automated decision-making, or to offer online services to them?		x

[5] This includes people's name, postal address, unique ID, IP address, voice, photo, video etc. When a person can be identified by combining multiple data points (e.g. gender + age + job role), this also constitutes personal data. When a person can be identified by a simple search online (e.g. with the content of a tweet) this also constitutes personal data. Note that Survey tool Qualtrics by default collects IP addresses and that the survey needs to be anonymized before distribution to prevent this.

[6] This is about the combined use of data sets that have been gathered for different purposes (so not within one study), making the data more personal or sensitive. For example, combining participant data with religion or ethnic statistics data from the CBS based on zip code.

DR4	Will you profile individuals on a large scale[7]?		**x**
DR5	Will you systematically monitor individuals in a publicly accessible area on a large scale[8] (or use the data of such monitoring)?[9]		**x**
DR6	Will you use special category[10] personal data, criminal offense personal data, or other sensitive personal data[11] on a large scale?		**x**
DR7	Will you determine an individual's access to a product, service, opportunity, or benefit[12] based on an automated decision or special category personal data?		**x**
DR8	Will you systematically and extensively monitor or profile individuals, with significant effects[13] on them?		**x**
DR9	Will you use innovative technology[14] to process sensitive personal data[15]?		**x**

If the answer to DR1-DR9 is no, continue with DM1, otherwise:

As high-risk data processing seems involved (yes to any of DR1-DR9), a fuller privacy assessment is required. Please provide more information on the DR1-DR9 questions with a yes here:

[7] Large scale is for example thousands of people, all visitors to a university website, data obtained over a very large time span
[8] Large scale is for example thousands of people, all visitors to the area, data obtained over a very large time span
[9] This may also include camera surveillance and use of drones
[10] Special category personal data is information about a person's health, ethnic origin, politics, religion, trade union membership, genetics, biometrics (where used in identification), sex life or sexual orientation.
[11] Other sensitive personal data includes for instance financial data (from which people's income, capital position or spending patterns can be derived), location data (from which people's movement patterns can be derived), achievement data (e.g. outcome of course work/exams, intelligence test; this excludes performance on tasks in a research study that are unrelated to their study/job), and communication data.
[12] Examples include: access to a mortgage, insurance, credit card, smartphone contract, course or degree programme, job opportunity.
[13] Significant effects are for example impacts on somebody's legal rights, automatic refusal of a credit application, automatic rejection for a job application.
[14] Innovative technology includes e.g. machine learning (including deep learning), neuro measurement (e.g. brain activity), autonomous vehicles, deep fakes, wearables, blockchain, internet of things.
[15] Sensitive personal data includes all data mentioned in DR6.

Data Minimization

		Yes	No
DM1	Will you collect only personal data that is strictly necessary for the research?	x	

If you answered yes to DM1 continue with DM4, otherwise:

		Yes	No
DM2	Will you only collect not strictly necessary personal data because it is (1) technically unfeasible not to collect it when collecting necessary data[16], or (2) needed as a source of necessary data[17]?		
DM3	Will you (1) extract any necessary data as soon as possible from the collected not strictly necessary data and (2) delete the not strictly necessary data immediately after any required extraction?[18]		
DM4	Will you anonymize the data wherever possible?[19]		
DM5	Will you pseudonymize the data if you are not able to anonymize it, replacing personal details with an identifier, and keeping the key separate from the data set?		

If the answer to any of DM2-DM5 is no, see warning below, otherwise continue with DC1.

As you do not seem to minimize data collection (no to any of DM2-DM5), a fuller privacy assessment is required. Please provide more information on the DM2-DM5 questions with a no here:

[16] This may for instance occur when IP data is collected automatically in Qualtrics, and it is unfeasible not to do so as other personal data such as email needs to be collected.
[17] This may, for instance, occur when audio data is captured from which audio features need extracting or a transcript needs to be produced.
[18] This may for instance happen when you collect audio data, extract audio features or transcribe an audio interview as soon as possible, and delete the original audio recording once done.
[19] Possible also means given the research question. So, for example, if you have done interviews and you need to be able to at a later date link them to performance data, it is impossible to anonymize the interviews, and you will need to pseudonymize them. You can then answer yes to DM4 as you are anonymizing where it is possible, and yes to DM5 if indeed you pseudonymize. Note that in such a case you should anonymize once the linking has been done, destroying the key that links the pseudonym to the identity of the participant.

Using Collaborators or Contractors that Process Personal Data Securely

		Yes	No
DC1	Will any organization external to Utrecht University be involved in processing personal data (e.g. for transcription, data analysis, data storage)?[20]	x	

If the answer to DC1 is yes, please complete DC2 otherwise continue with DI1.

		Yes	No
DC2	Will this involve data that is not anonymized?	x	

If the answer to DC2 is yes, please complete DC3-DC5, otherwise continue with DI1.

		Yes	No	Not Applicable
DC3	Are they capable of securely[21] handling data?	x		
DC4	Has been drawn up in a structured and generally agreed manner who is responsible for what concerning data in the collaboration?	x		
DC5	Is a written contract covering this data processing in place for any organization which is not another university in a joint research project?	x		

If the answer to any of DC3-DC5 is no, see warning below, otherwise continue with DI1.

As you do not seem to have appropriate processes in place for sharing data with collaborators or contractors (no to any of DC3-DC5), a fuller privacy assessment is required. Please provide more information on the DC3-DC5 questions with a no here:

[20] You can answer No if this is only the use of online software, as long as this software has been deemed safe by Utrecht University. See https://tools.uu.nl/tooladvisor/ for tools that are safe/not safe to use (e.g. Microsoft Word Online Transcribe is fine, NVivo Transcription is not).

[21] Secure handling includes for example: (1) only sharing data with those who legitimately need to see it, (2) data being securely stored on password-protected employer authorized IT systems (or in the case of non-digital data: in a secure locked location), (3) if portable devices such as USB sticks are used then only encrypted and password protected with data deleted as soon as it is no longer required to be portable, (4) reporting lost or stolen data immediately, (5) deleting or disposing of data as soon as it is no longer required and in a secure manner, (6) not discussing sensitive data in public places, (7) only carrying needed data when working off-site.

International Personal Data Transfers

		Yes	No
DI1	Will any personal data be transferred to another country (including to research collaborators in a joint project)?		x

If the answer to DI1 is yes, please complete DI2, otherwise continue with DF1.

		Yes	No
DI2	Do all countries involved in this have an adequate data protection regime?[22]		

If the answer to DI2 is no, please complete DI3, otherwise continue with DF1.

		Yes	No
DI3	Is a legal agreement in place?		

If the answer to DI2 and DI3 is no, see warning below, otherwise, continue with DF1.

As you do not seem to have appropriate safeguards in place for international data transfers (no to DI2 and DI3), a fuller privacy assessment is required. Please provide more information on intended international data transfers here:

Fair Usage of Personal Data to Recruit Participants

		Yes	No
DF1	Is personal data used to recruit participants?[23]		x

[22] Countries with an adequate data protection regime include EU countries, Andorra, Argentina, Canada (only commercial organizations), Faroe Islands, Guernsey, Israel, Isle of Man, Jersey, New Zealand, Switzerland, Uruguay, Japan, the United Kingdom, and South Korea.

[23] Intended here is the direct use of personal data to target a specific person. If you are using personal data indirectly to address a group of people, for example, sending a message via a *pre-existing* Microsoft Team, Blackboard course, Discord Channel, WhatsApp group, or crowd-sourcing platform, that is fine and will not be regarded as the use of personal data here. If you are asking friends or family members this will also not be regarded as use of personal data here.

If the answer to DF1 is yes please answer DF2-DF4, otherwise continue with DP1

		Yes	No	N/A
DF2	Have potential participants provided this personal data voluntarily to be contacted about the research or is the data publicly available?			
DF3	If contact details have been provided by a third party, would participants expect their details to be passed on to the university and to be used in this way?			
DF4	If contact details have been gathered for a purpose other than research, would participants expect their details to be used in this way?			

If the answers to DF2-DF4 are yes or N/A continue with DP1, otherwise:

As there seem to be issues with your use of personal data for recruitment (no to one or more of DF2-DF4), a fuller privacy assessment is required. Please provide more information on the intended use of personal data for recruitment here:

Participants' data rights and privacy information

		Yes	No	Not Applicable
DP1	Will participants be provided with privacy information? (Recommended is to use as part of the information sheet: For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information at www.uu.nl/en/organisation/privacy.)	**x**		
DP2	Will participants be aware of what their data is used for?	**x**		
DP3	Can participants request that their personal data be deleted?[24]	**x**		

[24] This only concerns requests for personal data that you still hold. If you can no longer link the data to a participant due to anonymization, you can no longer delete, rectify or provide access to it. This should be clear to participants in the consent form. If the data is pseudonymized and you cannot access the key but the participant can (for example when the key is a WorkerID from a crowd-sourcing platform), participants should be able to request deletion on the provision of the key.

		Yes	No	Not Applicable
DP4	Can participants request that their personal data be rectified (in case it is incorrect)?[24]	x		
DP5	Can participants request access to their personal data?[24]	x		
DP6	Can participants request that personal data processing is restricted?	x		
DP7	Will participants be subjected to automated decision-making based on their personal data with an impact on them beyond the research study to which they consented?		x	
DP8	Will participants be aware of how long their data is being kept for, who it is being shared with, and any safeguards that apply in case of international sharing?	x		
DP9	If data is provided by a third party, are people whose data is in the data set provided with (1) the privacy information and (2) what categories of data you will use?	x		

If the answer to DP1-DP6, DP8, DP9 is yes and DP7 is no, continue with DE1, otherwise:



As there seem to be issues with the data rights of your participants or the provision of privacy information (no to one or more of DP1-DP6, DP8, DP9, or yes to DP7), a fuller privacy assessment is required. Please provide more detail regarding data rights and/or privacy information here:

Using data you have not gathered directly from participants

		Yes	No
DE1	Will you use any personal data[25] that you have not gathered directly from participants (such as data from an existing data set, data gathered by a third party, data scraped from the internet)?		x

If the answer to DE1 is no please continue with DS1.

