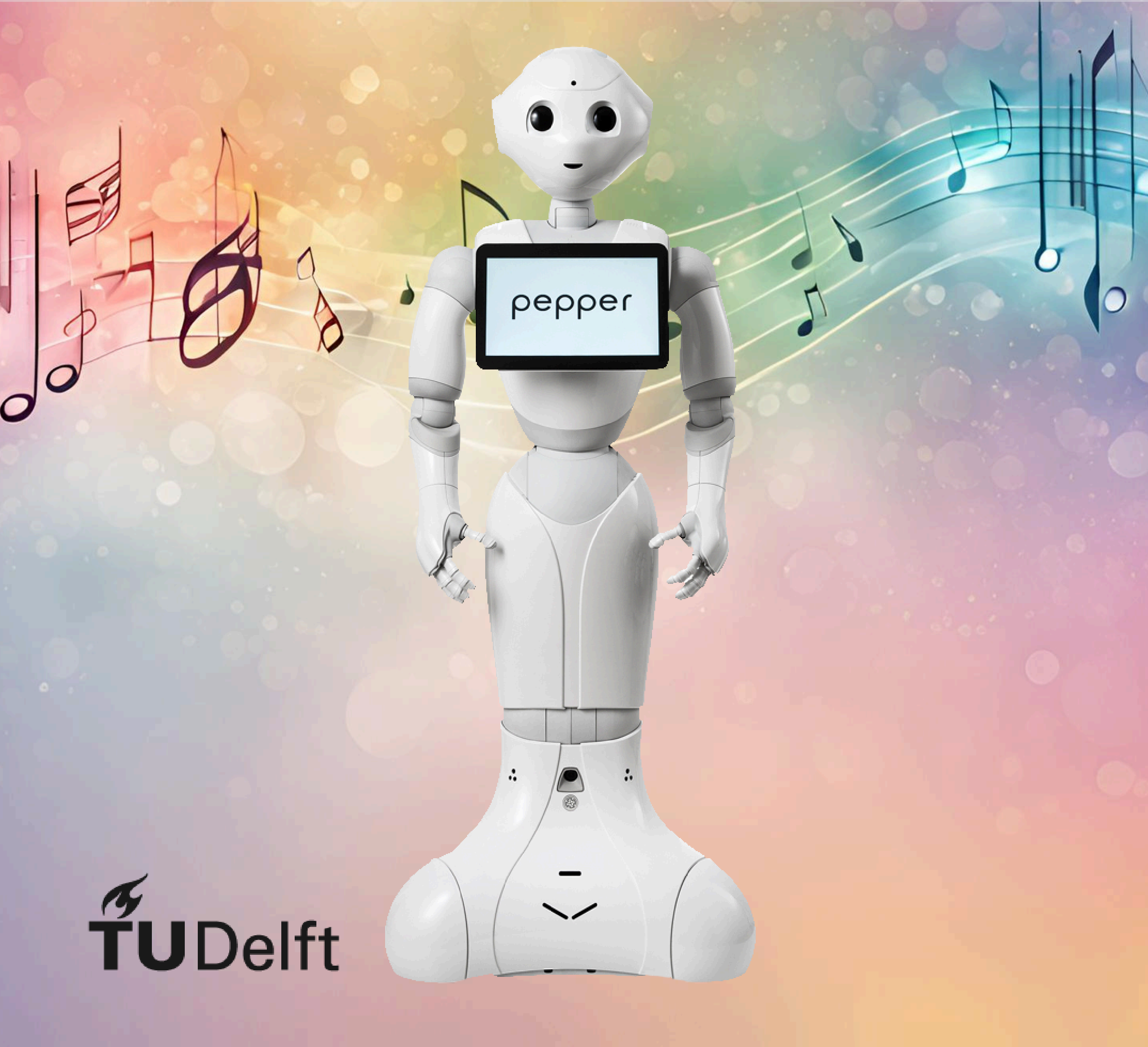
MSc Computer Science Thesis

Robot-Assisted Music-Making to Foster Creativity in Older Adults

Anagha Magadi Rajeev



TU Delft

MSc Computer Science Thesis

Robot-Assisted Music Making to Foster Creativity in Older Adults

Anagha Magadi Rajeev
5729661

July 2024

Thesis Committee:	Prof.dr. Mark Neerincx, TU Delft, Supervisor
	Dr. Myrthe Tielman, TU Delft, Co-Supervisor
	Dr. Jie Yang, TU Delft

A thesis submitted to the Delft University of Technology in partial fulfillment of the requirements for the degree of Master of Science in Computer Science

Anagha Magadi Rajeev: *Robot-Assisted Music Making to Foster Creativity in Older Adults* (2024)

The work in this thesis was carried out in the:

Interactive Intelligence Group
Delft University of Technology

Thesis Committee members:	Prof.dr. Mark Neerincx, TU Delft, Supervisor
	Dr. Myrthe Tielman, TU Delft, Co-Supervisor
	Dr. Jie Yang, TU Delft

Abstract

This project aims to harness the potential of music-making and robotic interaction to enhance creative expression and cognitive function among individuals with cognitive impairment and dementia. With the aging population, there is a growing demand for innovative interventions that support cognitive health and active engagement. Music therapy has demonstrated effectiveness in stimulating cognitive function and emotional expression in individuals with dementia. Creative expression through music serves as a unique outlet, fostering cognitive functions and emotional well-being. This study explores the synergy between music therapy and Socially Assistive Robots (SARs) to develop a more immersive therapeutic intervention. It represents an exploratory investigation into an end-to-end robotic intervention, proposing various interaction elements and examining their functionalities. Each element is designed to foster engagement, enhance perceptions of collaboration, and promote feelings of creativity.

In this thesis, we propose an end-to-end interactive music-making experience designed for use with the Pepper robot, an SAR. The system features a user-friendly interface with eight color-coded boxes, each corresponding to a musical note. Users simply tap the boxes to create melodies. The Pepper robot acts as a guide, assisting users in interacting with the interface. It additionally implements an engagement tracking system by monitoring user interaction through the screen taps on the interface and provides real-time feedback and encouragement. If a period of inactivity is detected, Pepper gently nudges the user to re-engage. Furthermore, the robot functions as a collaborative musical partner, providing rhythmic accompaniment if the user desires. The system also records user-created music and provides playback functionality, allowing users to revisit their compositions.

Methodologically, the study involves an end-to-end system comprising an intelligent music-making interface and an interactive robot providing real-time feedback and rhythmic accompaniment. Insights from the exploratory study highlight the benefits of real-time feedback in enhancing engagement, particularly among participants with musical backgrounds. However, rhythmic accompaniment shows mixed results in fostering collaboration, indicating a preference among participants for emotional connection in collaborative settings. Since this is an exploratory study, the empirical study focuses on healthy older adults, a population with an increased risk of cognitive decline. This is because individuals with dementia are a vulnerable group. Music interventions have shown promise in improving cognitive function and engagement in individuals with dementia. Therefore, this study informs the design of future interventions for people with early-stage dementia.

Key findings underscore the potential of real-time feedback and interaction in promoting engagement in the activity. The intelligent music interface also shows potential to support creative exploration, albeit with improvements needed for advanced musical participants. Participants appreciate the playback feature, enhancing their sense of creative ownership and motivation. Despite promising outcomes, the study acknowledges limitations in sample size and participant demographics, primarily recruiting from music-engaged older adults rather than the target demographic of individuals with cognitive impairments.

Future research directions include expanding participant diversity, refining robot interaction capabilities, and addressing technical challenges to improve system usability and accessibility. Integrating findings from ongoing research on music and memory could further enhance personalized interventions. Ultimately, this study lays the groundwork for future developments in robotic interventions that promote well-being through music therapy for individuals with cognitive impairments.

Acknowledgements

This thesis investigates the potential of interacting with robots to create melodies, and I am grateful to those who have played a key role in its composition. Throughout this project's development, I've had unwavering support from a remarkable chord of individuals, scattered across the globe. These pillars of strength who transcended the time signature, have been the source of my resilience and inspiration over the past couple of years.

- Firstly, I would like to express my deepest gratitude to my parents and brother, Advaith. Their support and tireless efforts made it possible for me to study abroad at TU Delft. While the decision to leave my family and pursue this opportunity was a difficult one, their faith in me inspires me to work hard and make them proud. Growing up in a multi-generational Indian household, music was always woven into the fabric of my life. I was especially privileged to be raised by four generations, and I eventually had to witness the resilience and challenges faced by my grandparents as they aged. Witnessing their struggles firsthand ignited a passion within me to explore ways technology can improve the lives of individuals experiencing cognitive decline, which lead me to my thesis.
- I had the privilege of being supervised by three experts during my thesis. I am particularly grateful to my supervisor, Dr. Mark Neerincx, for his support throughout this project. His weekly feedback, insightful suggestions, and constant encouragement to delve deeper into the research were instrumental in shaping this thesis. I also extend my appreciation to my co-supervisor, Dr. Myrthe Tielman, for her advice and guidance, especially in the final stages of completing this thesis. Her concrete feedback helped me drive the project towards a successful conclusion. My thanks also go to Dr. Frank Broz, whose initial supervision played a crucial role in directing and focusing my research on a specific and productive path.
- I am grateful to Frits van Hall, the student assistant who provided much needed support during my research. His expertise in Dutch was instrumental in crafting the Dutch dialogues, questionnaires, and consent forms. Additionally, his support in participant recruitment significantly contributed to the completion of this project.
- Furthermore, I would like to express my gratitude to the participants in this study. Their willingness to dedicate an hour of their time to participate is greatly appreciated. Their contributions were essential to the success of this research.
- During my master's, I had the privilege of collaborating with the "Dream Team," a group of four brilliant women who became my academic backing track throughout coursework. Each of them brought their unique expertise to the table, fostering invaluable learning experiences that I carried with me into my thesis. Their support has shaped me into a stronger researcher and enriched my academic journey. For my thesis, I was fortunate to reunite with two of them, Manali and Shambhawi, who also specialize in Human-Robot Interaction. They became my sounding boards, the perfect harmony to my research melody. Countless hours spent collaborating in the lab were not just about exchanging ideas and feedback, but also about the comforting knowledge that I wasn't alone in this endeavor.
- My special thanks go to my sister, Ananya, who not only provided emotional support but also offered valuable user perspectives during our brainstorming sessions. Her insights significantly enriched this work.
- Finally, I am immensely grateful to my friends, both in the Netherlands and scattered across the globe. Their encouragement and support have been a constant source of strength throughout this degree. The ability to connect, whether through long calls across time zones, work sessions on Discord, board game nights, or celebrations, provided a much-needed sense of community and balance during this journey.

Contents

List of Figures

List of Tables

1 Introduction

The world's demographic landscape is shifting dramatically. The population of older adults is rapidly expanding [21], leading to a significant increase in individuals experiencing age-related cognitive decline [26]. This decline can have a profound impact on a person's well-being, often leading to difficulties with memory, focus, and information processing. These cognitive challenges can also restrict an older adult's ability to engage in stimulating activities and express themselves creatively [48]. As a result, there's a growing need for innovative interventions that can support cognitive health, promote creative expression, and foster continued engagement in this increasingly prominent demographic [46].

Music therapy has emerged as a prominent evidence-based intervention to achieve personalized goals over the past five decades [71]. It offers a unique avenue to stimulate cognitive function, foster social engagement, and even enhance emotional expression in individuals with dementia and cognitive impairment[46]. The American Music Therapy Association (AMTA) [1] is a leading advocate for music therapy and it has become particularly impactful for individuals with dementia. It shows promise in enhancing patient and staff experiences in acute dementia care settings with numerous scientific studies support its effectiveness [32][15]. Notably, a pilot study [28] investigated the impact of Creative Music Therapy (CMT) on older individuals with delirium and/or dementia in an acute care setting. They found that CMT sessions led to lower negative engagement and affect (mood) compared to a control group receiving usual care. Additionally, the individuals showed higher average pleasure ratings during the CMT sessions. This suggests that music therapy can benefit beyond traditional settings and offer a non-invasive intervention for managing dementia symptoms. However, traditional methods can sometimes pose challenges for older adults with cognitive decline, such as requiring complex musical knowledge or precise motor skills to play instruments [51].

Specialised music interfaces designed to address the challenges faced by those with cognitive decline often feature simplified controls, visual cues, and adaptive features that cater to varying cognitive abilities. A case study [35] investigated the use of an accessible electronic musical instrument called Cymis [1] in music therapy for a patient with severe vascular dementia and worsening of behavioural and psychological symptoms. Despite declining cognitive function, the patient was able to play the Cymis and participate in music therapy sessions for 18 months. This suggests that even in late-stage dementia, patients may benefit from music therapy using accessible instruments that cater to preserved motor and visuospatial skills.

The integration of Socially Assistive Robots (SARs) with such music interfaces holds particular promise. Research suggests positive teacher and parent attitudes towards using SARs for music learning, highlighting their potential to motivate and provide feedback [62][63]. While these studies focus on children, they demonstrate the potential for SARs to be adapted for use with older adults with cognitive decline. SARs can provide additional support and engagement through features like offering guidance and encouragement, adapting to user preferences, and fostering a sense of social interaction. Hence, complementing music therapy with SARs creates a well-rounded approach to supporting the well-being of elderly people and people with dementia

1.1 Motivation

This thesis is motivated by the potential to leverage the synergy between music therapy and SARs. By combining the emotional and cognitive benefits of music with the accessibility and potential for companionship offered by SARs, we aim to create a more engaging and effective music therapy intervention for individuals with cognitive impairment. The goal is to potentially improve the lives of people through enhanced creative expression with a user-friendly tap-to-play interface. This interface might empower individuals to express themselves creatively through music, even with diminished cognitive abilities. Additionally, increased engagement through real-time feedback and encouragement could potentially

---

[1] https://www.musictherapy.org/

improve user engagement and motivation to participate in music therapy sessions.Improved social connection through collaboration with the robot might foster a sense of connection and social interaction, potentially reducing feelings of isolation among the elderly and people with cognitive impairment. Furthermore, increased accessibility by potentially allowing individuals experiencing cognitive decline to participate in music therapy more regularly, even in situations when a human therapist might not be available, is another significant advantage. Overall, this integrated approach seeks to use the strengths of music therapy and SARs to enhance the well-being of individuals with cognitive impairments.

1.2 Research Gaps

While research on SARs as well as music therapy and its benefits for people with dementia are ongoing, there are still gaps in understanding how to best integrate technology like robots into these interventions. The following are the primary research gaps in this domain that this project addresses.

1. **SARs design and use - to enhance music therapy for cognitive impairment**: While existing studies acknowledge the general benefits of SARs for social interaction in older adults [42], there is a gap in understanding how SARs can be programmed to effectively guide and support individuals during music therapy activities [59]. Studies [16] show promise with a music-playing social robot - Pepper [40] - triggering positive responses in PwD. But, the human-like appearance highlights a need for future research on robot design that balances user-friendliness with realistic expectations. Additionally, the potential for SARs to enhance user engagement and collaboration through real-time feedback, musical accompaniment, and encouragement [25] [67] is a relatively unexplored area. Furthermore, long-term effects of integrating SARs with music therapy on cognitive function, social interaction, and user acceptance among PwD require investigation [7]. This comprehensive research is crucial to ensure effective adoption and integration of this technology into dementia care routines.