		Yes	No
DE2	Will you use an existing dataset in your research?		

If the answer to DE2 is yes please answer DE3-DE5, otherwise, continue with DE6.

[25] Defined as any data related to an identified or identifiable living person. This includes people's name, postal address, unique ID, IP address, voice, photo, video etc. When a person can be identified by combining multiple data points (e.g. gender + age + job role), this also constitutes personal data.

		Yes	No
DE3	Do you have permission to do so from the owners of the dataset?		
DE4	Have the people whose data is in the data set consented to their data being used by other researchers and/or for purposes other than that for which that data set was gathered?		
DE5	Are there any contractual conditions attached to working with or storing the data from DE2?		

		Yes	No
DE6	Does your project require access to personal data about participants from other parties (e.g., teachers, employers), databanks, or files[26]?		

If the answer to DE6 is yes please answer DE7-DE8, otherwise, continue with DE9.

		Yes	No
DE7	Do you have a process in place to gain informed consent from these participants?		
DE8	Are there any contractual conditions attached to working with or storing the data from DE5?		

		Yes	No
DE9	Does the project involve collecting personal data from websites or social media (e.g., Facebook, Twitter, Reddit)?		

As there may be issues with the use of existing data (no to DE3, DE4, DE7 or yes to DE9), a fuller privacy assessment is required. Please provide more detail regarding the use of existing data here:

[26] For example, do you get a student's grade from the teacher, in addition to data gathered directly in your study or data in an existing research data set?

Secure data storage

		Yes	No
DS1	Will any data be stored (temporarily or permanently) anywhere other than on password-protected University authorized computers or servers?[27]		**x**

If the answer to DS1 is yes, please answer DS2, otherwise, continue with DS4.

		Yes	No
DS2	Does this only involve data stored temporarily during a session with participants (e.g. data stored on a video/audio recorder/sensing device), which is immediately transferred (directly or with the use of an encrypted and password-protected data-carrier (such as a USB stick)) to a password-protected University authorized computer or server, and deleted from the data capture and data-carrier device immediately after transfer?		

If the answer to DS2 is yes, continue with DS4, otherwise answer DS3.

		Yes	No
DS3	Does this only involve data stored with a collaborator or contractor?		
DS4	Excluding (1) any international data transfers mentioned above and (2) any sharing of data with collaborators and contractors, will any personal data be stored, collected, or accessed from outside the EU[28]?		

If the answer to DS2 and DS3 is no, or the answer to DS4 is yes, see the warning below, otherwise continue with Section 3.

As there may be issues with secure data storage (no to DS2 and DS3, or yes to DS4), a fuller privacy assessment is required. Please provide more detail regarding data storage here:

[27] OneDrive business, Qualtrics, Microsoft Forms are ok. Do not use Google Drive/Sheets/Docs/Forms, Dropbox, OneDrive personal. See https://tools.uu.nl/tooladvisor/ for tools that are safe/not safe to use. Bachelor and master students are authorized to use a password-protected personal computer, as long as that computer is not shared with other people.
[28] This may happen, for instance, when data is collected and stored on a Utrecht University laptop whilst abroad.

Section 3: Research that may cause harm

Research may harm participants, researchers, the university, or society. This includes when technology has dual-use, and you investigate an innocent use, but your results could be used by others in a harmful way. If you are unsure regarding possible harm to the university or society, please discuss your concerns with the Research Support Office.

		Yes	No
H1	Does your project give rise to a realistic risk to the national security of any country?[29]		**x**
H2	Does your project give rise to a realistic risk of aiding human rights abuses in any country?[30]		**x**
H3	Does your project (and its data) give rise to a realistic risk of damaging the University's reputation? (E.g., bad press coverage, public protest.)		**x**
H4	Does your project (and in particular its data) give rise to an increased risk of attack (cyber- or otherwise) against the University? (E.g., from pressure groups.)		**x**
H5	Is the data likely to contain material that is indecent, offensive, defamatory, threatening, discriminatory, or extremist?		**x**
H6	Does your project give rise to a realistic risk of harm to the researchers?[31]		**x**
H7	Is there a realistic risk of any participant experiencing physical or psychological harm or discomfort?[32]		**x**
H8	Is there a realistic risk of any participant experiencing a detriment to their interests as a result of participation?		**x**
H9	Is there a realistic risk of other types of negative externalities?[33]		**x**

[29] For example, research that can be used for autonomous armed vehicles/drones/robots, research on automated detection of objects, research on AI-enhanced forgery of video/audio data.
[30] For example, research on natural language/video/audio processing for automated identification of people's identity, sentiments, or opinions.
[31] For example, research that involves potentially violent participants such as criminals, research in likely unsafe locations such as war zones, research on an emotionally highly challenging topic, research in which the researcher is alone with a not previously known participant in the participant's home.
[32] For example, research that involves strenuous physical activity, research that stresses participants, research on an emotionally challenging topic.
[33] A negative externality is a harm produced to a third party, society in general, or the environment. For instance, intended or unintended negative ethical (e.g. bad governance or management practices), social (e.g. consumerism, inequality) or environmental effects (e.g. large CO_2 footprint or e-waste production) of your project.

If the answer to H1-H9 is no continue with Section 4, otherwise:

As you replied yes to one (or more) of H1-H9, a fuller ethical review is required. Please provide more detail here on the potential harm, and how you will minimize risk and impact:

Section 4: Conflicts of interest

		Yes	No
C1	Is there any potential conflict of interest (e.g. between research funder and researchers or participants and researchers) that may potentially affect the research outcome or the dissemination of research findings?		x
C2	Is there a direct hierarchical relationship between researchers and participants?		x

If the answer to C1-C2 is yes, continue with Section 5, otherwise:

As you replied yes to C1 or C2, a fuller ethical review is required. Please provide more information regarding possible conflicts of interest and how you mitigate them here:

Section 5: Your information

This last section collects data about you and your project so that we can register that you completed the Ethics and Privacy Quick Scan, sent you (and your supervisor) the summary of what you filled out, and follow up where a fuller ethics review and/or privacy assessment is needed. For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information. Please see the guidance on the ICS Ethics and Privacy website on what happens on submission.

Z0. Which is your main department?

- ○ Information and Computing Science
- ~~○ Freudenthal Institute~~
- ~~○ Pharmacy~~
- ~~○ Other, namely:~~

Z1. Your full name: Renske Eline Bootsma

Z2. Your email address: r.e.bootsma@students.uu.nl

Z3. In what context will you conduct this research?

~~o 1. As a student on a course with course coordinator:~~
~~o 2. As a student for my bachelor thesis, supervised by:~~
o 3. As a student for my master thesis, supervised by: Marit Bentvelzen
~~o 4. As a PhD student, supervised by:~~
~~o 5. As an independent researcher (e.g. research fellow, assistant/associate/full professor)~~

In case the answer to Z3 is 2:

Z4. Bachelor programme for which you are doing the thesis:

o Artificial Intelligence (Kunstmatige Intelligentie)
o Computing Science (Informatica)
o Information Science (Informatiekunde)
o Other:

In case the answer to Z3 is 3:

Z5. Master programme for which you are doing the thesis:

~~o Applied Data Science~~
~~o Artificial Intelligence~~
~~o Business Informatics~~
~~o Computing Science~~
~~o Data Science~~
~~o Game and Media Technology~~
o Human-Computer Interaction
~~o Other:~~

In case the answer to Z3 is 1, 2, 3, or 4:

Z6. Email of the course coordinator or supervisor (so that we can inform them that you filled this out and provide them with a summary):

m.bentvelzen@uu.nl

In case the answer to Z3 is 2 or 3:

Z7. Email of the moderator (as provided by the coordinator of your thesis project):
graduation.hci@uu.nl

Z8. Title of the research project/study for which you filled out this Quick Scan:

Communication Between Loved Ones: Sharing Biomusic

Z9. Summary of what you intend to investigate and how you will investigate this (200 words max):

We will focus on researching the effect of sharing biomusic on (remote) communication between loved ones. For that, we will create biomusic of participants, by mapping their biofeedback (heart rate, electrodermal activity and respiration) to musical elements (pitch, tempo, accents). This music will be shared between loved ones, after which we research its effect on perceived empathy and social connectedness, by using standardized and validated questionnaires. Lastly, interviews will be held to gain insights into the experiences of the participants with the biomusic and to find the reasoning behind their answers.