2. **Design of Music Interfaces for Cognitive Impairment**
   While user-friendly interfaces are crucial for people with dementia, the optimal design elements for music therapy applications remain unclear [17]. Beyond interface design, more research is also needed to explore user experience in music creation. This includes investigating how to address limitations, such as constraining musical choices through curated selections to ensure harmonious results [34]. Additionally, adaptive music generation could be explored. This approach would involve developing interfaces that adapt to user input and generate complementary musical elements, fostering a sense of co-creation without requiring complex user actions[55]. Ultimately, understanding how factors like touch screen size, simplicity of controls, feedback mechanisms, and the limitations of music creation itself can impact engagement and success for this population is crucial [59].

1.3 Research Questions

This thesis aims to explore the potential of using a humanoid robot as a companion for facilitating music-making through a user-friendly tap-to-play interface. By leveraging technology in this manner, we seek to enhance musical creativity among individuals with dementia, make music-making more accessible and less daunting, and ultimately promote their overall well-being. The research questions guiding this investigation are as follows:

1. How does real-time feedback and encouragement from an interactive robot influence engagement in the activity among older adults?

2. Does rhythmic accompaniment from an interactive robot enhance perceived collaboration in music creation among older adults?

3. Does an easy-to-use music interface foster musical creativity among older adults?

1.4 Report Outline

The literature review for this thesis is covered in Chapter 2. The implementation details of the experiment are described in Chapter 3. Chapter 4 contains the methods utilized to address the research questions. Chapter 5 presents the results and discussions of the experiments. Chapter 6 discusses the conclusions that are drawn from the results and observations, elaborates on the limitations and explores future work in this domain.

2 Related work

2.1 Theoretical Background

2.1.1 Cognitive Impairment

Cognitive impairment refers to a decline in thinking skills that falls outside the expected range for a person's age and education. This decline affects memory, attention, language, creativity, problem-solving and other cognitive functions [65]. Age-related cognitive decline, such as dementia affects millions of people worldwide. While there is no cure, various interventions can improve quality of life for those living with it[26].
Dementia is a progressive decline in cognitive function that interferes with daily life. It is a specific syndrome characterized by a progressive decline in cognitive function that impacts a person's daily life significantly [70]. Unlike age-related memory decline, dementia affects multiple cognitive domains and interferes with a person's ability to perform daily activities [69]. It is a progressive disease, meaning its symptoms worsen over time. While the specific progression can vary depending on the underlying cause, many forms of dementia follow a general pattern of stages. These stages are not always clear-cut; some individuals may experience symptoms differently. This is a breakdown of some common stages of dementia:

- **Early Stage:** The symptoms are subtle. There are signs of forgetfulness, difficulty concentrating, and problems with planning and organization. Individuals can often maintain independence at this stage, although they might require some assistance with complex tasks. Early signs can be mistaken for normal age-related memory decline [69].
- **Middle Stage:** Cognitive decline becomes more noticeable. Memory problems worsen, confusion and disorientation become more frequent and difficulties with language and communication may arise. Individuals may need help with daily activities like dressing, bathing, and managing finances. Some behavioural changes such as mood swings, anxiety and social withdrawal can become more prominent [69].
- **Late Stage:** There is significant cognitive decline. Memory loss becomes severe, individuals may have difficulty recognizing familiar faces, and communication may become limited. They may require total care for all daily activities. Physical health may also decline and there is an increased risk of infection and other medical complications [38].

Despite the challenges of cognitive impairment, there are various strategies to improve well-being. Music therapy has emerged as a promising approach, offering a unique avenue to stimulate cognitive function, foster social engagement, and even enhance emotional expression in individuals with dementia [46].

2.1.2 Music Therapy

Music therapy has emerged as a prominent evidence-based intervention to achieve personalized goals over the past five decades [71]. The American Music Therapy Association (AMTA) [1] is a leading advocate for music therapy, championing the use of music as a therapeutic tool. This approach has become particularly impactful for individuals with dementia, while numerous scientific studies support its effectiveness [32][6], suggesting that music therapy can reduce agitation, improve memory recall, cognitive function and promote emotional well-being among individuals with cognitive impairments. This highlights the potential of music therapy to support cognitive health in elderly care settings. This section explores the existing research on music therapy for dementia, examining its effectiveness in improving

---

[1] https://www.musictherapy.org/

cognitive function, reducing agitation, and promoting emotional well-being in individuals with this condition . One such application involves incorporating music therapy into cognitive stimulation therapy (CST) [50], a program designed for those with early- to mid-stage dementia. CST aims to stimulate cognitive function and foster social engagement. This approach, whether in group or individual settings, encompasses activities like singing, listening to music, playing instruments, and improvisation, which can evoke reminiscence, alleviate anxiety and depression, encourage social interaction, and reduce agitation. Music therapy has even shown promise in enhancing patient and staff experiences in acute dementia care settings, as evidenced by preliminary studies [15]. Music-making has a small but statistically significant effect on cognitive functioning for older adults with probable Mild Cognitive Impairment (MCI) or dementia [19]. Future music interventions can benefit from rigorous intervention protocols that isolate specific activities. One study [20] showcases the adaptability of music therapy. It explores online music-making in response to COVID-19 restrictions, identifying current opportunities for digital music activities. While challenges like digital accessibility and sound quality exist, the study highlights the potential for music therapy to reach wider audiences through online platforms. Research investigated the use of music for maintaining attention in older adults with cognitive impairments [27]. While a control group performed well on an attention task involving music and silence, the cognitively impaired group initially struggled. However, after repeated sessions with a therapist, their attention improved when listening to both music and silence. This suggests that music listening interventions, potentially including music making elements, can be beneficial for maintaining attention and possibly social interaction in this population. Another study investigated the short-term effects of music therapy on cognitive function in older adults with dementia [10]. Similar to [27], it involved music listening but incorporated active music therapy sessions. Patients who received music therapy showed significant improvements in cognitive function the next morning compared to the control group. While these improvements were short-lived, they suggest music therapy can positively impact cognitive function in people with dementia. The above mentioned research highlights the potential of music therapy, particularly music making activities, as a promising direction for improving cognitive function, attention, and overall well-being in older adults with cognitive decline. Future research can explore how to design and deliver music therapy interventions, both in-person and online, to maximize their effectiveness for various cognitive impairments. Since music therapy interventions are resource intensive and require trained therapists, social robots present themselves as a potential solution to enhance and expand the reach of music therapy.

2.1.3 Creativity and Collaboration

Building on the potential of music therapy for cognitive health in older adults, we try to understand the role of music in creativity and creative collaboration. Creativity is defined a characteristic of someone that forms something novel and valuable.[2] Notably, a pilot study [28] investigated the impact of Creative Music Therapy (CMT) on older individuals with delirium and/or dementia in an acute care setting. They found that CMT sessions led to lower negative engagement and affect (mood) compared to a control group receiving usual care. Additionally, the individuals showed higher average pleasure ratings during the CMT sessions. This suggests that music therapy can benefit beyond traditional settings and offer a non-invasive intervention for managing dementia symptoms.

A research [13] reviewed the link between creativity, music, and quality of life in older adults. Participating in creative music-making, which offered opportunities for self-expression, social engagement, collaboration, and inclusivity, was associated with improved well-being and social connections. These benefits included positive emotions, engagement, stronger relationships, a sense of meaning, and accomplishment. It also suggests future research to explore how to best facilitate creative musical expression for diverse older adults to maximize these benefits. The impact of music on senior citizen well-being is researched to understand the challenges and opportunities in music education for older adults, drawing on research from various fields [24]. Through these, the authors (who participated in the musical groups) offer insights and a call to action: music education should empower all ages to experience the enriching power of music. [4] highlights the complex interplay between musical, social, and personal factors that contribute to successful creative collaboration. In terms of music creation, collaboration was seen as central to creativity. Combining improvisation and composition was a common approach, with varying tempos (fast-paced vs. slow and evolving) observed. The research also showed a link between timing synchrony and successful collaboration. Informed by the identified benefits of collaborative music-making, our research introduces an interactive music-making experience designed for use with a social robot. It

---

[2] https://en.wikipedia.org/wiki/Creativity

encourages a collaborative experience between the user and the robot, potentially improving creativity and contributing to a more engaging and stimulating musical experience. This collaborative approach has the potential to enhance user creativity and engagement.

2.2 Socially Assistive Robots

Building on the potential of music therapy and collaborative creativity for cognitive health, we explore the emerging field of social robots designed specifically to address the needs of the elderly population. These robots go beyond basic functionality, offering companionship, cognitive stimulation, and even assistance with daily tasks, potentially improve well-being in older adults [8] . Several studies have explored the positive impacts of social robots on elderly people. Social robots have been found to improve mood, reduce loneliness, and foster social connection in older adults [8]. Similarly, a review [11] suggests that social robots can be helpful in reducing anxiety and improving social connection for elderly people. Notably, some studies [25][52][36] also found that social robots can improve independence, security, and reduce stress in elderly people, even those with dementia. These findings suggest that social robots can be a valuable tool to enhance elderly care. Building on these findings, SAR-Connect [22] describes a robotic system designed to engage elderly people in social and physical activities through virtual reality. This system can work with one or more elderly people at a time, and a small-scale study found that it was well-received by participants. The researchers believe this system has the potential to improve social and physical well-being, but acknowledge the need for further research, particularly on long-term effects and use with people of varying cognitive abilities. However, there are limitations to the current body of research. Many studies suffer from methodological weaknesses, including small sample sizes, short testing periods, and a lack of control groups [25][36][2]. Additionally, most research has focused on robots like Paro and Aibo, and have been conducted in Japan, limiting the generalizability of the findings [8]. Future research needs to address these limitations by employing more rigorous methodologies, including larger and more diverse study populations [25][36][2]. It is also important to consider the long-term effects of social robots on elderly users [25]. Involving social scientists and healthcare professionals in the development of social robots can ensure that these robots are designed to meet the specific needs and preferences of the elderly population [52]. Despite these limitations, the current research suggests that social robots have the potential to be a positive force in elderly care. Social robots can provide companionship, reduce loneliness, improve mental and social well-being, and even assist with daily tasks. Further research and development will ensure that social robots are effectively integrated into elder care programs. Building on the potential of social robots in elder care, this thesis explores their application in facilitating participatory music making for older adults. Imagine a social robot leading a music activity. It could provide clear instructions, offer encouraging feedback, and even adapt the difficulty to match the participant's abilities. This engaging intervention, powered by music, could promote social interaction, cognitive stimulation, and enjoyment among elderly people. While research on social robots specifically for music making is still emerging[16], the positive impacts seen in elder care settings suggest this technology holds promise for enriching the lives of older adults.

2.3 Technology and User Interaction

The core of this thesis lies in the interaction between a user and technology, specifically a social robot (Pepper) [40] and a music-making interface, to create a positive impact on individuals with cognitive decline. In this section, we will explore the existing research on technology and user interaction within the context of music making and cognitive health.

2.3.1 Music through Machine Learning

The realm of artistic creation is undergoing a transformation with the integration of machine learning (ML). This section delves into the research behind ML-powered music, exploring how algorithms are pushing the boundaries of creative expression. Google is spearheading this revolution through projects

like Magenta[3] and Chrome Music Lab[4].These initiatives foster a unique space for musicians and developers to collaborate with Artificial Intelligence (AI) tools to generate and explore entirely new artistic possibilities.One way this collaboration is happening is through Magenta.js[5], a JavaScript API powered by Tensorflow.js[6] which is a library for machine learning. As described in [44], Magenta.js allows the creation of various musical tools like a melody autocompletion tool, arpeggiator, and drum machines. These tools empower users to input musical ideas and receive AI generated continuations or variations, helping them explore and create music in new ways.
AI Duet [37], a collaborative effort between Magenta and Google Creative Lab teams[7], is another example. This user-friendly system allows users to create music interactively with an AI model. It translates user input on a virtual piano keyboard or MIDI (Musical Instrument Digital Interface) device into musical continuations, fostering creative exploration for musicians and non-musicians alike. Built with open-source Magenta tools, AI Duet exemplifies the potential of machine learning to inspire novel creative avenues. Clarion Lite [41] further expands the possibilities. This web-based experiment that empowers users to create music through a playful and accessible interface. Users can explore different on-screen patterns and personalize their musical experience. Playing these patterns is achieved in two ways: either through traditional mouse and keyboard interaction, or by using their webcam to track a designated body point, adding a layer of movement and physical expression to the music-making process. This thesis explores a similar concept with the integration of Piano Genie [18]. This system, designed to democratize musical improvisation, translates user input on a simple eight-button interface into meaningful musical sequences through machine learning, Piano Genie empowers individuals with no prior musical background, particular promise for users with cognitive impairments who may find traditional instruments challenging. It achieves this by striking a balance between user control and unexpected musical results, ultimately boosting confidence and competence. The implementation of this model is further described in Section 3.

2.3.2 Interactive tools for Cognitive Impairment

Traditional musical instruments can be challenging for people with cognitive impairment, physical limitations, or memory problems. This section explores how new interfaces have been developed to make music creation more accessible. These interfaces often feature simplified controls, visual cues, and adaptive features that cater to varying cognitive abilities. A case study [35] investigated the use of an accessible digital musical instrument (Cymis) in music therapy for a patient with severe vascular dementia (VaD) and worsening behavioral and psychological symptoms (BPSD). Despite declining cognitive function and worsening BPSD, the patient was able to play the Cymis and participate in music therapy sessions for 18 months. This suggests that even in late-stage dementia, patients may benefit from music therapy using accessible instruments that cater to preserved motor and visuospatial skills. A prototype for music-making tech for PwD has also been developed [54]. The study with people with dementia established that they were able to use the system to create pleasant-sounding music and that with minor adjustment, the system could provide an easy way to bring active music-making to people with dementia, whether for use at home, in residential housing, or day-care centres. Additionally, A human-centered design process for a Virtual Reality application [56] aims at supporting users in their creative endeavours when composing percussive beats in virtual environments. To achieve this goal, they drew insights from existing literature on factors influencing creativity and conducted focus group interviews to gain an understanding of how virtual environments and 3D user interfaces (3DUI) can be tailored to support creativity. A cognitive architecture for robots [31] has been developed based on neuro-psychological principles, enhancing anticipation and perceptual simulation. Tested with a non-anthropomorphic robotic lamp in collaborative tasks, the approach proved more efficient and fluent than systems lacking these features. Findings suggest mutual improvement between robots and humans, impacting human perception. Self-report data showed differences in team dynamics and attitudes towards the robot. This work lays a foundation for enhancing robot-human collaboration. [23]reviews how technology is creating new musical instruments (ADMIs) for people with disabilities. The authors analyzed existing research and found there are many ways to control these instruments, with most using physical controllers. Sound is often produced using common music software. The study concludes that more research is needed to create ADMIs for a wider

---

[3] https://magenta.tensorflow.org/

[4] https://musiclab.chromeexperiments.com/

[5] https://github.com/magenta/magenta-js/tree/master

[6] https://www.tensorflow.org/js

[7] https://experiments.withgoogle.com/search?q=google%20creative%20lab

range of people and disabilities. There's potential to make these instruments more customizable and incorporate new technologies. Kibo [3] is a musical instrument controller for elderly people's cognitive and motor rehabilitation. It utilizes tangible user interfaces and digital technologies for playing music through web-based games. The design incorporates feedback from therapists to improve usability and cater to different user abilities. The study believes that Kibo can stimulate cognitive functions, improve motor skills, and promote social engagement among elderly people. This study draws focus on usability and ensures that the mechanics of the interface are easy to understand for users with cognitive limitations. A music player [60] has also been designed for people with dementia. It has reconfigurable buttons and knobs that can be easily changed by caregivers to match the user's abilities. This is important because dementia is a progressive disease and a person's needs can change over time. The design also uses familiar controls such as knobs and buttons so that people with dementia can easily understand how to use it. It was successful in a user study and the researchers believe it can improve the lives of people with dementia by giving them more independence and control over their music. While this is a music player and not a music making interface, we can derive some design principals like using simple and familiar interactions in our music-making interface. An investigation was conducted to understand if music helps older adults with cognitive impairments focus[27]. Researchers played short music clips followed by silence to a group of older adults and compared their responses to healthy adults. The older adults with impairments had more difficulty staying focused during the silence than the music. However, after repeated listening sessions with a therapist, their ability to focus during both music and silence improved. This suggests music listening could be a tool to help maintain attention in older adults with cognitive decline. There are also challenges faced by elderly people with memory problems using technology [30] . These challenges highlight the importance of user-friendly interfaces for them to stay independent. The authors of [30] propose design principles for such interfaces and describe Mylife, a system that uses familiar devices like touchscreens to offer easy access to essential online services like calendars and photos. Mylife can be customized to individual needs and caregivers can manage the system remotely. A study [33] investigated how new musical interface designed for elderly people in residential care affects their engagement. The researchers built a prototype instrument and made changes to it based on feedback from the residents over a 10-week intervention. They found that the residents' enjoyment decreased with more complex versions of the instrument. Overall, the residents were more engaged when the instrument was easy to use and new songs were added over time. The study suggests that user-centered design with ongoing refinement is a good approach for developing musical interfaces for older adults. This research informs our own design choices, as we will describe in the Section 3 where we discuss the implementation of a user interface based on the Piano Genie web demo [18], redesigned to be more suitable for our target audience.