In case the answer to Z3 is 2 or 3:

		Yes	No	Not Applicable
Z10.	In case you encountered warnings in the survey, does your supervisor already have ethical approval for a research line that fully covers your project?			**x**

In case the answer to Z10 is yes:

Z11. Provide details on the ethical approval (e.g. ethical approval number):

C Pilot Test

C.1 Questionnaires and Interview Questions

Initial Protocol - Questionnaires and Interview Questions

Sender – Demographics

General

- What is your dyad number?
- …
- What is your gender?
  - Male
  - Female
  - Non-binary / third gender
  - Prefer not to answer
  - Other: …
- What is your age? *Please answer in number of years*
  - … year
- How often do you send voice messages?
  - Never
  - Rarely
  - Occasionally
  - Sometimes
  - Frequently
  - Very frequently
  - Always
- What is the content of these voice messages? *Please select all applicable answers*
  - Short practical statements (e.g. how late you are home, or which groceries to bring)
  - Sharing experiences (e.g. sharing some thoughts, emotions or updates)
  - Having a conversation (e.g. responding to someone's message and asking questions)
  - Other: ….
- What is the average duration of the voice messages you send?
  - … minutes
- How often do you receive voice messages?
  - Never
  - Rarely
  - Occasionally
  - Sometimes
  - Frequently
  - Very frequently
  - Always
- What is the content of these voice messages? *Please select all applicable answers*
  - Short practical statements (e.g. how late you are home, or which groceries to bring)

    - Sharing experiences (e.g. sharing some thoughts, emotions or updates)
    - Having a conversation (e.g. responding to someone's message and asking questions)
    - Other: ….
- What is the average duration of the voice messages you receive?
    - … minutes
- What type of relationship do you have with the loved one whom you perform this study?
    - Romantic relationship
    - Close friendship
    - Family bond, namely: …
    - Other: …
- What is the length of this relationship? *For example "3 years and 2 months"*
    - …
- How do you usually communicate with this loved one, when not being physically present? *Please select all applicable answers*
    - Phone calls
    - Video calls
    - Text messages
    - Voice messages
    - Letters or cards
    - Other: …

Sender – Follow-up

- What is your dyad number?
- …
- What type of relationship do you have with the loved one whom you perform this study?
    - Romantic relationship
    - Close friendship
    - Family bond, namely: …
    - Other: …
- What is the length of this relationship? *For example "3 years and 2 months"*
    - …
- How do you usually communicate with this loved one, when not being physically present? *Please select all applicable answers*
    - Phone calls
    - Video calls
    - Text messages
    - Voice messages
    - Letters or cards
    - Other: …

Sender – Interview

- What is your overall impression of sharing biofeedback through biomusic in communication with your loved one?
- How comfortable are you with sharing your biofeedback – biomusic with your loved one?
    - Does the type of relation with the interacting partner affect your answer?
    - Why would you share biofeedback with others?
- Would you like to receive biomusic?
    - Does the type of relation with the interacting partner affect your answer?
- What do you think about the ease of recording the biofeedback?
    - Would you in the future do this yourselves?
- What do you think about the current way of creating the biomusic?
- Would you be interested in using biomusic in your communication?
    - If so, in what type of communication? E.g. voice message, live conversation, audio calling video calling, listening to the music in the background without having a conversation etc.
    - With what type of interacting partners?
- Any other questions, remarks or suggestions?

Receiver – Demographics and B-IRI

General

- What is your dyad number?
- …
- What is your gender?
    - Male
    - Female
    - Non-binary / third gender
    - Prefer not to answer
    - Other: …
- What is your age? *Please answer in number of years*
    - … year
- How often do you send voice messages?
    - Never
    - Rarely
    - Occasionally
    - Sometimes
    - Frequently
    - Very frequently
    - Always
- What is the content of these voice messages? *Please select all applicable answers*
    - Short practical statements (e.g. how late you are home, or which groceries to bring)

    - Sharing experiences (e.g. sharing some thoughts, emotions or updates)
    - Having a conversation (e.g. responding to someone's message and asking questions)
    - Other: ….
- What is the average duration of the voice messages you send?
    - … minutes
- How often do you receive voice messages?
    - Never
    - Rarely
    - Occasionally
    - Sometimes
    - Frequently
    - Very frequently
    - Always
- What is the content of these voice messages? *Please select all applicable answers*
    - Short practical statements (e.g. how late you are home, or which groceries to bring)
    - Sharing experiences (e.g. sharing some thoughts, emotions or updates)
    - Having a conversation (e.g. responding to someone's message and asking questions)
    - Other: ….
- What is the average duration of the voice messages you receive?
    - … minutes
- What type of relationship do you have with the loved one whom you perform this study?
    - Romantic relationship
    - Close friendship
    - Family bond, namely: …
    - Other: …
- What is the length of this relationship? *For example "3 years and 2 months"*
    - …
- How do you usually communicate with this loved one, when not being physically present? *Please select all applicable answers*
    - Phone calls
    - Video calls
    - Text messages
    - Voice messages
    - Letters or cards
    - Other: …

Empathy – Brief Interpersonal Reactivity Index (B-IRI)

The following statements inquire about your thoughts and feelings in a variety of situations. For each item, indicate how well it describes you by choosing the appropriate answer on the scale. Read each item carefully before responding and answer as honestly as you can.

Answer options:

- Does not describe me at all
- Describes me slightly
- Describes me moderately
- Describes me well
- Describes me very well

Statements:

1. I often have tender, concerned feelings for people less fortunate than me.
2. I really get involved with the feelings of the characters in a novel.
3. In emergency situations, I feel apprehensive and ill-at-ease.
4. I try to look at everybody's side of a disagreement before I make a decision.
5. When I see someone being taken advantage of, I feel kind of protective toward them.
6. I sometimes try to understand my friends better by imagining how things look from their perspective.
7. After seeing a play or movie, I have felt as though I were one of the characters.
8. Being in a tense emotional situation scares me.
9. When I see someone being treated unfairly, I feel very much pity for them.
10. I would describe myself as a pretty soft-hearted person.
11. When I watch a good movie, I can very easily put myself in the place of a leading character.
12. I tend to lose control during emergencies.
13. When I'm upset at someone, I usually try to "put myself in his shoes" for a while.
14. When I am reading an interesting story or novel, I imagine how I would feel if the events in the story were happening to me.
15. When I see someone who badly needs help in an emergency, I go to pieces.
16. Before criticizing somebody, I try to imagine how I would feel if I were in their place.

Receiver – Voice Message

Voice message

In this questionnaire, you will answer some questions regarding the perceived empathy and social connectedness towards your loved one, based on the voice message you just listened.

- What is your dyad number?
  - …

Empathy

The following statements concern your thoughts and feelings towards the voice message you just heard. For each item, indicate to what extent you agree by choosing the

appropriate answer on the scale. Read each item carefully before responding and answer as honestly as you can.

Answer options:

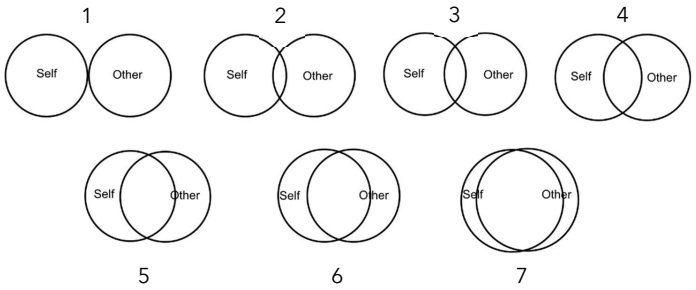
- I strongly disagree
- I disagree
- Neither agree nor disagree
- I agree
- I strongly agree

Statements:

- I understood my loved one's desire
- I understood how my loved one is feeling
- I understood the situation of the content
- I understood my loved one's motive behind their behaviour
- I experienced many of the same feelings that my loved one portrayed
- I experienced desires of my loved one which were similar with my current desire or desire that I could feel in the future
- I experienced the events in the content were similar with my experience or experience that could happen to me
- I felt as if the events in the content could happen to me

Social connectedness

Below, you see seven pairs of circles that range from just touching to almost completely overlapping. Based on listening to the previous voice message, indicate which picture best describes your relationship with your loved one.



Receiver – Interview

- What is your overall impression of sharing biofeedback through biomusic in communication with your loved one?
- Do you think the biomusic adds something to the voice message? E.g. information, feeling of closeness etc.
    - Why, or why not?
    - What would be better or worse?
- When comparing the two voice messages (one with and one without biomusic) do you experience a difference in empathy and / or social connectedness / closeness towards your loved one?
- Would you be interested in using biomusic in your communication?
    - If so, in what type of communication? E.g. voice message, live conversation, video calling, listening to the music in the background without having a conversation etc.
    - With what type of interacting partners?
- How comfortable are you with sharing your biofeedback – biomusic with your loved one?
    - Does the type of relation with the interacting partner affect your answer?
- Did you feel distracted by the biomusic while listening to the voice message?
- (What do you think about the sound of the music, the current way of creating the biomusic?)
- Any other questions, remarks or suggestions?

C.2 Protocol Sender and Receiver

User test - Protocol

General information

- Goal:
  - Determine the effect of adding biomusic to a voice message on the perceived empathy and social connectedness between loved ones
- Participants:
  - Adults
  - Loved ones → close relationships
    - Sender can be used multiple times
    - Receiver can be used once
- Recruitment process:
  - Convenience sampling →
    - asking colleagues at CWI
    - asking friends
    - asking family
  - Snowball sampling →
    - Asking friends of friends / family
  - Voluntary response sampling →
    - Distributing flyers / invitations amongst CWI and UU
- Timeline:
  - User tests: 29-04-2024 – 16-05-2024
- Language:
  - English and Dutch
- Data to be collected:
  - Audio recording and transcript of the user test
  - Photos of the user test
  - Biological data of Empatica E4: PPG, ACC, EDA, TEMP, HR, IBI
  - Demographic characteristics
  - Questions regarding empathy and social connectedness
  - Questions regarding feelings towards biomusic

Preparation

Thanks for willing to participate in my study! Hereby a message about the preparation of the study. As you know, you have been recruited in dyads of loved ones. With this, we mean people with a close relationship, such as romantic couples, close friends or family bonds. The dyads will send and listen to voice messages; therefore, one participant will be the sender and one participant will be receiver. The sender will record two voice messages, while their biofeedback (heart rate and electrodermal activity) will be recorded.

You will be the *sender*. Therefore, I ask you to *think about conversation topics* for recording the two voice messages. These messages should have a duration of 1 to 3 minutes, and should not be about practical updates (such as 'I'll be home at 5 and bring the groceries) but rather be of a conversational type, including a feeling or emotion. The two messages do not have to be about the same topic. The voice messages will be played to your loved one (the receiver) as soon as possible, at least within a week.

Below, a few example topics are listed for inspiration.