2.4 Evaluation Techniques

2.4.1 Qualitative Analysis methods for Social Robot Experiments

While quantitative data provides valuable insights into user behavior and performance metrics, social robot interactions often involve deeper emotional and social elements. To fully understand the user experience and the impact of social robots, qualitative analysis methods become crucial. This section explores the diverse qualitative methods employed in studies evaluating social robot interactions. These approaches offer valuable insights beyond numerical data, revealing the subjective experiences and perceptions of users interacting with social robots. Several studies highlight the importance of qualitative research in understanding user perspectives. For instance, one study [64] argues that social robots for older adults should be designed based on their actual needs and preferences. Currently, robots are often designed with assumptions that may not reflect the desires of older adults. Through interviews with older adults and their caregivers, the researchers found that older adults value their experiences with technology and are wary of robots that are overwhelming or not truly helpful. This paper emphasizes the importance of qualitative research to understand users' perspectives and calls for social robots to be developed with consideration for the social networks and contexts in which older adults live. This aligns with our goal of understanding how engagement with robots affects user well-being and user perception of the robot's helpfulness. Building on this foundation, our research incorporates a multi-method approach that echoes the work of [68] on measuring user experience (UX) with humanoid robots. Participants verbalize their thoughts and feelings during robot interaction through a think-aloud protocol implemented where the robot asks questions to make conversation. This provides qualitative UX data beyond metrics. Additionally, we will combine video analysis with questionnaires and potential think-aloud prompts based on participant reactions. This multi-method approach, similar to [68], offers a richer understanding of UX and societal impact compared to relying on a single method. Another study[66] advocates for the importance of qualitative research methods in the field of Human-Robot Interaction (HRI). The authors propose a taxonomy to categorize qualitative research in HRI based on study type and specific methods used to standardize qualitative methods and reporting. The taxonomy proposed has two dimensions: study type and qualitative method. It helps researchers situate their research within the interdisciplinary field and follow best practices in selecting and using qualitative methods. In our own research, we believe that observational analysis through videos can be used to support insight-driven research by exploring how engagement in specific activities, well-being, and physiology interact. Textual analysis through questionnaires, both quantitative and subjective, can also provide valuable data. While our ideal approach would have involved reflective and narrative accounts gathered through semi-structured interviews, limitations such as a language gap between participants and the interviewer, and time constraints, prevented this method.

2.4.2 Questionnaires for User Experience Evaluation

Building on the insights obtained from qualitative methods, questionnaires provide a complementary approach to UX evaluation in social robot research. They offer standardized data collection, facilitating efficient comparisons across studies and participants. This section examines the role of questionnaires in UX evaluation and their integration with qualitative methods to achieve a more comprehensive understanding of user experience with social robots. While questionnaires like the one proposed for senior usability evaluation [58] can be helpful in general, they may not capture the specific aspects of user experience relevant to social robots. This scale focuses on general usability for applications, whereas social robots involve collaborative experiences with emotional and social dimensions. The Flow Short Scale (FSS) Questionnaire [53] is a 16-item self-report tool designed to assess the flow state. The FSS can be applied in various contexts, such as computer games, experimental settings, and daily activities. It measures three factors: fluency, absorption, and worry. Fluency denotes the smooth execution of an action, absorption signifies complete immersion in an activity, and worry indicates the extent of concern about making mistakes. The FSS can assess flow as a continuous variable or classify a person's experience into distinct categories. While insightful, this scale may not be entirely suitable for our research focused on insights, as it relies solely on participants' self-reported feelings. Although social robots can be engaging, user experiences with them might not always achieve a flow state. For social robots, observing user behavior and interactions can provide valuable insights that a self-report questionnaire might overlook. The Godspeed Scales questionnaire [5] is a widely used tool for assessing human perceptions of robots. It measures four key dimensions: Anthropomorphism, Likeability, Intelligence, and Social Presence. While the questionnaire provides valuable insights into how users perceive robots, it is not ideal for our research. This is because it primarily measures users' perceptions of the robot itself rather than the quality of the user experience during interaction. Although perception can influence experience, they are not the same. The System Usability Scale (SUS) [9] is a widely utilized questionnaire designed to assess overall system usability. It comprises 10 brief Likert-scale statements, with response options ranging from "strongly disagree" to "strongly agree." The responses are aggregated into a single score between 0 and 100, with higher scores indicating better usability. SUS primarily addresses general usability aspects such as ease of use, learnability, and efficiency. However, it does not explore emotional responses, the quality of social interactions, or user perceptions specific to social robots—areas critical for our research. Additionally, SUS mainly measures objective usability metrics like task completion time and error rate. While these are important, the user experience with social robots also encompasses subjective elements like enjoyment, helpfulness, and emotional connection. Our research primarily uses a questionnaire that contains subjective questions to understand the ENJOY scale[14], a new tool for measuring enjoyment across various activities. The ENJOY scale assesses enjoyment through five dimensions: pleasure, relatedness, competence, challenge/improvement, and engagement. The adaptability of this scale proved valuable. By tailoring the questions to focus on aspects like enjoyment of social robot interaction and user engagement, we gain valuable insights. While the scale is less established in the specific field of HRI (Human-Robot Interaction), it provided a structured way to quantify user experience and understand participant engagement during social robot interactions, despite the limitations in participant numbers for strong quantitative analysis.

2.4.3 Observational Metric Design for Video Analysis

While questionnaires offer valuable insights into user experience, they can miss some of the richness and subtlety of user interaction. This section explores observational metrics designed for video analysis. These metrics allow researchers to capture non-verbal cues, user behavior patterns, and the overall flow of interaction during user studies with social robots. By analyzing video data, we can gain a deeper understanding of how users engage with social robots and identify potential areas for improvement in the design and functionality of the robot. This approach complements the insights gathered from questionnaires, providing a more comprehensive picture of the user experience. [12] is the Observational Measurement of Engagement (OME) questionnaire, a tool used to assess engagement in people with dementia. It records direct observations of a person's interaction with a particular stimulus. It can be used to measure a variety of things, including a person's attention level, disruptive behaviour, and attitude towards the stimulus. The OME is a standardized tool that can be used to compare engagement levels between different people or groups. While quantitative analysis with tools like the Observational Measurement of Engagement (OME) questionnaire ([ometool]) might be ideal, our small sample size hinders its effectiveness in drawing strong conclusions. [45] provides a valuable framework for understanding the internal aspects of engagement. It goes beyond measuring outward behaviors (like the OME) and delves into the core components of user experience during an activity. The researchers developed a model called ENGAGE-DEM and tested it by collecting data on participants with dementia engaged in various activities. The results showed that the model successfully captured the different components of engagement and the relationships between them. This model could be used to develop new systems for measuring engagement in human-computer interaction (HCI) and human-robot interaction (HRI). Based on the ENGAGE-DEM model, we propose a coding scheme described in Appendix 3 focusing on the key aspects of user engagement with the music-making robot - affective, behavioural and cognitive.

3 Prototype Design and Implementation Methodology

3.1 Introduction

As discussed in Chapter 1, our objective is to address three key research questions. In summary, these questions aim to explore the impact of a musical interface, enhanced by social interaction, on creativity, engagement, and collaboration. Specifically, we need an interface that allows cognitively impaired individuals to create music, regardless of their skill level. Additionally, the interaction with a social robot should cognitively stimulate the user, providing necessary support, encouragement, and collaboration. To achieve this, we leveraged elements of both interface and interaction design in our prototype. We developed an intelligent music interface using the existing PianoGenie model [18] (introduced in section 2.3.1) and connected this interface to a socially assistive robot (SAR) called the Pepper Robot [40] (introduced in section 2.2). Details about the model and the robot will be provided in the following sections of this chapter. The rationale behind choosing this model and robot is elaborated below.

3.2 Design Rationale

In developing the prototype for this study, several design choices were made to ensure that the system would meet the objectives outlined in our research questions. These choices were driven by the need to create a user-friendly, engaging, and effective music creation environment for individuals with varying musical backgrounds and cognitive impairments. Below, we elaborate on the considerations and the rationale behind these design decisions.

1. **User Accessibility**: Ensuring that the musical interface is intuitive and easy to use, regardless of the user's prior musical experience led to the adoption of the PianoGenie [18] model. The decision to use this model was based on its ability to map complex piano inputs to a simplified eight-button interface, thus reducing the cognitive load on users.

2. **Engagement and Motivation**: Enhancing user engagement through real-time feedback and encouragement led to the use of The Pepper Robot. Its ability to provide personalized interaction and encouragement are critical for maintaining user motivation. The design aimed to use Pepper not just as a facilitator but as an active participant in the music creation process, providing real-time feedback and encouragement. This choice was informed by studies highlighting the positive impact of social robots on engagement and collaboration in various activities, particularly among older adults [25].

3. **Social Interaction**: Leveraging the social aspects of human-robot interaction to foster a sense of collaboration and support. Pepper's capabilities in recognizing and responding to human emotions and its ability to use gestures and voice modulation were key factors in this decision.

4. **Creativity Stimulation**: Providing an environment that supports creative expression. The interface's design and the robot's interactive capabilities were aimed at making users feel confident and motivated to explore their musical creativity.

Based on this design rationale, we integrated the Pianogenie [18] model with the Pepper [40] robot. This integration facilitated an interaction that supported the use of the music interface. Consequently, our prototype consisted of:

1. The Intelligent Musical Interface

2. The Human-Robot Interaction (HRI)

These components were developed independently and subsequently integrated, as the HRI component relies on user interaction with the musical interface. The Musical Interface was powered by a neural network model combined into a user-friendly interface. Concurrently, the HRI component orchestrated a dynamic interaction between users and the social robot, enhancing engagement and creativity. The design overview of this implementation are also described in Figure 1.
In the following sections, we examine the technologies and frameworks used for the different components of the system and explain how they were integrated to achieve the overall system's goals. We detail how the user interacts with the interface, the mechanisms behind the musical generation, and the features of the HRI system that provide personalized feedback, rhythmic accompaniment, music recording and playback, and conversation to foster a collaborative music-making experience for individuals with cognitive impairment.

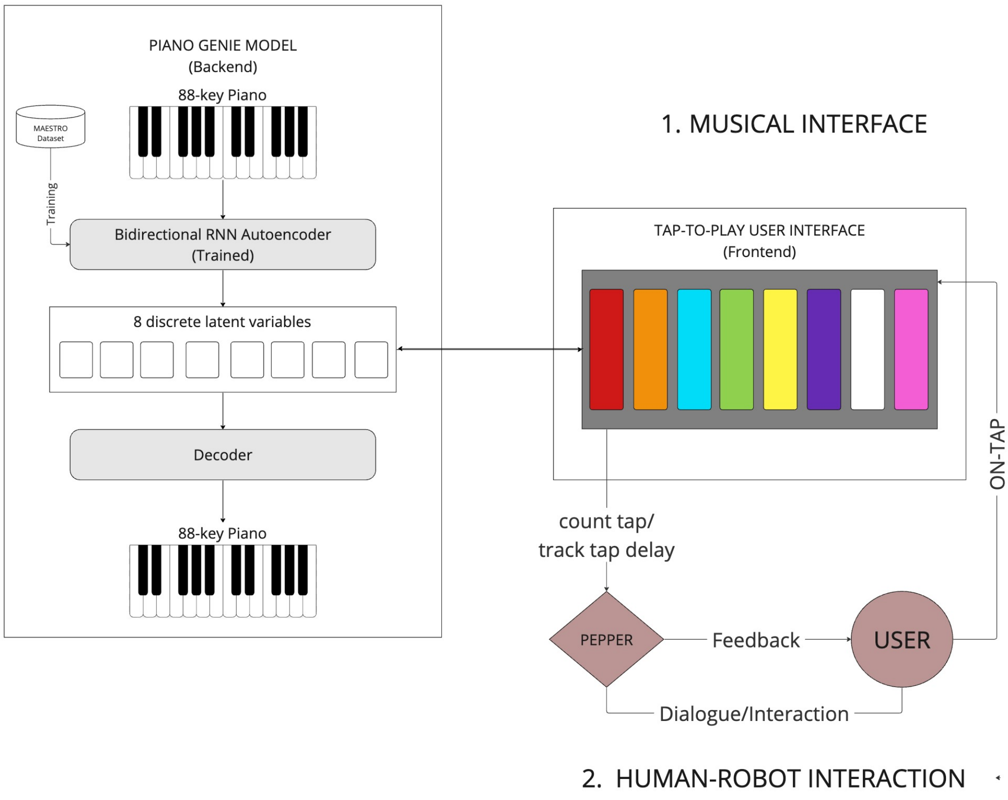


Figure 3.1: Overview of the musical interface implementation and its integration with the HRI system

3.3 Intelligent Musical Interface

To make an accessible musical interface, it is crucial to ensure that it is as easy for novice musicians as it is for experts. PianoGenie [18] is a model which allows people with no musical background to improvise on the piano. This is a part of Magenta[1], an open source research project exploring the role of machine learning as a tool in the creative process. We will delve into the details of the model and the technology used to implement it in the following subsections.

---

[1] https://magenta.tensorflow.org/

3.3.1 Introduction to the Piano Genie Model

[18] introduces a system called 'Piano Genie' - an intelligent musical interface which allows people with no musical background to improvise on the piano. It is a system for learning low-dimensional discrete representation of piano music. The system utilizes a user interface with eight buttons that the user interacts with. These button presses are then fed into a machine learning model, specifically a bidirectional recurrent neural network (RNN) autoencoder [57] with a discrete bottleneck, which interprets the button presses and translates them into sequences that can be played on a standard piano. Thus, an encoder RNN compresses piano sequences (88 keys) into many fewer buttons (8). A decoder RNN is responsible for converting the simpler sequences back to piano space. The model producing music is not only playable but also sounds natural. To achieve this, the model is trained on a dataset of piano pieces performed by skilled pianists. Additionally, the model incorporates musically relevant constraints to make the generated music more intuitive. Thus, Piano Genie enhances creative expression through its simplified interface, real-time feedback, and balance between control and surprise.

3.3.2 Model Adaptation

For this thesis, we adapted the core functionalities of the Piano Genie model. We trained the model on a more updated dataset from the Piano-e-Competition [2]. This was primarily done to increase the training data available for the model. The remaining model specifications, network architecture and training parameters remained the same as described in the original paper.

3.3.3 Dataset Acquisiton

For training the model in our project, we utilized the MAESTRO dataset v3.0.0 [29] in Musical Instrument Digital Interface (MIDI) format. MIDI is a special code that lets electronic instruments and computers communicate with each other. This lets them work together to play, edit, and record music. The MAESTRO dataset is curated from the international Piano-e-Competition [2] and offers high quality paired audio and recordings of piano performances.It is an updated version of the original dataset used in [18] with additional high-quality data. This dataset provided precise musical data in MIDI format making it a strong choice to train the improvisation model.

3.3.4 User Interface

The user interface (UI) for our model was based on the Piano Genie web demo [18]. Maintaining consistency with the original system, we utilized Tensorflow.js [3] at the back end of our web application to handle the real-time processing of user input and generation of musical sequences based on the trained neural network. When a user presses a button, the input is sent to a trained decoder, which generates a vector of 88 logits representing the 88 piano keys. These logits are converted into a probability distribution, from which the next note is sampled, as detailed in the original paper [18]. On the front-end, the goal was to make the user-interface accessible and simplistic so that it is suitable for our target demographic. [72] acknowledges various types of UI for people with disabilities (PwD), emphasizing the widespread use of touchscreen interfaces on tablets for rehabilitation and daily life, and highlighting the importance of social participation. Given that this study involves real participants over the age of 60, we designed a digital tablet interface (refer to Figure 3.2). The interface follows principles of simplicity, natural motion, and familiarity with music, featuring a tap-to-play functionality that minimizes complexity. Inspired by a keyboard, the design includes colored rectangular boxes that play notes when pressed and allow multiple notes to be played simultaneously. This approach fosters familiarity, as tapping boxes to generate music mimics the natural expectation of playing a percussion instrument. Additionally, the eight-button layout, derived from [18], reduces cognitive load and promotes immediate engagement. Dynamic music generation based on user input fosters a sense of agency and control, while unexpected musical elements add joy and motivation. This balance allows users with cognitive impairments to contribute creatively and explore new possibilities. Producing recognizable and surprising music boosts self-confidence and

---

[2] http://www.piano-e-competition.com/

[3] https://www.tensorflow.org/js

Figure 3.2: User Interface hosted on the Chrome browser on an Android tablet

competence, encouraging ongoing engagement with the system. For this setup, we require an Android tablet with the Chrome browser (Figure 3.2) that supports WebMIDI (Web Musical Instrument Digital Interface). WebMIDI is an application programming interface (API) that allows browsers to understand and use MIDI messages, enabling real-time interaction with musical instruments through the web interface.

3.4 Human-Robot Interaction

3.4.1 Pepper Robot

The Pepper robot [40] is a humanoid robot developed by Softbank Robotics[4] designed specifically for social interaction, differing from its industrial counterparts used in manufacturing. Pepper boasts a friendly and expressive design that features a large tablet-like chest screen to display information and emotions (Figure 3.3). This socially adept robot can recognize and respond to human emotions through facial expressions and voice tones. Its repertoire extends beyond emotional intelligence, as Pepper can engage in conversation, tell jokes, and even perform dances. Pepper's ability to navigate its surroundings and interact effectively with people stems from its array of sophisticated sensors, including cameras, microphones, and lasers.

Pepper's compact size (120 cm height, 28 kg weight) allows for maneuverability in various settings. Its 48 cm depth and 40 cm head width further contribute to its ability to navigate around people and objects. A single charge provides Pepper with up to 12 hours of operational life, ensuring consistent engagement and interaction throughout the day. Pepper's capabilities position it as a valuable research platform in the field of Human-Robot Interaction (HRI). In addition, Pepper finds practical applications in real-world scenarios, such as greeting customers in businesses [43] and guiding visitors through museums [61] .

In this experiment, the Pepper robot fulfills dual roles as both a companion and a guide for the participants. Further elucidation on the design and interaction flow will be provided in Chapter 4. Fundamentally, our aim is to capitalize on Pepper's anthropomorphic qualities to foster a sense of companionship and support during the activity. To achieve this, we integrated features, including adjusting Pepper's

---

[4] https://us.softbankrobotics.com/pepper

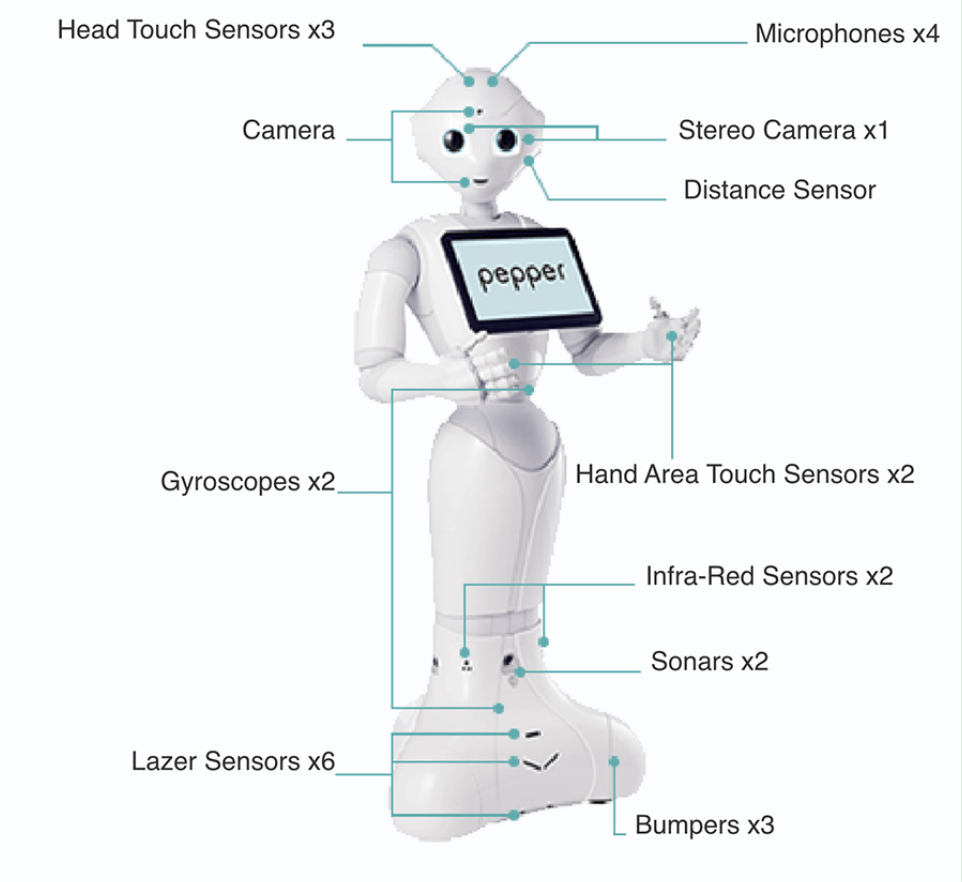


Figure 3.3: Pepper Robot. (Source: Softbank Robotics)

voice, utilizing its gestures, modulating facial expressions, and varying tones according to the communication content. Pepper's voice could be modified in two ways: speed and pitch. Multiple gestures, such as clapping, dancing, greeting, saying goodbye, and showing appreciation, were incorporated into the conversation. Although facial expressions couldn't be modulated directly, changing the eye colors based on sentiment created the illusion of facial expression changes. These adjustments were refined through repeated trials with an expert, peers, and a pilot study, detailed in Chapter 4. We also aimed to utilize the tablet on the Pepper robot to display captions, assisting users who might struggle with Pepper's accent or speaking pace. Unfortunately, this feature could not be implemented because the tablet on the robot was incompatible with our framework. This issue is discussed in more detail in the limitations section of Chapter 6. It is important to note that the robot was specifically programmed and deployed to facilitate interaction and the social aspect of the experiment during the evaluation process.

3.4.2 Social Interactive Cloud Framework

The Social Interactive Cloud (SIC) framework[5] is a lightweight and user-friendly tool developed by the Social AI group at Vrije University, Amsterdam. It is used to simplify the development of socially interactive systems, particularly for physical devices such as robots. It empowers developers to create robots that can naturally interact with humans. It offers a range of services to make interactions more natural and social. It also supports multi-modal interaction, meaning it can handle different forms of communication like speech and gesture. It enables seamless interaction across different devices and provides independent services that developers can choose to build custom applications.

SIC offers components that facilitate the integration of various robots, online services, and data processing tools. These components serve as the fundamental building blocks of the framework. Each component is capable of receiving input, executing processing tasks, and potentially generating output. An apt analogy is to liken these components to blocks. When programming a robot, we assemble specific

---

[5] https://socialrobotics.atlassian.net/wiki/spaces/CBSR/overview

functionalities by combining these blocks. For instance, to enable the robot to greet a person approaching it, we would need to integrate a camera component for visual input, a face detection component for identifying the person, and a text-to-speech component for verbal interaction. We employed the SIC framework in our implementation primarily to host our web-based music interface and to deploy the human-robot interaction (HRI) aspect, where the robot reacts to the user's performance on the digital interface. The implementation involves the following setup. A schematic diagram illustrating this setup is depicted in Figure 3.4.

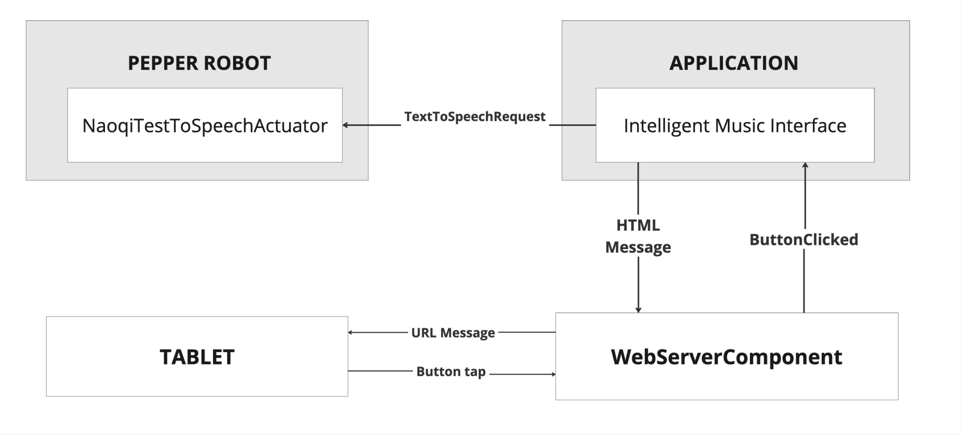


Figure 3.4: Schematic Diagram of Implementation in SIC

The WebserverComponent service, operating on the local machine, is primarily responsible for managing interactions with web clients. In our configuration, the tablet serves as the web client, functioning as the musical interface for users. The backend of the musical interface acts as the user application control, sending a HtmlMessage, which represents the user interface front end, as input for the WebserverComponent to render. Subsequently, the WebserverComponent sends it as a URLMessage to be hosted on the tablet. When users interact with the colored boxes on the tablet, the WebserverComponent detects these actions, listening for events originating from the tablet as the web client. It handles the Button Click event received from the tablet, which is then processed by the application control. The application control monitors events transmitted through the WebserverComponent, such as taps on the tablet screen serving as the music interface. Upon receiving these events, the application sends a NaoqiTextToSpeechRequest to the robot, prompting it to respond accordingly. The NaoqiTextToSpeechActuator then translates text responses provided by the developer into speech, allowing the Pepper robot to vocalize these responses. In this manner, the Pepper robot detects user interaction with the interface and responds in the following four situations:

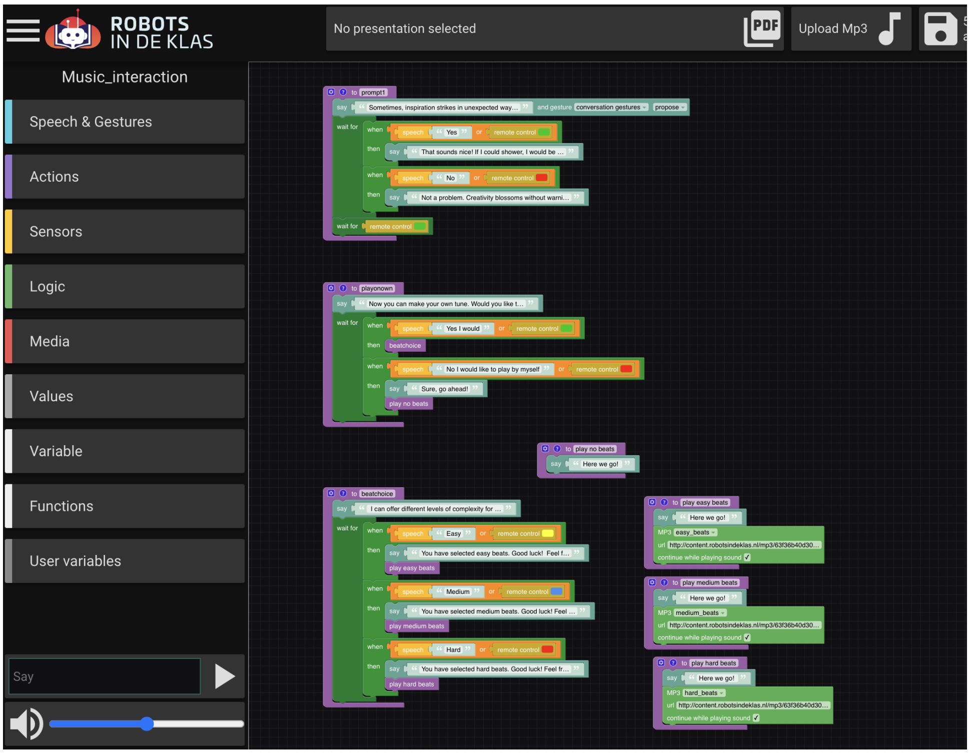
- If the user is continuously playing music and exploring its full potential, the robot detects the activity and encourages the user, appreciating their efforts.
- If the user repeatedly presses a single box, the robot provides suggestions to tap different boxes and hold notes for varying durations.
- If the user takes a short pause, Pepper encourages them to try something new.
- If the user takes a long pause, Pepper asks if they want to stop the activity or try some challenges.