- Share your thoughts and feelings about a book you've read, movie you've seen, a museum you've been, a city you have explored etc
- Recall a (childhood) memory, express how it affected you
- Tell about something you are proud of, an achievement of yourself or a loved one
- Tell about your plans and feelings towards the next holiday, which plans you made
- Tell about what's on your bucket list: what are your dreams, goals and motives
- Tell about which food you love, or what cuisine you would like to try out some time
- Tell about something that happened to you and how that made you feel
- Tell about how you feel towards the other

Protocol - Sender

Materials

- Empatica E4 + charger
- Laptop + charger
- Slides with explanations
- Information sheets
- Consent forms
- Questionnaire regarding demographics
- Pens
- Backup conversation topics and written text
- Recording device
- FOOD

Preparation

- Present slide deck on laptop
- Position consent forms + information sheets + pens
- Position Empatica E4, ensure a full battery
- Open the questionnaire on laptop
- Check whether the voice message recording device works
- Open teams, start meeting
- Turn off Laptop notifications

User test overview

Introduction (10min)

- Let them fill in the consent + demographics + empathy questionnaire
- Start Teams recording
- Explaining the goal of the research
- Explain the working of biomusic
    - Play an example of biomusic
- Explain the voice message recording

Part 1: Record voice message 1 (10min)

- Attach Empatica E4 → on non dominant wrist
    - Ask participants to hold their arm still during the recording
- Start biofeedback recording
- Check whether they have conversation topics
    - Wait at least 14 seconds

- Leave the room
- Let them start audio recording + click on the time stamp on the Empatica E4
- When finished: let them click on the time stamp on the Empatica E4
- Come back
- Stop audio recording
- Stop Empatica recording
- Check whether the recording appears

Part 2: Record voice message 2 (5min)

- Start biofeedback recording
- Check whether they have conversation topics
    - Wait at least 14 seconds
- Leave the room
- Let them start audio recording + click on the time stamp on the Empatica E4
- When finished: let them click on the time stamp on the Empatica E4
- Come back
- Stop audio recording
- Stop Empatica recording
- Check whether the recording appears

Interview (10min)

- Stop Teams recording
- Start Teams recording
- Explain the conversion process
- Ask interview questions
- Thank the participant for joining
- Stop Teams recording

Follow-up:

- Fill in follow-up questionnaire
- Record voice message 1
- Record voice message 2

Detailed user test description

Introduction (10 min)

Let the participant read the information sheet, sign the consent form + fill in questionnaire

Start Teams recording on laptop

This session will consist of the following topics: an introduction to the study, recording 2 messages, and a closing interview.

Goal. Nowadays, more and more communication is asynchronous and online. Not being physically present while communicating brings challenges and offers opportunities for new ways of communication. Therefore, I am researching the use of BioMusic in communication and want to explore it's effect on empathy and social connectedness.

With BioMusic, I mean generating music based on one's biofeedback, and in this study, BioMusic will be added to voice messages that you send to loved ones.

Biomusic. The biomusic is generated, based on biofeedback. For that, we chose to use heart rate and electrodermal activity. Simply said, EDA is measuring the skin conductance, or sweat level. EDA peaks occur when your body reacts on a sudden event, such as someone scaring you, laughing, but also physical activity and emotional reactions.

Using these biofeedback elements, I create the BioMusic as follows:

- Tempo of the music, this is based on your heartbeat
    - the higher your heartbeat, the faster the music will be
- A chord in the background, this is based on the average EDA values
    - The chord is played on a guitar and a piano
    - An increase of EDA will increase the pitch of the chord, and simultaneously, a decrease of EDA will decrease the pitch of the chord
- A little twinkle, this is played when an EDA peak occurs

Combining those elements results in the following biomusic → ***play biomusic sample***. Thus, changing music indicates changes in the physiological state.

Voice message. For the communication, we will use the format of voice messages, being used for communication rather than practical statements.

Therefore, you will record two voice messages for one of your loved ones, while your biofeedback will be recorded. This biofeedback will be converted into music and added as a background music to your voice message. Following, we will send the messages to your loved one and ask about their opinion, their perceived empathy and social connectedness.

Part 1: Record voice message 1 (10min)

Check whether the participant has thought about a topic of conversation. If it appeared to be difficult, give the participant the sheet of conversation topics as inspiration. If it still appears to be difficult, let the participant read example text.

I will leave the room while you record, and won't listen to the voice messages myself. The only thing I have to do is checking whether something is recorded and merging the voice message with the music. In addition, while playing the voice message to the sender I will not be present, so the message you record will be kept private, only for your loved one.

- Attach Empatica E4 → on non dominant wrist
    - Ask participants to hold their arm still during the recording
- Start biofeedback recording
- Check whether they have conversation topics
    - Wait at least 14 seconds
- Leave the room
- Let them start audio recording + click on the time stamp on the Empatica E4
- When finished: let them click on the time stamp on the Empatica E4
- Come back
- Stop audio recording
- Stop Empatica recording
- Check whether the recording appears

Part 2: Record voice message 2 (5min)

- Start biofeedback recording
- Check whether they have conversation topics
    - Wait at least 14 seconds
- Leave the room
- Let them start audio recording + click on the time stamp on the Empatica E4
- When finished: let them click on the time stamp on the Empatica E4
- Come back
- Stop audio recording
- Stop Empatica recording
- Check whether the recording appears

Interview (10min)

I will convert the biofeedback into music, and attach this to the voice message. Following, I will have the experiment with your loved one (either online or in person) and let them hear the voice messages. Following, I ask questions regarding their perceived empathy and social connectedness.

Stop Teams recording.

Start Teams recording.

For now, I have some questions regarding your opinion about biomusic and its use.

Interview questions

- What is your overall impression of sharing biofeedback through biomusic in communication with your loved one?
- How comfortable are you with sharing your biofeedback – biomusic with your loved one?
    - Does the type of relation with the interacting partner affect your answer?
    - Why would you share biofeedback with others?
- Would you like to receive biomusic?
    - Does the type of relation with the interacting partner affect your answer?
- What do you think about the ease of recording the biofeedback?
    - Would you in the future do this yourselves?
- What do you think about the sound of the music, the current way of creating the biomusic?
- Would you be interested in using biomusic in your communication?
    - If so, in what type of communication? E.g. voice message, live conversation, audio calling video calling, listening to the music in the background without having a conversation etc.
    - With what type of interacting partners?
- Any other questions, remarks or suggestions?

Stop teams recording.

Thanks a lot for joining!!

Follow-up:

- Fill in follow-up questionnaire
- Record voice message 1
    - Check whether the participant has thought about a topic of conversation. If it appeared to be difficult, give the participant the sheet of conversation topics as inspiration. If it still appears to be difficult, let the participant read example text.
    - Attach Empatica E4 → on non dominant wrist
    - Start biofeedback recording
    - Check whether they have conversation topics
        - Wait at least 14 seconds
    - Leve the room
    - Let them start audio recording + click on the time stamp on the Empatica E4
    - When finished: let them click on the time stamp on the Empatica E4
    - Come back
    - Stop audio recording
    - Stop Empatica recording
    - Check whether the recording appears
- Record voice message 2
    - Start biofeedback recording
    - Check whether they have conversation topics
        - Wait at least 14 seconds
    - Leve the room
    - Let them start audio recording + click on the time stamp on the Empatica E4
    - When finished: let them click on the time stamp on the Empatica E4
    - Come back
    - Stop audio recording
    - Stop Empatica recording
    - Check whether the recording appears

Protocol - Receiver

Materials

- Slides with explanations
- Laptop + charger
- Audio sample of biomusic changing beats
- Audio sample of biomusic changing chords
- Audio sample of sound effect
- Audio sample of biomusic
- Audio recording device
- Information sheets
- Consent forms
- Questionnaire regarding demographcis and ESC
- Questionnaire regarding ESC and general feelings
- Pens
- FOOD

Preparation

- Present slide deck on laptop
- Position consent forms + information sheets + pens
- Open the questionnaires on laptop
- Open Teams, start meeting
- Turn off laptop notifications

User test overview

Introduction (5min)

- Let them fill in the consent + demographics + empathy questionnaire
- Start Teams recording
- Explaining the goal of the research
- Explain the working of biomusic
    - Play an example of biomusic
    - Explain the meaning of the individual elements
- Explain the voice message listening

Part 1: Listen to voice message 1 (10min)

- Listen to voice message 1
- Fill in questionnaire regarding ESC

Part 2: Listen to voice message 2 (5min)

- Listen to voice message 2
- Fill in questionnaire regarding ESC

Interview (10min)

- Stop Teams recording
- Start Teams recording
- Ask interview questions
- Thank the participant for joining
- Stop Teams recording

Detailed user test description

Introduction (15 min)

Let the participant read the information sheet, sign the consent form + fill in questionnaire

Start Teams recording

This session will consist of the following topics: an introduction to the study, listening to the first voice message, then a little questionnaire, then listening to the second voice message, a little questionnaire again and the closing interview.

Goal. Nowadays, more and more communication is asynchronous and online. Not being physically present while communicating brings challenges and offers opportunities for new ways of communication. Therefore, I am researching the use of BioMusic in communication and want to explore it's effect on empathy and social connectedness.

With BioMusic, I mean generating music based on one's biofeedback, and in this study, BioMusic will be added to voice messages that you send to loved ones.

Biomusic. The biomusic is generated, based on biofeedback. For that, we chose to use heart rate and electrodermal activity. Simply said, EDA is measuring the skin conductance, or sweat level. EDA peaks occur when your body reacts on a sudden event, such as someone scaring you, laughing, but also physical activity and emotional reactions.

Using these biofeedback elements, I create the BioMusic as follows:

- Tempo of the music, this is based on your heartbeat
    - the higher your heartbeat, the faster the music will be
- A chord in the background, this is based on the average EDA values
    - The chord is played on a guitar and a piano

    - An increase of EDA will increase the pitch of the chord, and simultaneously, a decrease of EDA will decrease the pitch of the chord
- A little twinkle, this is played when an EDA peak occurs

Combining those elements results in the following biomusic → ***play biomusic sample***. Thus, changing music indicates changes in the physiological state.

Voice message. For the communication, we will use the format of voice messages, being used for communication.

Therefore, you will listen to two recorded voice messages of one of your loved ones. Their biofeedback was recorded, converted into BioMusic and added as background music to the voice message. After hearing the voice messages, you will fill in a questionnaire.

Part 1: Listen to voice message 1 (10min)

- Listen to voice message 1
- Fill in questionnaire regarding demographics and ESC

Part 2: Listen to voice message 2 (10min)

- Listen to voice message 2
- Fill in questionnaire regarding ESC and general feelings

Interview (10min)

Stop Teams recording

Start Teams recording

I have a few questions

- What is your overall impression of sharing biofeedback through biomusic in communication with your loved one?
- Do you think the biomusic adds something to the voice message? E.g. information, feeling of closeness etc.
    - Why, or why not?
    - What would be better or worse?
- When comparing the two voice messages (one with and one without biomusic) do you experience a difference in empathy and / or social connectedness / closeness towards your loved one?
- Would you be interested in using biomusic in your communication?
    - If so, in what type of communication? E.g. voice message, live conversation, video calling, listening to the music in the background without having a conversation etc.

    - With what type of interacting partners?
- How comfortable are you with sharing your biofeedback – biomusic with your loved one?
    - Does the type of relation with the interacting partner affect your answer?
- Did you feel distracted by the biomusic while listening to the voice message?
- (What do you think about the sound of the music, the current way of creating the biomusic?)
- Any other questions, remarks or suggestions?

Stop Teams recording

Thanks a lot for joining!!

C.3 Voice Message Topic Insipration

Voice message inspiration

Conversation topics

You can gain inspiration from the following topics

- Tell about how you feel towards the other
- Express your feelings towards a recent event
- Recall a (childhood) memory, express how it affected you
- Tell about something you are proud of, an achievement of yourself or a loved one
- Tell about what's on your bucket list: what are your dreams, goals and motives
- Share your thoughts and feelings about a book you've read, movie you've seen, a museum you've been, a city you have explored etc
- Tell about something that happened to you and how that made you feel
- Tell about your plans and feelings towards the next holiday, which plans you made
- Tell about which food you love, or what cuisine you would like to try out some time

Example text

If it's still difficult, please read the following message in a convincing way

Hi …. I'm not really sure what to say, so I'll just tell you what I loved about my previous holidays! I visited ….

Hi …. I'm not really sure what to say, so I'll just share my excitement about the coming holidays! I booked a trip to….

Hi …. I'm not really sure what to say, so I'm going to recommend you this cool book / city / movie / music I recently discovered!

D Reviewed User Test

D.1 Consent Sender

Sender – consent

Information sheet for collection and use of your personal data

Thank you for agreeing to participate in the user test session run by Utrecht University (UU) and Centrum Wiskunde & Informatica (CWI) the national research institute for mathematics and computer science. This study is carried out by Renske Bootsma (renske.bootsma@cwi.nl) as part of my master thesis regarding BioMusic, under supervision of Marit Bentvelzen (m.bentvelzen@uu.nl) and Abdallah El Ali (abdallah.el.ali@cwi.nl). We thank you for participating in our user test, which has a duration of approximately 30 minutes.

Information about the research

The goal of my research project is to investigate the effect of sharing biomusic on the perceived empathy and social connectedness between loved ones. For this, the biomusic will be generated based on biofeedback. In this user test, you will record voice messages for one of your loved ones, while your biofeedback is recorded. In addition, you will answer questions regarding demographical characteristics and questions regarding the use of biomusic.

Gathered data in this study

We will analyze your answers to the questionnaire and interview, and this will be linked to the basic demographic information you provide. No highly personal data (e.g., your name, nationality, etc.) will be collected. We will audio and video record and transcribe the session and take photos throughout the whole session, however faces will always be blurred. We will record the voice messages and record biofeedback using the Empatica E4. This will record your Blood Volume Pulse (BVP), Electrodermal Activity (EDA), skin temperature and motion based activity. This will be processed to subtract your Heart Rate, EDA and EDA peaks during the voice messages, which will be used to generate biomusic. The biomusic will be added to one of the voice messages as background music, resulting in one voice message with and one without biomusic. Following, both voice messages will be played to your loved one. After generating the biomusic, the biofeedback recordings will be deleted.

Data protection and privacy notice

This study has been allowed to proceed by the Research Institute of Information and Computing Sciences on the basis of an Ethics and Privacy Quick Scan. If you have a complaint about the way this study is carried out, please send an email to: ics-ethics@uu.nl. If you have any complaints or questions about the processing of personal data, please send an email to the Faculty of Sciences Privacy Officer: privacy-beta@uu.nl. The Privacy Officer will also be able to assist you in exercising the rights you have under the GDPR. For

details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information at www.uu.nl/en/organisation/privacy.

UU and CWI will store the data and would like to be able to use your data for academic research. This means that the data may be part of benchmark data study and/or scientific publication and/or presentations available to the scientific community in and outside Europe, where the personal data protection legislation may not offer the same level of protection to you as in the Netherlands and Europe. We assure you that your identity will remain fully confidential and secured at all times and in no way connected to the collected data. Your data will remain in the databases of CWI for 1 year; after this period they will be removed. As your data will be disseminated in the scientific community and integrated in computer models, they may remain in their possession for a longer period. You can exercise your rights according to personal data protection laws by contacting CWI, privacy@cwi.nl.

Consent form for collection and use of your personal data

Please complete the form below by ticking the relevant boxes and signing on the line below. A copy of the completed form will be given to you for your own record.

- ✓ I declare that I have carefully studied and understand the above information;
- ✓ I confirm that I am 18 years of age or over.
- ✓ I confirm that the research project BioMusic has been explained to me. I have had the opportunity to ask questions about the project and have had these answered satisfactorily. I had enough time to consider whether to participate.
- ✓ I consent to the material I contribute being used to generate insights for the research project BioMusic.
- ✓ I consent to audio and photo and video recordings being used in this study as explained in the information sheet. I understand that I can request to stop recordings at any time.
- ✓ I consent to biofeedback being recorded and these recordings being used in this study as explained in the information sheet. I understand that I can request to stop recordings at any time.
- ✓ I understand that if I give permission, the audio, photo, video and biofeedback recordings will be held confidentially so that only the researchers have access to the recordings. The recordings will be held in a secure storage for up to 31 July 2026 after which period they will be destroyed. In accordance with the General Data Protection Regulation (GDPR) I can have access to my recordings and can request them to be deleted at any time during this period.
- ✓ I understand that in addition to the recordings, other personal data will be collected from me as explained in the information sheet and that this data will be held confidentially so that only the researchers have access to this data and are able to trace it back to me personally. The data will be held in a secure storage for up to 31 July 2026 after which period it will be fully anonymized. In accordance with the General Data Protection Regulation (GDPR) I can have access to my personal data and can request it to be deleted at any time during this period.

- ✓ I understand that my participation in the study is voluntary and that I am free to withdraw at any time without giving a reason. Such withdrawal will only impact the session data, biofeedback data, images, audio and video recording in the database of UU and CWI; my session data, biofeedback data, images, audio and videorecording may still be available to those recipients in the scientific community who received it prior to my withdrawal;
- ✓ I consent to allow the fully anonymized data to be used in future publications and other scholarly means of disseminating the findings from the research project.
- ✓ I understand that the data acquired will be securely stored by researchers, but that appropriately anonymized data may in future be made available to others for research purposes. I understand that Utrecht University and CWI may publish appropriately anonymized data in appropriate data repositories for verification purposes and to make it accessible to researchers and other research users.
- ✓ I declare my consent to participate in the above described study, conducted within the BioMusic research project at Centrum Wiskunde & Informatica and Utrecht University.

- Name:
    - …
- Date:
    - …
- Signature:
    - …

D.2 Consent Receiver

Receiver – consent

Information sheet for collection and use of your personal data

Thank you for agreeing to participate in the user test session run by Utrecht University (UU) and Centrum Wiskunde & Informatica (CWI) the national research institute for mathematics and computer science. This study is carried out by Renske Bootsma (renske.bootsma@cwi.nl) as part of my master thesis regarding BioMusic, under supervision of Marit Bentvelzen (m.bentvelzen@uu.nl) and Abdallah El Ali (abdallah.el.ali@cwi.nl). We thank you for participating in our user test, which has a duration of approximately 45 minutes.

Information about the research

The goal of my research project is to investigate the effect of sharing biomusic on the perceived empathy and social connectedness between loved ones. For this, the biomusic will be generated based on biofeedback. In this user test, you will listen to two recorded voice messages from one of your loved ones. In addition, you will answer questions regarding demographical characteristics, empathy, social connectedness and questions regarding the biomusic.

Gathered data in this study

We will analyze your answers to the questionnaire and interview, and this will be linked to the basic demographic information you provide. No highly personal data (e.g., your name, nationality, etc.) will be collected. We will audio record and transcribe the session and take photos throughout the whole session, however faces will always be blurred.

Data protection and privacy notice

This study has been allowed to proceed by the Research Institute of Information and Computing Sciences on the basis of an Ethics and Privacy Quick Scan. If you have a complaint about the way this study is carried out, please send an email to: ics-ethics@uu.nl. If you have any complaints or questions about the processing of personal data, please send an email to the Faculty of Sciences Privacy Officer: privacy-beta@uu.nl. The Privacy Officer will also be able to assist you in exercising the rights you have under the GDPR. For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information at www.uu.nl/en/organisation/privacy.

UU and CWI will store the data and would like to be able to use your data for academic research. This means that the data may be part of benchmark data study and/or scientific publication and/or presentations available to the scientific community in and outside Europe, where the personal data protection legislation may not offer the same level of

protection to you as in the Netherlands and Europe. We assure you that your identity will remain fully confidential and secured at all times and in no way connected to the collected data. Your data will remain in the databases of CWI for 1 year; after this period they will be removed. As your data will be disseminated in the scientific community and integrated in computer models, they may remain in their possession for a longer period. You can exercise your rights according to personal data protection laws by contacting CWI, privacy@cwi.nl

Consent form for collection and use of your personal data

Please complete the form below by ticking the relevant boxes and signing on the line below. A copy of the completed form will be given to you for your own record.