3.4.3 Robots in de Klas GUI (Interactive Robotics)

This system utilized the capabilities of Interactive Robotics, a company specializing in social robots for healthcare and education. Their robot interaction control framework, accessible through the online platform 'robotsindeklas'[6], simplifies robot interaction development using pre-built code blocks, as illustrated in Figure 3.5. This platform provided the foundation for the HRI aspects of our system, facilitating supplementary dialogues with the user. The four purposes where this platform was used in the interaction were:

---

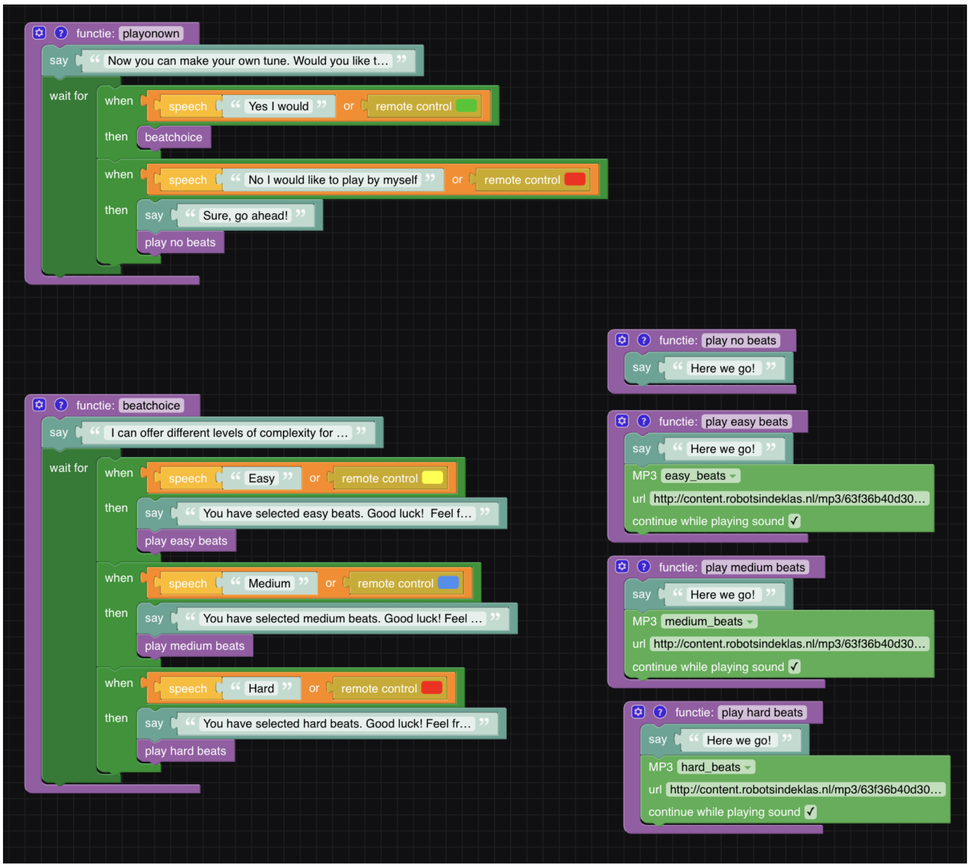
[6] https://portal.robotsindeklas.nl/



```
to prompt1
  say “Sometimes, inspiration strikes in unexpected way…” and gesture conversation gestures propose
  wait for
    when speech “Yes” or remote control 🟩
    then say “That sounds nice! If I could shower, I would be …”
    when speech “No” or remote control 🟥
    then say “Not a problem. Creativity blossoms without warni…”
  wait for remote control 🟩

to playonown
  say “Now you can make your own tune. Would you like t…”
  wait for
    when speech “Yes I would” or remote control 🟩
    then beatchoice
    when speech “No I would like to play by myself” or remote control 🟥
    then say “Sure, go ahead!”
         play no beats

to play no beats
  say “Here we go!”

to beatchoice
  say “I can offer different levels of complexity for …”
  wait for
    when speech “Easy” or remote control 🟨
    then say “You have selected easy beats. Good luck!  Feel f…”
         play easy beats
    when speech “Medium” or remote control 🟦
    then say “You have selected medium beats. Good luck! Feel …”
         play medium beats
    when speech “Hard” or remote control 🟥
    then say “You have selected hard beats. Good luck! Feel fr…”
         play hard beats

to play easy beats
  say “Here we go!”
  MP3 easy_beats
  url http://content.robotsindeklas.nl/mp3/63f36b40d30…
  continue while playing sound ☑

to play medium beats
  say “Here we go!”
  MP3 medium_beats
  url http://content.robotsindeklas.nl/mp3/63f36b40d30…
  continue while playing sound ☑

to play hard beats
  say “Here we go!”
  MP3 hard_beats
  url http://content.robotsindeklas.nl/mp3/63f36b40d30…
  continue while playing sound ☑
```

Figure 3.5: Robot in de Klas GUI

- **Rhythmic Accompaniment**: As depicted in Figure 3.6, the HRI module incorporates a feature – rhythmic accompaniment tailored to user preference. Pepper acts as a musical collaborator, offering the user the option to add rhythmic backing to their melodies. Pepper first inquires if the user desires such accompaniment. If the user consents, Pepper presents three difficulty levels: easy, medium, and hard. This allows users to choose the level that best complements their musical creation, fostering a sense of agency and control. Should the user prefer to create unaccompanied melodies, Pepper readily encourages this choice, demonstrating adaptability and attentiveness to user desires.
- **Engagement Through Strategic Buffer Questions**: To maintain user interest and promote a sense of connection throughout the music creation process, Pepper strategically incorporates subjective questions. These questions delve into themes of creativity and personal experience, fostering user engagement. The timing of these questions is crucial – Pepper asks them before and after the music-making activity, as well as during strategically placed pauses, such as breaks or playback editing intervals. This thoughtful placement ensures that the questions don't disrupt the creative flow but rather provide opportunities for reflection and conversation, further enriching the user experience. To ensure a positive user experience, responses are prepared for both positive and negative feedback. When a user responds negatively, Pepper's replies are carefully crafted to be supportive and avoid any negativity that might discourage them. The implementation of this is shown in Figure 3.7
- **Record and Playback (Wizard-of-Oz Approach)**: Following the collaborative music-making session, Pepper offers the chance to playback the user's creation. This playback functionality employs a creative "Wizard-of-Oz" technique. While Pepper initiates the playback request, a human operator (the wizard) manages the recording and editing process outside the robot. This ensures high-quality audio for playback. The wizard records the music during the session and makes any necessary edits during the buffer conversations. Upon user consent, the wizard then initiates playback, allowing the user to relive their musical creation. This collaborative approach between Pepper and the human operator enhances the user experience by ensuring both a seamless recording process and high-fidelity playback.
- **Failsafe Mechanism for Unheard Dialogue**: Anticipating situations where Pepper might miss user responses due to background noise or other factors, a failsafe mechanism is incorporated



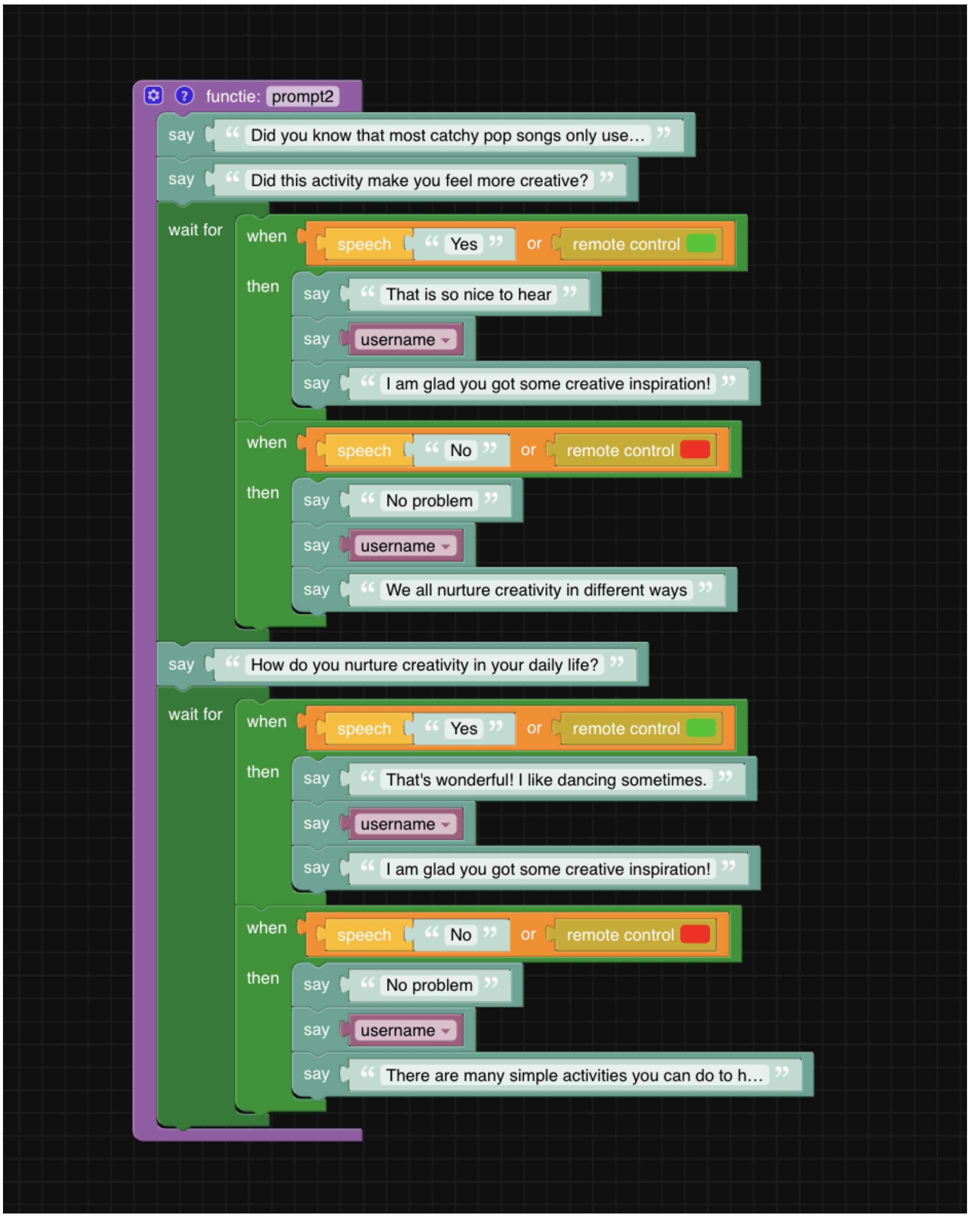
```
functie: playonown
  say “ Now you can make your own tune. Would you like t… ”
  wait for
    when speech “ Yes I would ” or remote control 🟩
    then beatchoice
    when speech “ No I would like to play by myself ” or remote control 🟥
    then say “ Sure, go ahead! ”
         play no beats

functie: play no beats
  say “ Here we go! ”

functie: beatchoice
  say “ I can offer different levels of complexity for … ”
  wait for
    when speech “ Easy ” or remote control 🟨
    then say “ You have selected easy beats. Good luck!  Feel f… ”
         play easy beats
    when speech “ Medium ” or remote control 🟦
    then say “ You have selected medium beats. Good luck! Feel … ”
         play medium beats
    when speech “ Hard ” or remote control 🟥
    then say “ You have selected hard beats. Good luck! Feel fr… ”
         play hard beats

functie: play easy beats
  say “ Here we go! ”
  MP3 easy_beats
  url http://content.robotsindeklas.nl/mp3/63f36b40d30…
  continue while playing sound ☑

functie: play medium beats
  say “ Here we go! ”
  MP3 medium_beats
  url http://content.robotsindeklas.nl/mp3/63f36b40d30…
  continue while playing sound ☑

functie: play hard beats
  say “ Here we go! ”
  MP3 hard_beats
  url http://content.robotsindeklas.nl/mp3/63f36b40d30…
  continue while playing sound ☑
```

Figure 3.6: Rhythmic Accompaniment

through the interactive robotics platform. This mechanism ensures a smooth user experience by empowering a human operator (the wizard) to remotely trigger a response from Pepper through the remote control seen in Figure 3.7. If Pepper doesn't detect user input within a certain timeframe, the wizard can intervene by sending a signal that prompts Pepper to request clarification or offer additional guidance. This ensures that the activity or conversation continues uninterrupted, even in scenarios where Pepper might miss an initial user response.

3.5 Comprehensive Dialogue Process

To ensure a natural and engaging user experience, we employ a dialogue flow between the Pepper robot and the user. The flowchart in Figure 3.8 acts as a roadmap, illustrating the various conversation paths that the interaction can take. It depicts the initial prompts offered by the Pepper robot, the potential user responses, and the robot actions based on those choices. The robot first introduces itself and guided the participant through the music interface. It enables them to familiarize themselves with the interface by pressing specific buttons, multiple buttons at a time and holding a button (similar to holding a note). To get them comfortable, the robot then asks about creative hobbies before offering a choice between a guided or self-play session.
In the guided session, the robot plays simple beats and instructs participants on specific coloured buttons to press, gradually building up to combinations. This aims to help participants understand the interface and spark creative ideas. The self-play session offered more freedom. Participants can choose to play with or without beats, with varying complexity levels. The robot provided positive feedback, encouraging exploration and suggesting alternative colors if repetitive notes are played. During pauses, the robot gently prompts them to continue, and offered a chance to stop if the pause persists. For an extra challenge, participants can choose to play with a limited colour palette of three to four colours, with the robot continuing to offer beats and feedback. Throughout this session, the wizard silently records the robot and participant's musical creation. Following the playing session, the robot compliments the



```
functie: prompt2
say "Did you know that most catchy pop songs only use…"
say "Did this activity make you feel more creative?"
wait for
    when speech "Yes" or remote control 🟩
    then
        say "That is so nice to hear"
        say username
        say "I am glad you got some creative inspiration!"
    when speech "No" or remote control 🟥
    then
        say "No problem"
        say username
        say "We all nurture creativity in different ways"
say "How do you nurture creativity in your daily life?"
wait for
    when speech "Yes" or remote control 🟩
    then
        say "That's wonderful! I like dancing sometimes."
        say username
        say "I am glad you got some creative inspiration!"
    when speech "No" or remote control 🟥
    then
        say "No problem"
        say username
        say "There are many simple activities you can do to h…"
```

Figure 3.7: Buffer Questions and Discussion

participant's musicality and offers to play back the recording. If they agree, the wizard edits out any pauses while the robot chats with the participant about the experience. Even if they decline to listen, the robot still maintained a positive conversation. Finally, the participant's musical creation is played back, and the robot concludes the activity with positive reinforcement. This approach aims to allow participants to explore the music interface creatively, receive positive encouragement, and ultimately, enjoy the experience of creating their own music.

The next chapter covers the research methodology, detailing the pilot study, experimental setup and design, and how the research questions were addressed and answered through the experiments.

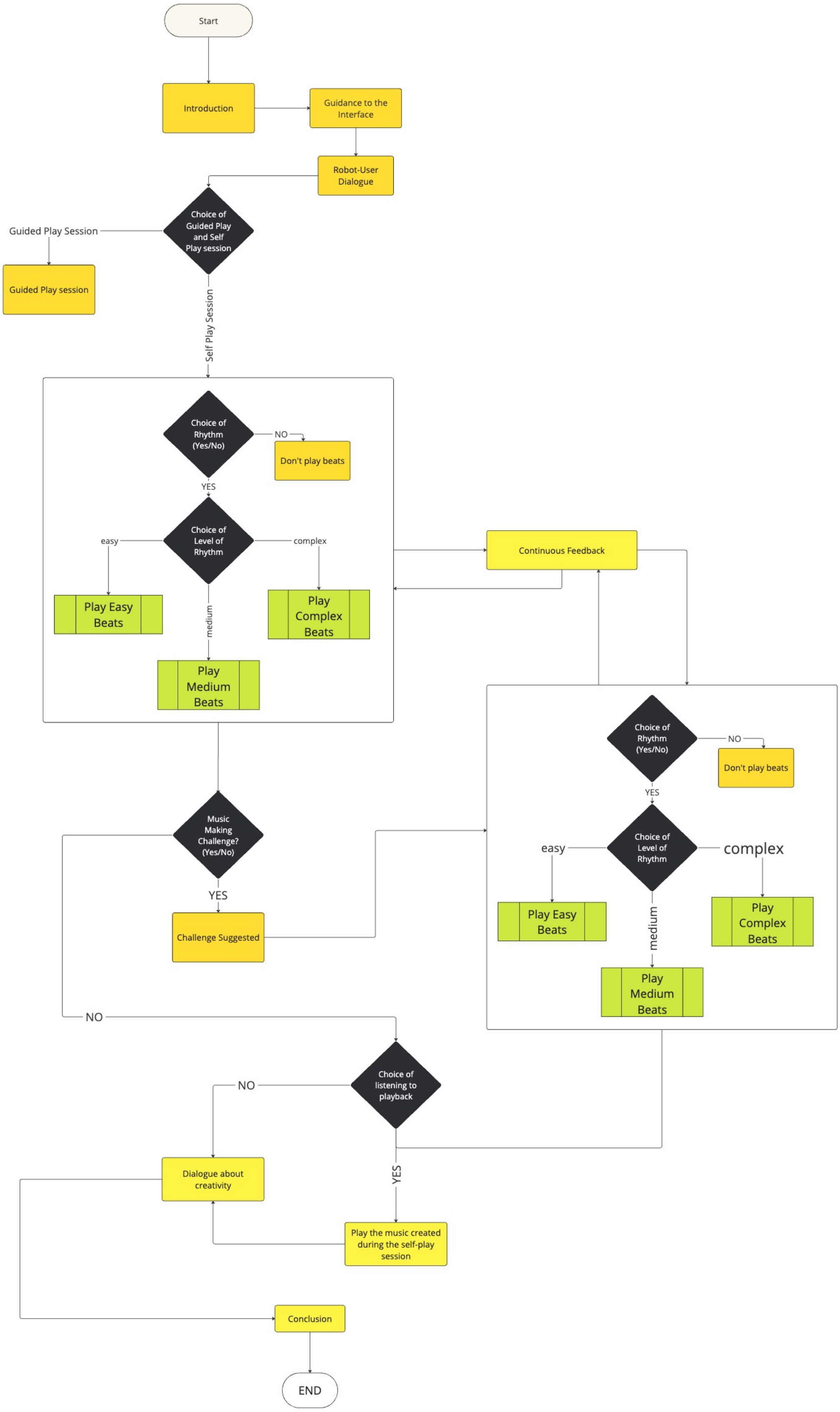


Figure 3.8: Dialogue Flow

4 Research Methodology

4.1 Introduction

This chapter details the methodology followed to investigate how a music-making system designed for older adults with congitive impairment influences their engagement, perceived collaboration with the system, and overall creative expression. Our main research questions, as outlined in Chapter 1, are:

1. How does real-time feedback and encouragement from an interactive robot influence engagement in the activity among older adults?
2. Does rhythmic accompaniment from an interactive robot enhance perceived collaboration in music creation among older adults?
3. Does an easy-to-use music interface foster musical creativity among older adults?

We opted for a qualitative approach to address these research questions. Qualitative methods provide insights into user experiences which allows us to go beyond simply measuring engagement and enjoyment. By observing participants interact with the system, analysing their responses to questionnaires, and capturing their thought process through think-aloud protocols, we aimed to gain a nuanced understanding of how the system impacted them. This approach also allowed us to understand how the participants perceived their collaboration with the robot and the system's potential to foster creative expression.
The following sections of this chapter will elaborate on the specific methods used in the study and the rationale behind our methodological choices. We will discuss the pilot study conducted to refine the system based on user feedback, the ethical considerations addressed throughout the research process, and the recruitment of participants. We will then detail the research design, including the qualitative methods employed and how they addressed each of our research questions. Finally, the chapter will outline the data collection procedures and the fail-safe protocols implemented to ensure participant safety, user comfort, and the smooth operation of the experiment.

4.2 Pilot Study

We carried out a pilot study with students from TU Delft. In this pilot study, participants were given a scenario and asked to provide feedback within that context. The scenario simulated older adults experiencing gradual cognitive impairment. The system featured dialogues in both Dutch and English, so we conducted the pilot with five students: four sessions were in English and one in Dutch. We collected their feedback through semi-structured interviews that were based on the ENJOY scale[14] detailed in 4.7.1 and the subjective questionnaire detailed in 4.7.1. The most feasible suggestions were incorporated into the system. The following changes were made based on the pilot study feedback:

- **User Interface**: Participants requested larger colored boxes spaced out across the tablet, making the interface resemble a piano. This adjustment helped users interact with the tablet more easily and intuitively. We also changed the colors of the boxes to avoid any obvious choices, opting for basic and popular colors so everyone could easily recognize them. Colors like lavender and cyan were replaced with primary, distinguishable colors. Additionally, the background color was changed from midnight blue to black to provide better contrast and stimulation.
- **Introduction of a Guided Play Session**: Initially, the pilot did not include a guided play session. Participants overwhelmingly requested more guidance, feeling "thrown into" the self-play session without sufficient time to familiarize themselves with the instrument. We added an optional guided play session, catering to participants who needed more orientation, while allowing those with a musical background to skip it.

- **Adjusting Pepper's Speaking Speed**: Four out of five participants felt that Pepper spoke too quickly, making it difficult to understand. Consequently, we slowed down the robot's speech in both Dutch and English.

4.3 Participant Selection and Rationale

While directly testing with individuals experiencing cognitive decline is the ultimate goal, ethical considerations and potential participant burden necessitate a more controlled initial study. Therefore, this research recruited older adults without dementia. This population segment is increasingly at risk of cognitive decline, and studying their interaction with the system offers valuable insights.
Understanding how healthy older adults interact with the system establishes a baseline for cognitive and physical capabilities of the target age group. This allows us to identify potential design challenges related to ease of use and engagement. These challenges might be even more significant for those with cognitive decline. Additionally, studying healthy older adults can reveal age-related cognitive changes, such as slower processing speed or mild memory lapses, that could inform the design of an adaptable system. This adaptability would allow for tailoring the system to different levels of cognitive impairment in future iterations. Ultimately, this study lays the groundwork for developing a user-friendly and engaging music-making system specifically for older adults with cognitive decline.

4.4 Ethical Considerations

This research prioritizes the safety, well-being, and privacy of all participants. The following ethical considerations were addressed:

- **Informed Consent**: A written informed consent form, approved by HREC (Human Resource Ethics Comittee) was provided to all participants, explaining the study's purpose, procedures, potential risks and benefits, and participant rights (including the right to withdraw at any time). The form was written in clear and concise language (Dutch or English, based on the preference of the participant), understandable to the target population of older adults. Researchers obtained written informed consent before any data collection begins.

- **Cognitive and Physical Considerations**: The research team is sensitive to the potential for cognitive or physical limitations in older adults. The music interface and robot interactions was designed to be user-friendly and accessible, with clear instructions and opportunities for breaks as needed.

- **Data Privacy and Confidentiality**: All participant data is anonymized and stored securely. Recordings were stored locally and deleted immediately after analysis. Transcripts did not include any identifiable information. Data will only be used for research purposes and will not be shared with any third party without explicit consent. Participants are informed about how their data will be used and stored.

- **CE Certifications**: All devices use in the study are CE Certified. They are assessed and deemed to meet the safety, health, and environmental protection requirements set by the European Union.

4.5 Participants

Seven older adults over 60 years old were recruited for the experiments. While five participants had musical backgrounds from a choir or TU Delft staff (suggesting some musical knowledge), the remaining two participants offered a broader range of experiences, with one individual even expressing a dislike for musical activities. Despite the varied musical experiences, data from the seven participants was included in our qualitative analysis to provide a richer understanding.

4.6 Material

4.6.1 Interface and Audio

- A Lenovo Tab P11 was used to run the tap-to-play music interface.
- An iPhone served as the microphone to record the user's playing.
- Two JBL speakers were set up:
  - One speaker played the user's output from the music interface on the tablet.
  - The other speaker played back the user's recorded performance.

4.6.2 Data Collection

- A smartphone was mounted on a tripod to record the human-robot interaction for all participants.
- The questionnaire and informed consent forms were provided on paper to cater to the preference of older adults.

4.6.3 Control and Wizard-of-Oz Elements

A laptop and an extra monitor were used to control the robot and any elements of the experiment requiring a hidden human operator ("Wizard of Oz").

4.7 Research Design

To answer our research questions mentioned at the start of the chapter, we elaborate our approach and design to understanding user experience with the music-making system designed for older adults.

4.7.1 Qualitative Methods

This study utilizes qualitative methods to gather rich data and gain insights into how various aspects of the system influence engagement, perceived collaboration, and musical creativity in older adults. These methods include video observations, a questionnaire based on the ENJOY Scale [14] and an open ended questionnaire. The design of these methods are elaborated below.

Video Observations

Participants are observed interacting with the system, focusing on factors like engagement levels, interaction with the robot, and use of the interface. Video recordings are used to capture these interactions for later analysis. Engagement is the extent to which participants actively listen, react and respond to robot prompts and encouragement. The analysis is based on ENGAGEDEM [45], a model for understanding how people with dementia engage with activities. It focuses on the observable and behavioral aspects of engagement, rather than just emotions or internal states. In the observations, we focus on active participation and levels of engagement. The model acknowledges that engagement can vary. It can be high-energy and positive (YES) or low-key and more focused (NO). For ease of understanding, we divide our session into three phases - Introduction and Setup phase, Music Making Phase and Post Phase. Based on the ENGAGEDEM model, our coding scheme for video observations cover the following categories through the different phases.

1. Musical Interest Expression
2. Choice of Guidance
3. Participation Level
4. Exploration of the Music Interface

5. Challenge Selection
6. Limited Colour Palette use
7. Social Interaction
8. Non Verbal Cues
9. Body Language
10. Frequency of Feedback and Encouragement
11. Participant Initiated Pauses
12. Playback Participation
13. Response to Pepper's questions

The detailed coding scheme for this analysis is given in Appendix 3.
We used Interrater Reliability[39] to ensure the consistency and reliability of our video coding. Raters outside the research independently coded a subset of the video recordings. They used the pre-defined coding scheme (available in Appendix 3) to categorize participant behaviors. We employed the percent agreement to assess the level of agreement between coders for each category within the ENGAGEDEM framework.

The ENJOY Scale

We utilized the ENJOY scale[14] as a standardized tool to gather some quantitative data to complement our qualitative findings on participants' enjoyment levels while using the music-making system. The scale uses a 7-point rating system, based on the Likert Scale, with clear labels for each point (like "Strongly Disagree" and "Strongly Agree") to capture how much someone enjoyed an activity. The final 25-item version of the original ENJOY scale is composed of 5 factors: pleasure, relatedness, competence, challenge/improvement, and engagement. The ENJOY scale was adapted slightly to capture the specific context of the human-robot collaborative activity. The modified questionnaire, detailed in Appendix 1, includes 20 questions focusing on user experience in this setting and incorporates 4 out of the above mentioned 5 factors: pleasure, relatedness (with the robot), competence and engagement. To analyze the results, we averaged the scores for questions that measure similar aspects of enjoyment. This gave us sub-scores for different the dimensions. Finally, the overall enjoyment score was calculated by adding up the averages from each sub-dimension. While our relatively small sample size may limit statistically significant insights, the ENJOY scale scores provided numerical data points for reporting participant engagement. A few of the prompts that are in the questionnaire are:

1. I felt encouraged by Pepper during the activity.
2. I found it confusing when Pepper spoke during the activity.
3. I felt immersed in the activity.
4. I felt capable in the activity.
5. The activity was pleasurable to me.

By responding to these statements, participants indicated their state of mind during the activity, allowing us to visualize their level of enjoyment on a quantitative scale.

Following the ENJOY scale, participants completed a short, subjective questionnaire designed to gather rich, qualitative data about their specific thoughts and feelings about the music-making system. This questionnaire aimed to gain deeper insights beyond basic enjoyment levels, particularly regarding their perception of creative collaboration with the robot. The questionnaire explored various aspects of the user experience, categorized as follows:
User Interface and Interaction

- **Perceived ease of use of the interface:** This section focused on understanding how participants navigated and interacted with the music-making system. Questions aimed to identify any difficulties or frustrations encountered while using the interface.

Robot Feedback and Collaboration

- **Helpfulness of the robot's feedback:** This section investigated participants' perceptions of the robot's feedback during the activity. Questions explored whether they found the feedback helpful, encouraging, or confusing, and how it impacted their creative process.
- **Sense of collaboration with the robot:** This core aspect of the study focused on participants' feelings of working together with the robot to create music. Questions aimed to understand their perception of the robot's role in the collaboration and whether they felt a sense of shared creativity.

Creative Expression and Emotional Engagement

- **Level of creative expression experienced:** This section delved into participants' subjective experiences of expressing themselves creatively through the music-making system. Questions explored how well they felt they could express their creativity and whether the system fostered new musical ideas.

Overall Impression and Suggestions

- **Suggestions for improvement:** This section provided an opportunity for participants to offer constructive feedback on the system. Questions encouraged them to suggest improvements to the interface, robot interaction, or overall functionality.

By analyzing the subjective questionnaire responses, we gained valuable insights into user experience that complemented the quantitative data from the ENJOY scale. This comprehensive approach allowed us to understand not only how much participants enjoyed the activity, but also how they perceived the various aspects of the music-making system in relation to creative collaboration, ease of use, and overall user experience. The entire questionnaire is available for reference in Appendix 2. The coding scheme used to analyse the questionnaire is available for reference in Appendix 4.

Think-aloud protocols

During the interaction, Pepper asks some questions on creativity and the experience of the participant to make them verbalise their thoughts while they interact with the system. This also supports the observational analysis done while watching the videos.

4.7.2 Addressing Research Questions

The following section outlines how we will address each research question using the chosen qualitative methods and questionnaires:

Research Question 1: Real-Time Feedback and Engagement

To address the impact of real-time feedback on engagement, our observational analysis will focus on participant behavior throughout the music creation sessions. We'll be particularly attentive to facial expressions, body language, and how they interact with both the robot and the interface. This will allow us to compare their behavior in moments when they receive real-time feedback versus moments when they are left to play without it. Our coding scheme reflects this focus, with categories like "Frequency of Feedback and Encouragement" and "Participation Levels" directly correlating to engagement levels. Additionally, the presence of "Participant Initiated Pauses" can also serve as a valuable indicator of engagement. By analyzing these observational details, we aim to understand how real-time feedback influences participants' level of involvement and enthusiasm during the music creation activity.
Scores on the ENJOY scale provide a quantitative measure of enjoyment with and without real-time feedback, although statistical analysis may not be feasible due to the small sample size.
The subjective questionnaire includes questions specifically designed to assess participants' perceptions of the robot's guidance and feedback. By analyzing these responses, we can gain valuable insights into how helpful participants found the feedback and its potential impact on their engagement with the music creation activity.

Research Question 2: Rhythmic Accompaniment and Collaboration

Successful creative collaboration requires a complex interplay between musical, social, and personal factors [4]. To understand the effectiveness and the perception of collaboration in the activity, video recordings from sessions with rhythmic accompaniment are analyzed to understand participant interactions. Particular focus is placed on communication with the robot and cues suggesting collaboration, both verbal and nonverbal. The coding scheme incorporates categories like ”Social Interaction,” ”Non-Verbal Cues,” and ”Body Language during Rhythmic Accompaniment.” These categories can provide insights into perceived collaboration through the presence of positive expressions and active body movements during interaction with the rhythmic accompaniment.
Responses from the Subjective questionnaire regarding participants' sense of collaboration with the robot are analyzed. This analysis aims to understand how the presence of rhythmic accompaniment influences their perception of working together with the robot to create music.

Research Question 3: Easy-to-Use Interface and Creativity

In section 2.1.3, we defined creativity as a characteristic that forms something novel and valuable, inducing a sense of ownership. In order to assess the impact of the interface on creative exploration, participant interactions are analyzed through observations. This analysis focuses on how participants navigate features, the ease of use of the interface, and the level of creative exploration within the system's capabilities. The coding scheme category ”Exploration of Music Interface” directly addresses this aspect. Additionally, categories like ”Challenge Selection” and ”Limited Color Palette Use” can be informative. Choosing challenges and actively utilizing the limited color palette suggest participants feel comfortable pushing the boundaries of their creativity with the interface. Think-aloud protocols further illuminate participants' creative thought processes during their interaction. Insights from the ”Response to Pepper's Questions” category of the coding scheme can reveal whether the activity fostered a sense of creativity. Finally, the Subjective questionnaire sheds further light on this topic. Responses to questions regarding perceived ease of use and the level of creative expression experienced provide valuable data on how participants' experience with the interface influenced their creative exploration.