- ✓ I declare that I have carefully studied and understand the above information;
- ✓ I confirm that I am 18 years of age or over.
- ✓ I confirm that the research project BioMusic has been explained to me. I have had the opportunity to ask questions about the project and have had these answered satisfactorily. I had enough time to consider whether to participate.
- ✓ I consent to the material I contribute being used to generate insights for the research project BioMusic.
- ✓ I consent to audio and photo and video recordings being used in this study as explained in the information sheet. I understand that I can request to stop recordings at any time.
- ✓ I consent to biofeedback being recorded and these recordings being used in this study as explained in the information sheet. I understand that I can request to stop recordings at any time.
- ✓ I understand that if I give permission, the audio, photo, video and biofeedback recordings will be held confidentially so that only the researchers have access to the recordings. The recordings will be held in a secure storage for up to 31 July 2026 after which period they will be destroyed. In accordance with the General Data Protection Regulation (GDPR) I can have access to my recordings and can request them to be deleted at any time during this period.
- ✓ I understand that in addition to the recordings, other personal data will be collected from me as explained in the information sheet and that this data will be held confidentially so that only the researchers have access to this data and are able to trace it back to me personally. The data will be held in a secure storage for up to 31 July 2026 after which period it will be fully anonymized. In accordance with the General Data Protection Regulation (GDPR) I can have access to my personal data and can request it to be deleted at any time during this period.
- ✓ I understand that my participation in the study is voluntary and that I am free to withdraw at any time without giving a reason. Such withdrawal will only impact the session data, biofeedback data, images, audio and video recording in the database of UU and CWI; my session data, biofeedback data, images, audio and videorecording may still be available to those recipients in the scientific community who received it prior to my withdrawal;
- ✓ I consent to allow the fully anonymized data to be used in future publications and other scholarly means of disseminating the findings from the research project.

- ✓ I understand that the data acquired will be securely stored by researchers, but that appropriately anonymized data may in future be made available to others for research purposes. I understand that Utrecht University and CWI may publish appropriately anonymized data in appropriate data repositories for verification purposes and to make it accessible to researchers and other research users.
- ✓ I declare my consent to participate in the above described study, conducted within the BioMusic research project at Centrum Wiskunde & Informatica and Utrecht University.

- Name:
  - …
- Date:
  - …
- Signature:
  - …

D.3 Protocol Sender

Sender – detailed

Materials

- Empatica E4 + charger
- Laptop + charger
- Slides with explanations
- Questionnaire regarding consent + demographics + follow-up questionnaire
- Voice message recording device
- Interview recording device (laptop with Teams)
- FOOD

Preparation

- Present slide deck on laptop
- Position Empatica E4, ensure a full battery
- Open the consent + demographics questionnaire on laptop
- Check whether the voice message recording device works
- Open teams, start meeting
- Turn off Laptop notifications

User test detailed description

Before the experiment

Hii, thanks for participating in my research towards BioMusic😊! I will explain the details of the experiment later, but before that, I would like to ask you to select *one photo*, for your loved one, containing a certain *feeling*, e.g. a memory or something recognizable and send this to me. It should be a photo that contains a certain feeling. Your loved one does not necessarily have to be in the picture, but it should contain e.g. a memory or something recognizable (such as a holiday, your family, wedding, activity together etc).

You will record one voice message and write one text message regarding this photo, during the experiment and your loved one will also see this photo.

Except for selecting a photo, you don't have to prepare anything!✨

Introduction (10 min)

- Let the participant fill in the consent + demographics questionnaire
- Open photo on laptop
- Start Teams recording on laptop

This session will consist of the following topics: an introduction to the study, recording 2 messages, and a closing interview.

Goal. Nowadays, more and more communication is asynchronous and online. Not being physically present while communicating brings challenges and offers opportunities for new ways of communication. Therefore, I am researching the use of BioMusic in communication and want to explore it's effect on empathy and social connectedness.

With BioMusic, I mean generating music based on one's biofeedback, and in this study, BioMusic will be added to voice messages that you send to loved ones.

Biomusic. The biomusic is generated, based on biofeedback. For that, we chose to use heart rate and electrodermal activity. Simply said, EDA is measuring the skin conductance, or sweat level. EDA peaks occur when your body reacts on a sudden event, such as someone scaring you, laughing, but also physical activity and emotional reactions.

Using these biofeedback elements, I create the BioMusic as follows:

- Tempo of the music, this is based on your heartbeat
    - the higher your heartbeat, the faster the music will be
- A chord in the background, this is based on the average EDA values
    - The chord is played on a guitar and a piano
    - An increase of EDA will increase the pitch of the chord, and simultaneously, a decrease of EDA will decrease the pitch of the chord
- A little twinkle, this is played when an EDA peak occurs

Combining those elements results in the following biomusic → ***play biomusic sample***. Thus, changing music indicates changes in the physiological state.

Text and voice message. For the communication, we will use the format of text messages and voice messages, since these are widely used for online communication. Therefore, you will record one voice message, and write one text message for your loved one, while your biofeedback will be recorded. This biofeedback will be converted into music and added as a background music to your voice message and text message. Following, we will send the messages to your loved one and ask about their opinion, their perceived empathy and social connectedness.

Part 1: Record voice message 1 (10min)

- Show their photo on the laptop

You will first record a voice message for your loved one, regarding your photo. Pay attention that it will not become a practical statement (such as 'I will be home at 3 and bring the groceries' but communicative, containing a certain emotion. For example, tell what made you choose the photo, how felt at the moment of the photo or how you feel

now, what you find interesting, funny, remarkable, memorable etc. Your loved one will see the photo when the voice message is played.

I will leave the room while you record, but be aware that for converting reasons, I probably have to read and listen to the messages, but will not be present while the sender listens and reads the messages. We will keep the messages private, only for us as researchers and your loved one.

- Attach Empatica E4 → on non dominant wrist
    - Ask participants to hold their arm still during the recording
- Start biofeedback recording
- Indicate that the participant has to stop the voice recording when finished
- Start the voice recording and mark the biofeedback recording on the Empatica and leave the room
- Let them record the message (this can be in the language that they usually use while communicating with their loved one)
- Come back when finished
- Stop biofeedback recording

Part 2: Record text message 2 (5min)

You will now write a text message for your loved one, regarding your photo for at least. Just as the voice message, pay attention that it will not become a practical statement (such as 'I will be home at 3 and bring the groceries' but communicative, containing a certain emotion. Your loved one will see the photo when the text message is shown. The text message you write may contain the same information as the voice message, as long as it is regarding the (feelings towards) the photo. For example, tell what made you choose the photo, how felt at the moment of the photo or how you feel now, what you find interesting, funny, remarkable, memorable etc.

- Start biofeedback recording
- Ask them to take their phone and go to the chat with their loved one
- Mark the start of the biofeedback recording on the Empatica when the participant starts typing
- Let them write the text message, BUT NOT SEND IT
- Mark the end on the biofeedback recording on the Empatica
- Let the participant send the text message to you

Interview (10min)

I will convert the biofeedback into music, and attach this to the voice message and text message. Following, I will have the experiment with your loved one, show them the photo and let them listen to the voice message and read the text message with and without biomusic. Following, I ask questions regarding their perceived empathy and social connectedness.

For now, I have some questions regarding your opinion about biomusic and its use.

- How does it feel to share your biofeedback, with your loved one, through biomusic?
    - Does this feel uncomfortable, difficult, easy, familiar etc?
- What is your overall impression of sharing biofeedback through biomusic in communication with your loved one?
- In what type of communication or which context would biomusic be valuable?
- Would you like to send your own biomusic to others (thus sharing your biofeedback), in the context of / while communicating?
    - does the type of communication (text, audio, image, video, live conversation, just listening) influence your answer?
    - does the interaction partner influence your answer?
- Would you like to receive biomusic from other people (thus hearing their biofeedback), in the context of communication?
    - does the type of communication (text, audio, image, video, live conversation, just listening) influence your answer?
    - does the interaction partner influence your answer?

- What do you think about the way the biomusic is currently created?
    - (how) would you change the creation and sound of the biomusic?
    - does changing the way the music is created change any of your previous answers?
- What do you think about the ease of recording the biofeedback?
    - Would you in the future do this yourselves?
- Do you have any other thoughts about the use of biomusic in communication?
- Do you have any other questions, remarks, suggestions?

Thank the participant for joining

- Stop teams recording

D.4 Protocol Receiver

Receiver – detailed

Materials

- Laptop + charger
- Slides with explanations
- Questionnaire regarding consent + demographics
- Questionnaire ESC1 and ESC2 (regarding empathy and social connection for the first and second condition)
- Voice message with and without biomusic
- Text message and biomusic
- Interview recording device (laptop with Teams)
- FOOD

Preparation

- Present slide deck on laptop
- Open the consent + demographics questionnaire on laptop
- Open ESC1 and ESC2 questionnaires on laptop
- Open photo
- Open teams, start meeting
- Turn off Laptop notifications
- Check which condition the participants hears first (biomusic or no biomusic)
- Open the user data (voice message, text message, photo) and ensure they are the correct format for sharing
- Send invitation link to the receiver

User test detailed description

Introduction (10 min)

- Let the participant fill in the consent + demographics questionnaire
- Start Teams recording on laptop

This session will consist of the following topics: an introduction to the study, listening to a voice message, reading a text message and a closing interview.

Goal. Nowadays, more and more communication is asynchronous and online. Not being physically present while communicating brings challenges and offers opportunities for new ways of communication. Therefore, I am researching the use of BioMusic in communication and want to explore it's effect on empathy and social connectedness.

With BioMusic, I mean generating music based on one's biofeedback, and in this study, BioMusic will be added to voice and text messages that are sent to loved ones.

Biomusic. The biomusic is generated, based on biofeedback. For that, we chose to use heart rate and electrodermal activity. Simply said, EDA is measuring the skin conductance, or sweat level. EDA peaks occur when your body reacts on a sudden event, such as someone scaring you, laughing, but also physical activity and emotional reactions.