4.8 Combining Qualitative and Quantitative Data

The collected data (video recordings, interview transcripts, ENJOY scale scores, Subjective questionnaire responses is analyzed using a mixed-methods approach. While the ENJOY scale provides some quantitative data, this study primarily focuses on qualitative analysis. We use thematic analysis techniques to identify recurring themes and patterns in the video recordings, interview transcripts, and subjective questionnaire responses. By integrating these different data sources, we gain a richer understanding of how various aspects of the system influence engagement, perceived collaboration, and musical creativity in older adults.

4.9 Procedure

The study first received ethical approval from the Delft University of Technology's Human Research Ethics Committee. Following approval, participant recruitment began. Participants were invited to the INSYGHT Lab on the Delft campus, where they signed informed consent forms before participating in the experiment. The experimental setup is illustrated in Figure 4.1 The experiment was designed to be flexible and accommodating for older adult participants, with a duration ranging from 30 to 45 minutes. This variation depended on the participant's individual choices and creative exploration within the music-making system. Upon arrival, participants were greeted warmly and offered refreshments to ensure their comfort throughout the experiment. This gesture acknowledges the importance of catering to the needs of older adults. The participant was then seated comfortably at a table within the designated experimental area, as illustrated in the schematic diagram (Figure 4.1). A photograph from the participant's perspective is included in Figure 4.2 to provide further context. The researcher provided

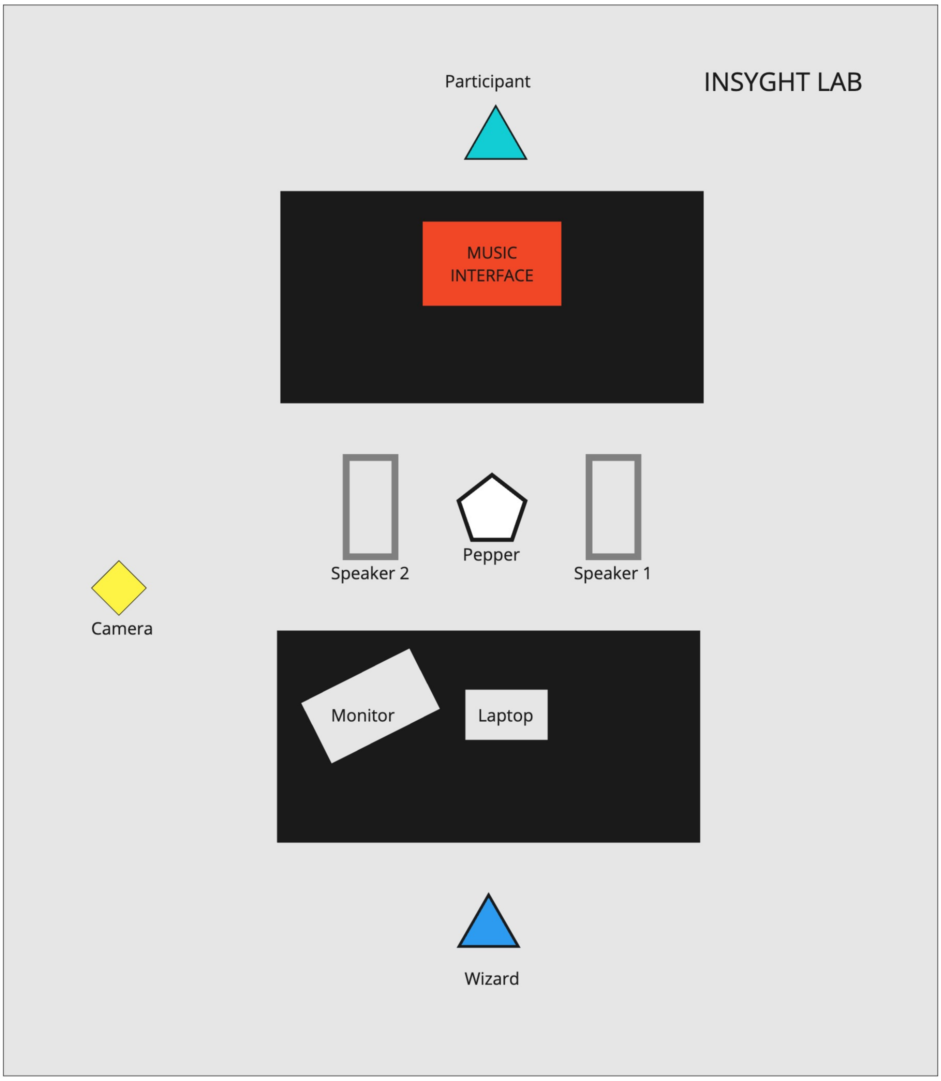


Figure 4.1: Schematic Setup of the experiment

a clear and concise summary of the informed consent form, including details about video recording, the right to withdraw at any time, and the questionnaires to be completed after the experiment. A brief overview of the experimental procedure was also given to ensure the participant fully understood the process. Following this explanation, both the researcher and the participant signed the informed consent forms. The researcher then initiated video recording and assumed the role of the "wizard" within the experimental setup, operating the system behind the scenes. Pepper, the social robot, and the music interface were then activated. Pepper introduced the activity, and the participant engaged with the music-making system as described in Section 3. The music creation activity itself typically lasted between 15 and 25 minutes. Once the music creation activity ended, the researcher stopped the video recording. The participant was then provided with the questionnaires, and the researcher explained the purpose of each section and what kind of responses were expected. Participants were given approximately 15 minutes to complete the questionnaires at their own pace. Finally, after completing the questionnaires, the participant was thanked for their time and participation, and they were free to leave.

4.10 Fail-safe Protocols

This section outlines the measures taken to ensure participant safety, user comfort, and the smooth operation of the experiment.

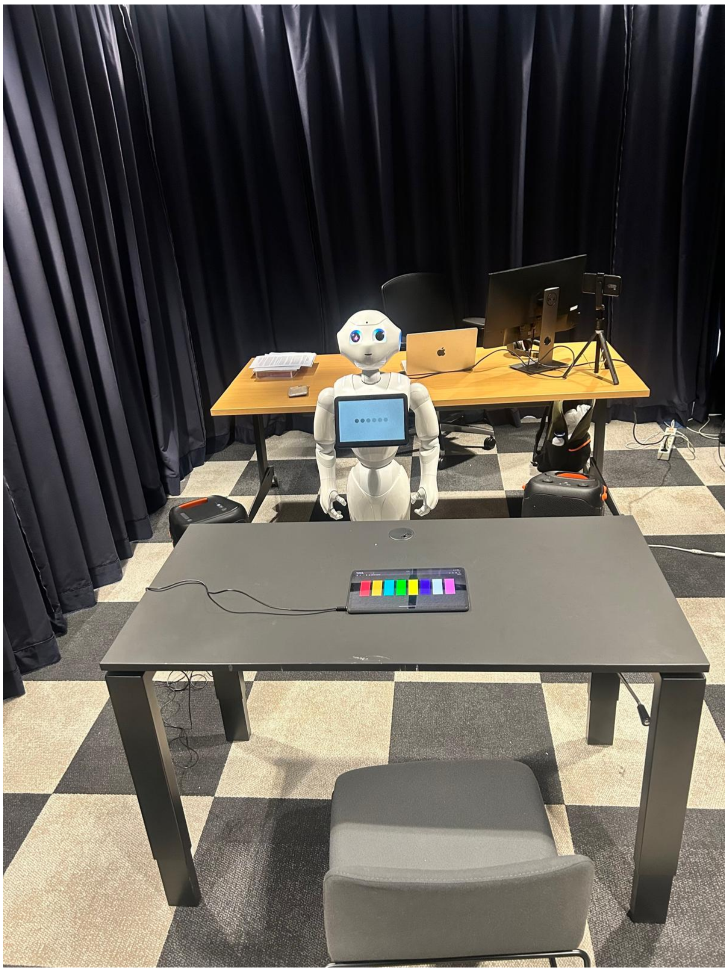


Figure 4.2: Participant view of Experimental Setup

4.10.1 Safety and User Comfort

We prioritized participant well-being by providing them with full control over the experiment. Participants could stop the experiment at any point by simply informing the researcher (acting as the "wizard") present in the room. The researcher could then halt the system immediately.
Volume Control: The researcher could adjust the robot's volume or the music interface to ensure a comfortable listening experience for the participant.
Breaks: While the music making activity was designed to last under 30 minutes to minimize fatigue, participants were offered the option to pause the session and take a break at any time.
Simple Interface and Clear Instructions: The music interface and interactions with Pepper were designed to be clear, user-friendly, and free from complex instructions. The robot offered step-by-step guidance and could repeat instructions if needed.
Accessibility Considerations: Large buttons on the tablet interface and Pepper's slower speaking rate catered to the potential physical limitations of older adults.

4.10.2 Technical Failsafes

Addressing Pepper's response issue: As mentioned in Section 3.4.3, we anticipated situations where Pepper might miss a user response. To address this, we utilized the interactive robotics platform to provide additional support and ensure smooth communication throughout the experiment.
System Malfunctions: In the unlikely event of a system malfunction with Pepper, the robot was programmed to automatically reboot and restart the application, minimizing disruption to the experiment.
Internet Connectivity: Recognizing our reliance on internet connectivity, the experiment setup included access to two separate Wi-Fi networks to provide backup in case of any network issues.

4.10.3 Data Privacy

The informed consent form clearly outlined data collection and storage procedures, emphasizing participant privacy. All participant data was anonymized and kept secure.

5 Results and Discussion

This section delves into the key findings of our study which explores user experience with the music-making system designed for older adults. To recap, our research goal was to understand the impact of a music interface, enhanced by social interaction with a robot, on creativity, engagement and collaboration. We utilized a combination of qualitative and quantitative methods, including observations and questionnaires, to gather rich data on participant interactions and experiences. Each research question was addressed based on the method described in Section 4.7.2 of Chapter 4. The analysis of the ENJOY questionnaire was done based on individual responses while the analysis of the subjective questionnaires followed the coding scheme described in Appendix 4. The video observations were conducted using the researcher's field notes, which were compiled after reviewing a recorded video of the interaction. Additionally, the coding scheme detailed in Appendix 3 was applied. A summary of the observations based on this coding scheme is provided in Table 5.1. This coding scheme was also provided to two researchers outside the experiment, who rated and provided feedback on the videos. As explained in Section 4.7.1, we used Interrater Reliability[39] to ensure the consistency and reliability of our video coding. The external raters independently coded two of the video recordings. Using the percent agreement metric, we achieved an interrater reliability of 89.8%. The ratings provided by each researcher and the computation details are included in Appendix 5.The following sections present the results of our study, organized by the research questions. For easier understanding, a brief summary of the topics addressed by our research questions is provided:

- RQ1: Impact of robotic social motivation on engagement.
- RQ2: Impact of rhythmic accompaniment on perceived collaboration
- RQ3: Impact of intelligent music interface on creativity

Table 5.1: Summary of Participant Observations in the Video based on Coding Scheme

Participant ID		P 1	2	3	4	5	6	7
SECTION 1: DEMOGRAHPICS								
	Age	74	60	60	64	68	69	62
3.2 Introduction and Setup(YES/NO								
• Interest in music expressed: Can be coded as Positive (YES) if participant shows enthusiasm for music or Negative (NO) if they show disinterest.		YES	YES	YES	NO	YES	YES	YES
3.3 Music Making session								
1. Participation Level • Initiates exploration (YES): Participant independently explores the music interface. (YES) • Responds to prompts (YES): Participant actively participates in response to robot's prompts or suggestions. • Passively observes (NO): Participant watches the robot's music making but doesn't actively participate.		YES	YES	YES	NO	YES	NO	YES

• Disengaged (NO): Participant shows disinterest and withdraws from the activity.								
2. Choice of Guidance • Chooses Guided Play (YES): Participant actively seeks or accepts the robot's guidance during music making. (YES/NO) • Chooses Self-Play (YES/NO): Participant prefers to explore the music interface independently. This can be coded as YES if the participant actively explores, or NO if they show minimal exploration.		YES	YES	YES	YES	YES	NO	YES
3. Exploration of Music Interface (YES) • High Exploration (YES): Participant tries a variety of buttons and combinations, showing active engagement with the interface • Moderate Exploration (YES/NO): Participant explores the interface to some extent but not extensively. • Low Exploration (NO): Participant shows minimal exploration of the interface, suggesting limited engagement.		YES	YES	YES	NO	YES	YES	YES
4. Challenge Selection (YES/NO): Accepted Challenge (YES) or Declined Challenge (NO).		YES	YES	YES	YES	YES	YES	YES
5. Limited Color Palette Use (YES/NO): Embraced limited colour palette (YES) or Did not stick to the challenge(NO) based on engagement during the limited palette segment		YES	YES	YES	NO	YES	NO	NO
6. Social Interaction • Focuses on robot (YES): Participant directs most attention towards the robot during music making.(YES)		YES	YES	YES	NO	NO	NO	YES
• Shared interaction (YES): Participant interacts with both the robot and interface during music making, without letting the robot distract them from playing. • Minimal social interaction (NO): Participant shows minimal interaction with the robot during music making.								
7. Non-verbal Cues(YES/NO)								

• Positive expressions (YES): Participant smiles, laughs, or shows other signs of enjoyment during music making. • Neutral expressions (YES/NO): Participant has a neutral expression through-out the activity. • Negative expressions (NO): Participant frowns, looks away, or shows signs of boredom or frustration during music making.		YES	YES	YES	NO	YES	NO	YES
8. Body Language (YES/NO) • Active body movements (YES): Participant claps, sways, taps feet, or shows other signs of physical engagement with the music. • Minimal body movements (YES/NO): Participant shows minimal physical movement during music making. • Restlessness (NO): Participant fidgets, looks around, or shows signs of disengage-ment from the activity.		YES	YES	YES	NO	NO	NO	YES
9. Frequency of Feedback and Encouragement (YES/NO): Retained for analysis but categorized as Positive Feedback(YES) or Encouraging Feedback (through asking them to try something (NO) based on participant's reaction.		3, YES	6, YES	4, YES	5, NO	4, YES	2, NO	4, YES
10. Participant Initiated Pauses (Number): (Retained)		2	4	3	3	2	2	4
3.4 Post session								
1. Playback Participation • Engaged with playback (YES): Participant actively watches or listens to the playback. • Passively observes playback (NO): Participant shows minimal interest in the playback		YES	YES	YES	NO	YES	NO	YES
2. Response to Pepper's questions (YES) • Enthusiastic response (YES): Participant actively responds to the robot's questions. • Subdued response (NO): Participant shows limited interest in responding to the robot's questions.		YES	YES	YES	NO	NO	NO	YES
3. Technical Issues (Yes/No): (Retained)		No	Yes (Minor)	Yes (Minor)	No	No	Yes (Minor)	No

5.1 Analysis of RQ1

The first research question aims to understand the impact of real-time feedback from the robot on engagement among older adults. As mentioned in Section 4.7.1,we define engagement as the extent to which participants actively listen, react and respond to robot prompts and encouragement. To address this, we analyzed data collected through observations, the subjective questionnaire, and the ENJOY scale.