Using these biofeedback elements, I create the BioMusic as follows:

- Tempo of the music, this is based on your heartbeat
    - the higher your heartbeat, the faster the music will be
- A chord in the background, this is based on the average EDA values
    - The chord is played on a guitar and a piano
    - An increase of EDA will increase the pitch of the chord, and simultaneously, a decrease of EDA will decrease the pitch of the chord
- A little twinkle, this is played when an EDA peak occurs

Combining those elements results in the following biomusic → ***play biomusic sample***. Thus, changing music indicates changes in the physiological state.

Text and voice message. For the communication, we will use the format of text messages and voice messages, since these are widely used for online communication. Therefore, one of your loved ones has recorded one voice message and written one text message, while heir biofeedback was recorded. This biofeedback has been converted into music and added to the messages. After each message, you will fill in a questionnaire.

Part 1: Listen to voice message 1 (5min)

- Send the voice message with / without biomusic
- Send the photo
- Let them listen to the voice message while looking at the photo and fill in the ESC1 questionnaire
- Send the voice message with / without biomusic
- Let them listen to the voice message while looking at the photo and fill in the ESC2 questionnaire

Part 2: Read the text message 1 (5min)

- Send the text message with / without biomusic
- Let them read the text message while looking at the photo and (not) listen to the biomusic and fill in the ESC1 questionnaire
- Send the message with / without biomusic
- Let them read the text message while looking at the photo and (not) listen to the biomusic and fill in the ESC2 questionnaire

Interview (10min)

I have a few questions regarding your experience.

- How did it feel to listen to your loved one's biofeedback through biomusic?
    - Does this feel uncomfortable, difficult, easy, familiar etc?

- Did you notice any difference regarding empathy based on the biomusic?
    - would another emotion in the message (neutral, sad, angry) have another effect?
- Did you notice any difference regarding social connection based on the biomusic?
    - would another emotion in the message (neutral, sad, angry) have another effect?

- Biomusic was played for two types of communication (audio, text), and you answered for each whether or not you liked it being added to the message. Did your answers differ per type of communication, or did you notice a difference in experience?
    - And if so, why?
- In what type of communication or which context would biomusic be valuable?
    - does the type of communication (text, audio, image, video, live conversation, just listening) influence your answer?
    - does the interaction partner influence your answer?

- Would you like to receive biomusic from other people (thus hearing their biofeedback), in the context of communication?
    - does the type of communication (text, audio, image, video, live conversation, just listening) influence your answer?
    - does the interaction partner influence your answer?
- Would you like to send your own biomusic to others (thus sharing your biofeedback), in the context of / while communicating?
    - does the type of communication (text, audio, image, video, live conversation, just listening) influence your answer?
    - does the interaction partner influence your answer?
- Do you think the biomusic provided information about the sender?

- Did you feel distracted by the biomusic while listening to the voice message or reading the text message?
- What do you think about the way the biomusic is currently created?
    - (how) would you change the creation and sound of the biomusic?
    - does changing the way the music is created change any of your previous answers?
- Do you have any other thoughts about the use of biomusic in communication?

D.5 Questionnaires

Reviewed Protocol - Questionnaires

Sender – Demographics

General

- What is participant ID?
  - …
- What is your dyad number?
  - …
- What is your gender?
  - Male
  - Female
  - Non-binary / third gender
  - Prefer not to answer
  - Other: …
- What is your age? *Please answer in number of years*
  - … year
- How often do you send voice messages?
  - Never
  - Rarely
  - Occasionally
  - Sometimes
  - Frequently
  - Very frequently
  - Always
- What is the content of these voice messages? *Please select all applicable answers*
  - Short practical statements (e.g. how late you are home, or which groceries to bring)
  - Sharing experiences (e.g. sharing some thoughts, emotions or updates)
  - Having a conversation (e.g. responding to someone's message and asking questions)
  - Other: ….
- How often do you receive voice messages?
  - Never
  - Rarely
  - Occasionally
  - Sometimes
  - Frequently
  - Very frequently
  - Always
- What is the content of these voice messages? *Please select all applicable answers*
  - Short practical statements (e.g. how late you are home, or which groceries to bring)
  - Sharing experiences (e.g. sharing some thoughts, emotions or updates)

    - Having a conversation (e.g. responding to someone's message and asking questions)
    - Other: ….
- How often do you send text messages?
    - Never
    - Rarely
    - Occasionally
    - Sometimes
    - Frequently
    - Very frequently
    - Always
- What is the content of these text messages? *Please select all applicable answers*
    - Short practical statements (e.g. how late you are home, or which groceries to bring)
    - Sharing experiences (e.g. sharing some thoughts, emotions or updates)
    - Having a conversation (e.g. responding to someone's message and asking questions)
    - Other: ….
- How often do you receive text messages?
    - Never
    - Rarely
    - Occasionally
    - Sometimes
    - Frequently
    - Very frequently
    - Always
- What is the content of these text messages? *Please select all applicable answers*
    - Short practical statements (e.g. how late you are home, or which groceries to bring)
    - Sharing experiences (e.g. sharing some thoughts, emotions or updates)
    - Having a conversation (e.g. responding to someone's message and asking questions)
    - Other: ….
- What type of relationship do you have with the loved one whom you perform this study?
    - Romantic relationship
    - Close friendship
    - Family bond, namely: …
    - Other: …
- What is the (approximate) duration of this relationship? *For example "3 years and 2 months"*
    - …
- How do you usually communicate with this loved one, when not being physically present? *Please select all applicable answers*
    - Phone calls

    - Video calls
    - Text messages
    - Voice messages
    - Letters or cards
    - Other: …

Sender – Follow-up

- What is your participant ID?
    - …
- What is your dyad number?
    - …
- What type of relationship do you have with the loved one whom you perform this study?
    - Romantic relationship
    - Close friendship
    - Family bond, namely: …
    - Other: …
- What is the (approximate) duration of this relationship? *For example "3 years and 2 months"*
    - …
- How do you usually communicate with this loved one, when not being physically present? *Please select all applicable answers*
    - Phone calls
    - Video calls
    - Text messages
    - Voice messages
    - Letters or cards
    - Other: …

Receiver – Demographics and B-IRI

General

These questions are exactly the same as the general demographic questions for the sender.

Empathy – Brief Interpersonal Reactivity Index (B-IRI)

The following statements inquire about your thoughts and feelings in a variety of situations. For each item, indicate how well it describes you by choosing the appropriate answer on the scale. Read each item carefully before responding and answer as honestly as you can.

Answer options:

- Does not describe me at all
- Describes me slightly
- Describes me moderately
- Describes me well
- Describes me very well

Statements:

1. I often have tender, concerned feelings for people less fortunate than me.
2. I really get involved with the feelings of the characters in a novel.
3. In emergency situations, I feel apprehensive and ill-at-ease.
4. I try to look at everybody's side of a disagreement before I make a decision.
5. When I see someone being taken advantage of, I feel kind of protective toward them.
6. I sometimes try to understand my friends better by imagining how things look from their perspective.
7. After seeing a play or movie, I have felt as though I were one of the characters.
8. Being in a tense emotional situation scares me.
9. When I see someone being treated unfairly, I feel very much pity for them.
10. I would describe myself as a pretty soft-hearted person.
11. When I watch a good movie, I can very easily put myself in the place of a leading character.
12. I tend to lose control during emergencies.
13. When I'm upset at someone, I usually try to "put myself in his shoes" for a while.
14. When I am reading an interesting story or novel, I imagine how I would feel if the events in the story were happening to me.
15. When I see someone who badly needs help in an emergency, I go to pieces.
16. Before criticizing somebody, I try to imagine how I would feel if I were in their place.

Receiver – ESC1 (first condition)

Message perception

In this questionnaire, you will answer some questions regarding the perceived empathy and social connectedness towards your loved one, based on the message that was displayed before.

- What is your participant ID?
  - …
- What message was just displayed?
  - Voice message, with biomusic
  - Voice message, without biomusic
  - Text message, with biomusic
  - Text message, without biomusic

Empathy

The following statements concern your thoughts and feelings towards the voice message you just heard. For each item, indicate to what extent you agree by choosing the appropriate answer on the scale. Read each item carefully before responding and answer as honestly as you can.

Answer options:

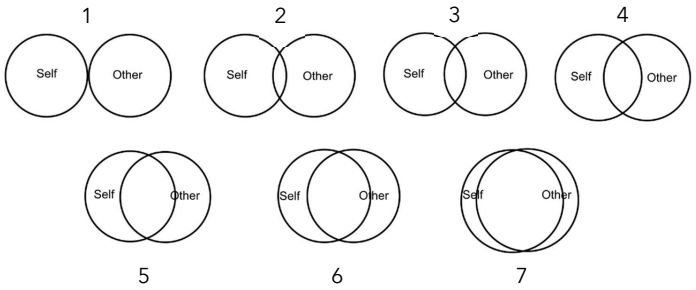
- I strongly disagree
- I disagree
- Neither agree nor disagree
- I agree
- I strongly agree

Statements:

- I understood my loved one's desire
- I understood how my loved one is feeling
- I understood the situation of the content
- I understood my loved one's motive behind their behaviour
- I experienced many of the same feelings that my loved one portrayed
- I experienced desires of my loved one which were similar with my current desire or desire that I could feel in the future
- I experienced the events in the content were similar with my experience or experience that could happen to me
- I felt as if the events in the content could happen to me

Social connectedness

Below, you see seven pairs of circles that range from just touching to almost completely overlapping. Based on listening to the previous voice message, indicate which picture best describes your relationship with your loved one.



Receiver – ESC2 (second condition)

Message perception

These questions are exactly the same as the ESC1 message perception questions.

Empathy

These questions are exactly the same as the ESC1 message perception questions.

Social connection

These questions are exactly the same as the ESC1 message perception questions.

General feeling

The following statements concern your thoughts and feelings towards the BioMusic and your loved one.

- Please choose the most applicable answer
  - I really don't like that biomusic was added to the message
  - I don't like that the biomusic was added to the message
  - Neutral / no strong feelings about biomusic being added to the message
  - I like that biomusic was added to the message
  - I really like that biomusic was added to the message
- Please indicate how the biomusic made you feel towards your loved one:
  - Much less emphatic
  - A bit less emphatic
  - The same emphatic
  - A bit more emphatic
  - Much more emphatic
- Please indicate how the biomusic made you feel towards your loved one:
  - Much less connected
  - A bit less connected
  - The same connected
  - A bit more connected
  - Much more connected

D.6 Protocol Converting the Biofeedback

Protocol - Converting

Materials

- Laptop with Ableton Live and the python script
- Biofeedback recording
- Voice message recording
- Music recording device – snippet on laptop
- Microsoft Clipchamp
- VLC Media player
- Audacity
- FOOD

Gathering all needed materials

- Save photo for loved one in the folder
- Make a screenshot of the text message for the loved one, crop this and save in the folder
- Save the voice message in the folder
- Convert voice message into mp3 format using VLC media player
- Crop the biofeedback of the voice message (how: see below)
- Crop the biofeedback of the text message (how: see below)
- Check and prepare the biofeedback data
    - Visual check in Empatica E4 visualisation
    - Clean the data running the python code
        - Check ranges – use mean imputation
        - Upsample EDA to 20Hz
- Create the biomusic by running the python code, while recording the screen
- Crop screen recording so that it contains solely the biomusic using Microsoft Clipchamp
- Convert the biomusic screen recording into mp3 using VLC media player
- Merge the voice message and biomusic using Audacity

Cropping biofeedback for voice message

- Fill in time stamp start
- Fill in duration of voice message in seconds
- Fill in time stamp start EDA
- Delete the first 2 rows of EDA
- Delete the number of values **before** the recording (indicated in orange)

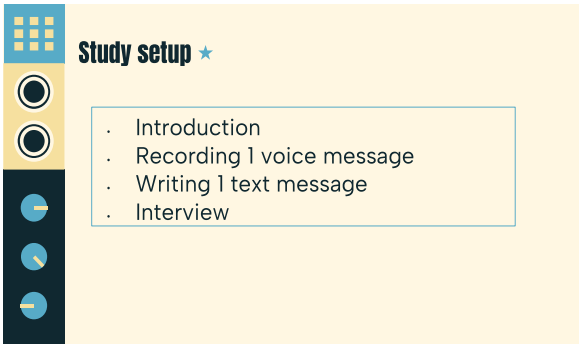
    - Based on the number of seconds before the recording * 4 (because frequency of 4Hz) - 15 (because these are used for taking the average of the first value)
    - Values are rounded downward, since a half number means that the new recording has not occurred yet.
- Delete the number of values **after** the recording (indicated in orange)
- Fill in time stamp start HR
- Delete the first 2 rows of HR
- Delete the number of values **before** the recording (indicated in orange)
    - Based on the number of seconds before the -3 (because these are used for taking the average of the first value)
    - Values are rounded downward, since a half number means that the new recording has not occurred yet.
- Delete the number of values **after** the recording (indicated in orange)

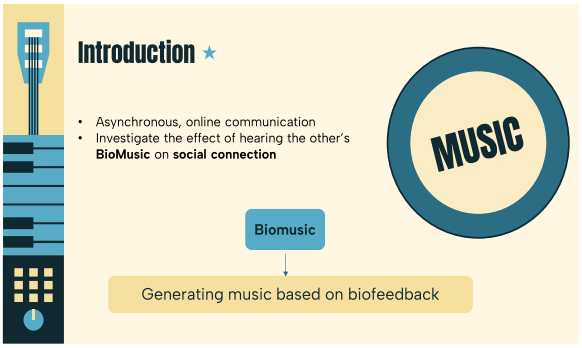
Cropping biofeedback for text message

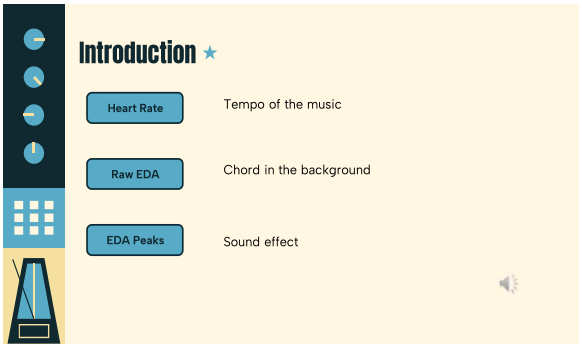
- Fill in time stamp start
- Fill in time stamp stop
- Fill in time stamp start EDA
- Delete the first 2 rows of EDA
- Delete the number of values **after** the recording (indicated in orange)
- Delete the number of values **before** the recording (indicated in orange)
    - Based on the number of seconds before the recording * 4 (because frequency of 4Hz) + 15 (because these are used for taking the average of the first value)
    - Values are rounded downward, since a half number means that the new recording has not occurred yet.
- Fill in time stamp start HR
- Delete the first 2 rows of HR
- Delete the number of values **after** the recording (indicated in orange)
- Delete the number of values **before** the recording (indicated in orange)
    - Based on the number of seconds before the + 3 (because these are used for taking the average of the first value)
    - Values are rounded downward, since a half number means that the new recording has not occurred yet.

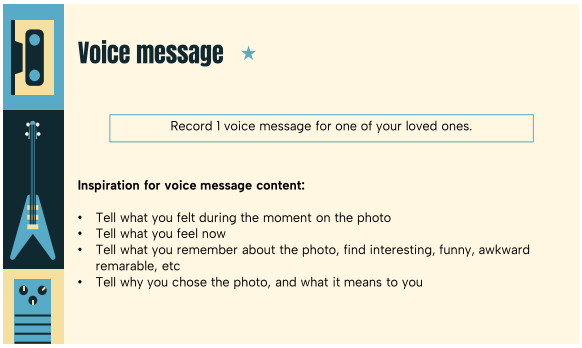
D.7 Slides Sender

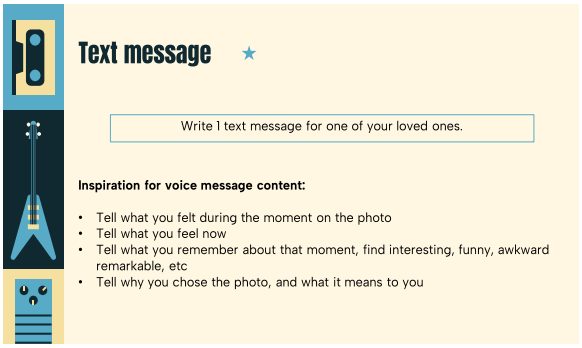






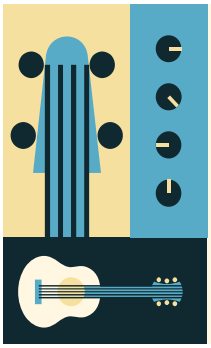






★ Interview





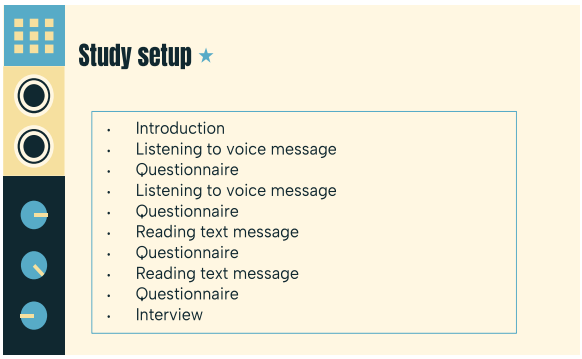
★

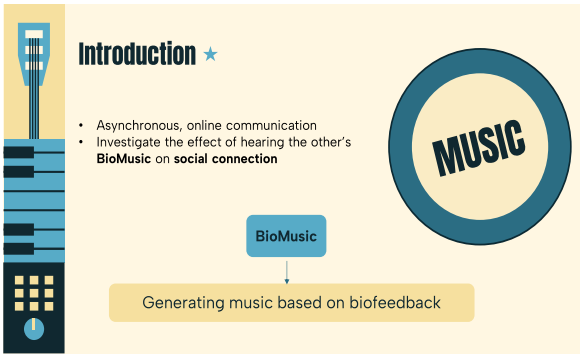
Thanks!!

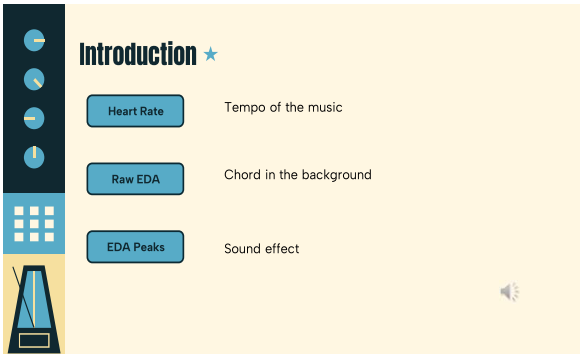
Suggestions, Questions?

D.8 Slides Receiver

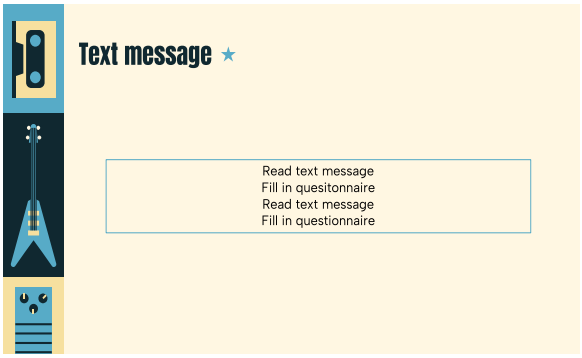






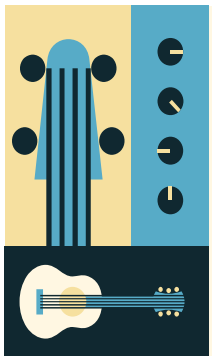






★ Interview





★

Thanks!!

Suggestions, Questions?