5.1.1 ENJOY Questionnaire

A questionnaire based on the ENJOY scale was administered to the participants. This scale assessed enjoyment across four dimensions: pleasure, relatedness, competence, and engagement. The questionnaire contained the most prompts (7) to understand engagement, followed by relatedness (6), competence (4), and pleasure (3). This emphasis reflects the primary focus on engagement through interaction with the robot Pepper. Figure 5.1 shows the average score provided by seven participants across the four dimensions. Based on this, the average ratings for each dimension were:

- Engagement: 4.5
- Relatedness: 4.5
- Pleasure: 4.4
- Competence: 3.5

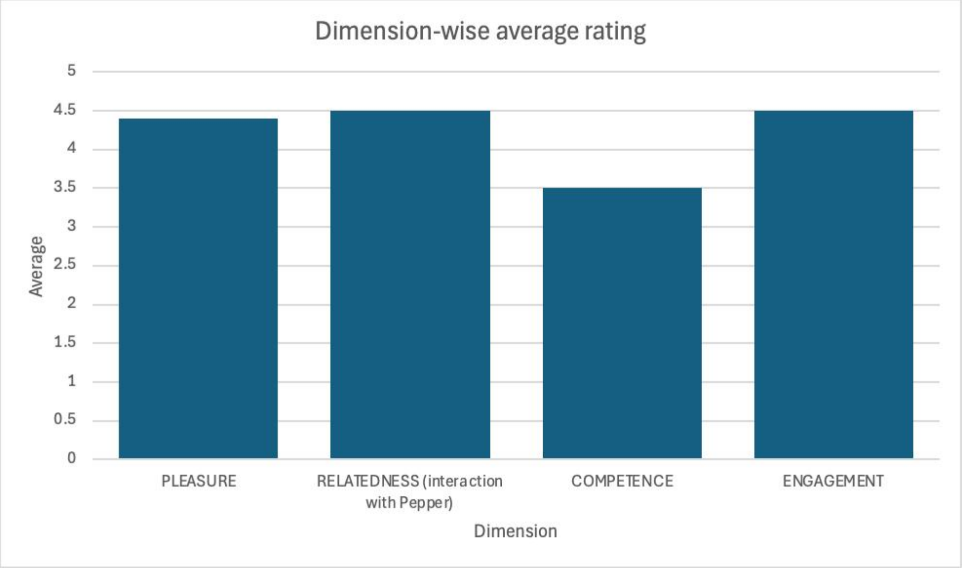


Figure 5.1: Average ratings for each dimension of enjoyment

Due to the limited sample size of seven participants, these results are inconclusive. However, a deeper analysis of specific prompts can provide insights into the participant experiences. Figure 5.2 shows a participant-wise rating across the different dimensions. Based on the figure, we observe that five out of seven participants consistently exhibit higher ratings across all dimensions, whereas participants 4 and 6 show relatively lower ratings.

Engagement Analysis
Engagement is high among five out of seven participants. Those with low *engagement* ratings have consistently low ratings across all dimensions. The majority of participants strongly agreed with prompts related to high engagement, such as *"I was concentrating on the activity"* and *"I blocked out most distractions in the activity."* Conversely, participants who rated their engagement low gave ratings of 1 or 2 on the same prompts, indicating they did not feel immersed in the activity.

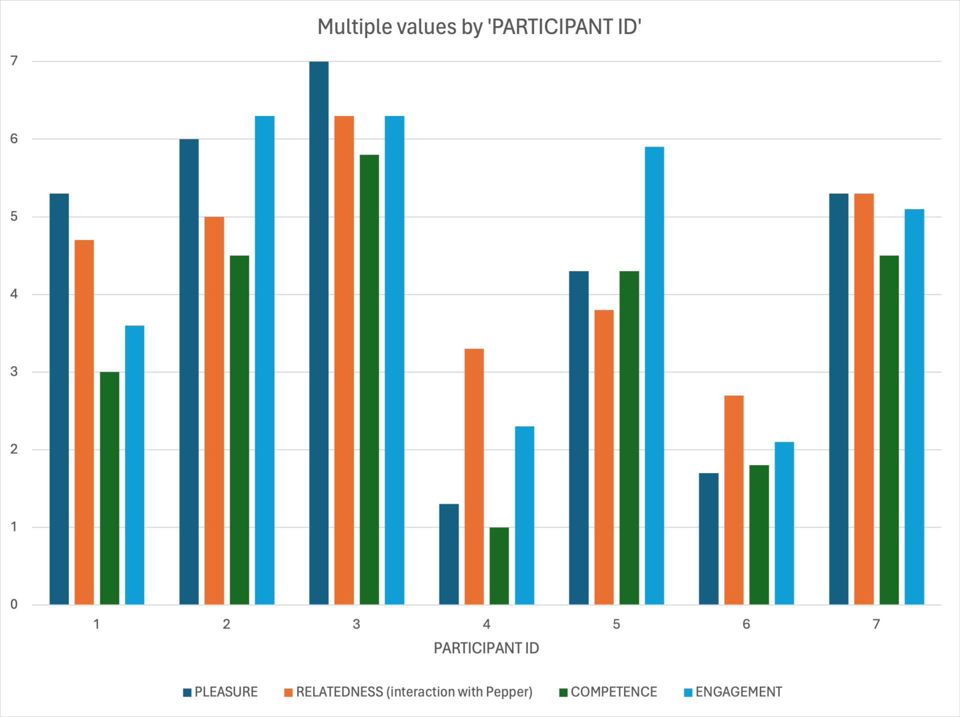


Figure 5.2: Participant-wise rating of different dimensions

Relatedness Analysis
The *relatedness* dimension explored participants' interactions with Pepper. The prompt *"I liked interacting with Pepper"* received a high score, indicating positive interaction. In contrast, the prompt *"I felt frustrated when Pepper spoke"* received a lower score. Responses to prompts about feeling connected to or encouraged by Pepper were more neutral, varying based on individual experiences. These prompts included *"I felt connected with Pepper during the activity"* and *"I felt encouraged by Pepper during the activity"* Overall, relatedness had mixed responses: four out of seven participants had a higher average relatedness score, while the others rated it below average.

5.1.2 Subjective Questionnaire

Table 5.2 summarizes responses from a subjective questionnaire concerning the impact of Pepper's real-time feedback and encouragement on engagement in the music making activity among older adults based on the coding scheme defined in Appendix 4.
These are the key observations

- **Positive Impact on Engagement**
The majority of participants (1, 2, 3, 5, and 7) reported a positive influence of Pepper's feedback and encouragement on their enjoyment and motivation to continue the activity. One participant stated, *"The positive feedback told me I am succeeding at something, so it makes me want to continue and raise the level to reach for,"* while another said, *"(the feedback) was positive and encouraging."* Words like *enjoyable, helped, motivated,* and *encouraging* highlight the positive impact on engagement. Participants enjoyed the guidance and found Pepper's encouragement helpful for staying engaged (refer to participants 2, 3, 5, and 7 in the table). For some participants with limited musical experience (7), Pepper's guidance provided structure and a "baseline" (3) that enhanced their enjoyment. One participant commented, *"It is nice to be guided while playing, because everything is new. It provides something to hold on to,"* and another said, *"It did (help) in steering the activity to a certain level and form. The encouragement helped me to stay in the game."*

- **Mixed Impact on Engagement**
Participant 4, a beginner with no musical background, reported a neutral impact on both enjoyment

Participant Details		**Musical Background**		**Social Impact on Engagement**	
Participant ID	**Age**	**Musical Experience Level**	**Specific Musical Skills**	**Impact of Pepper's Guidance on Enjoyment**	**Impact of Pepper's Feedback on Continuing**
1	74	Intermediate	Piano	Positive - Enjoyable	Neutral
2	60	Intermediate	Singing	Positive - Helped stay in the game and steered the activity	Positive - motivated to continue and improve
3	60	Advanced	Professional	Positive - nice to be guided because everything is new and it gives a nice baseline	Positive - Maintained engagement
4	64	Beginner	None	Neutral - No impact	Neutral - Could not take it seriously
5	68	Advanced	Singing	Positive - Guidance was sometimes too fast but I liked it because it felt like memory training	Positive - influenced to play
6	69	Intermediate	Beginner Piano	Negative	Neutral - No impact
7	62	Intermediate	None	Positive - enjoyed the activity more	Positive - encouraging

Table 5.2: Summary of Feedback from Subjective questionnaire for Research question 1

and motivation, noting difficulty in taking Pepper's feedback seriously. Participant 5 remarked, *"Yes, it was a kind of memory training, but sometimes I found his guidance too fast."*

- **Limited Impact on Engagement**
  Participant 6 reported a negative impact on their enjoyment but a neutral impact on motivation to continue. They stated *"no real impact, I found the tablet annoying."*

5.1.3 Video Observations

The analysis of participant behavior during music creation sessions suggests an optimistic relationship between real-time feedback and engagement. Here's a breakdown of the key observations derived from field notes and Table 5.1.

- **Positive Influence:** Several participants displayed positive reactions to real-time feedback. Examples include smiling, laughing, and continuing to play after receiving feedback. Many of them also leaned in during interactions, suggesting enjoyment. One of the participants seemed to have reached a flow state, where they were tapping their feet in sync with the rhythm, being immersed in the musical experience. The feedback encouraged a majority of the participants and served as a boost for interest and motivation. One participant squealed with delight when Pepper called out their name and praised their playing. A couple of other participants were flattered by Pepper's compliments, even though they felt Pepper was being overly optimistic.
- **Potential Disruption:** Some participants paused or stopped playing entirely after receiving feedback from Pepper (Participants 1 and 3). Pepper then had to prompt them to continue playing the tablet. It seemed like the feedback disrupted their musical flow or that they anticipated a new activity or challenge whenever Pepper spoke.
- **Individual Preferences:** There were variations in how participants responded to feedback. Two participants had a disinterested posture and demeanour. They were slouching, fidgeting and looking at their phone and appearing rushed indicating boredom or lack of engagement. One of the participants wanted more interaction in Pepper in terms of conversation. They said that conversing with Pepper about the activity gave them a small break which was enough motivation

to continue the activity. While some thrived on encouragement, others seemed to prefer playing without interruptions.

5.2 Analysis of RQ2

The second research question aims to understand the impact of rhythmic accompaniment from the interactive robot on the perception of collaboration. As explained in Section 4.7.2, successful creative collaboration requires a complex interplay between musical, social, and personal factors. To observe this, we analyzed data collected through videos and the subjective questionnaire.

5.2.1 Subjective Questionnaire

Table 5.3 summarizes responses from a subjective questionnaire concerning the impact of Pepper's rhythmic accompaniment on perceived collaboration in the music making activity among older adults based on the coding scheme defined in Appendix 4.

Participant Details		**Musical Background**		**Cognitive Experience**		
ID	**Age**	**Musical Experience Level**	**Specific Musical Skills**	**Influence of Pepper's rhythm on musical choices**	**Exploration of ideas through interaction**	**Robot vs Human Collaboration**
1	74	Intermediate	Piano	Positive - Hooked	Positive - Enlightening	Not the same emotionally
2	60	Intermediate	Singing	Neutral - struggle to keep rhythm	Positive - played multiple notes in sync with rhythm	Not the same emotionally
3	60	Advanced	Professional	Positive - good challenge to keep rhythm	Neutral - was fun	Not the same emotionally
4	64	Beginner	None	Neutral - No impact	Negative - Not interested	Neutral - Do not know
5	68	Advanced	Singing	Neutral - No rhythm chosen	Positive - intuitive play	Not the same since reactions don't feel genuine
6	69	Intermediate	Beginner Piano	Negative - disruptive	Negative	Not the same at all
7	62	Intermediate	None	Positive - rhythm gave a goal	Positive - through the challenge given by robot	Neutral - robot is calmer

Table 5.3: Summary of Feedback from Subjective questionnaire Research Question 2

These are the key observations

- **Perceived Collaboration**
  Three participants reported a positive influence of Pepper's rhythm on their musical choices and creation process. One participant said, *”It challenged me rhythmically to introduce a variation and to coincide in sound.”* Phrases used in the questionnaire like *”hooked,” ”good challenge,”* and *”gave a goal”* suggest that the rhythm provided a structure for their musical exploration. However, one participant reported a negative experience, stating, *”It (rhythm) was more disruptive than supportive.”* In terms of comparing the collaboration with a human, 6 out of 7 participants felt that working with Pepper differed emotionally. One participant remarked, *”With a robot, it still feels like instruction; you are guided more. With a real person, you 'fall together' in the movement, there is more interaction on an emotional level. I connect less or not at all emotionally with a robot.”* Responses included terms like *”not the same emotionally”* and *”reactions don't feel*

genuine," highlighting this distinction. There appears to be no clear correlation between musical background and the perceived influence of Pepper's rhythm, as participants with varying levels of musical experience (beginner, intermediate, advanced) reported both positive and negative impacts.

- **Exploration and Interaction**
  Some participants (2, 5, and 7) reported positive experiences exploring musical ideas through interaction with Pepper. One participant noted, *"I tried to explore and play in the same rhythm but was still struggling to make a melody."* Another said, *"Yes, the interaction with rhythm encouraged me to play more intuitively and improvise more. So and so more playing at home."* Terms like *"enlightening"* and *"intuitive play"* bolster these experiences. Conversely, two participants expressed disinterest in the collaboration and exploration, responding, *"No, I'm not really interested."*

5.2.2 Video Observations

While observing the videos, particular focus is placed on communication with the robot and cues suggesting collaboration, both verbal and nonverbal.The analysis of video recordings suggests that rhythmic accompaniment does not strongly influence perceived collaboration. Here is a deeper look based on field notes and Table 5.1.

- **Effect of Rhythm**
  While some participants interacted with the robot and responded positively to the rhythmic accompaniment, there was a lack of consistent cues explicitly indicating a sense of collaboration. It seemed that participants used the beat to guide them through playing the music rather than collaborating with Pepper. Participants did seem to enjoy the rhythm's guidance, but they perceived it more as an interactive tool. Active body movements, like swaying or tapping feet during rhythmic segments, could indicate a feeling of being "in sync" with the robot. However, this does not directly indicate perceived collaboration, as most participants enjoy tapping to music passively as well.
- **Effect of Social Interaction with Rhythm**
  4 participants exhibited positive social cues during the rhythmic accompaniment sections. Participants who smiled, laughed, or showed other positive expressions while playing with the accompaniment seemed to enjoy interacting with the robot. One participant's positive social cues and body language, along with pausing to listen to Pepper's encouragement, highlighted the importance of well-timed feedback within rhythmic accompaniment. However, even though Pepper paused the rhythm to make conversation or encourage participants to continue playing after taking a break, this didn't seem to foster a sense of collaboration as much as it made them feel obliged to play with the rhythm. Three out of seven participants had minimal social interaction during the rhythmic accompaniment, suggesting a lack of engagement with Pepper and potentially a diminished sense of collaboration. The observations were mixed where some participants seemed to enjoy the challenge of the accompaniment, while others found it overwhelming.

5.3 Analysis of RQ3

The third research question aims to understand the impact of an intelligent music interface on creativity. As mentioned in Section 4.7.2, we define creativity as a characteristic that forms something valuable and novel, inducing a sense of ownership. To address this, we analyzed data collected through observations and the subjective questionnaire.

5.3.1 Subjective Questionnaire

Table 5.4 summarizes responses from a subjective questionnaire concerning the use of an accessible music interface to foster creativity among older adults based on the coding scheme defined in Appendix 4.

These are the key observations

Participant Details		**Musical Background**		**Technology and Exploration**	
Participant ID	**Age**	**Musical Experience Level**	**Specific Musical Skills**	**Ease of Tablet use**	**Re-listening to created music for motivation**
1	74	Intermediate	Piano	Neutral	Negative - felt like what they played was different from what they heard
2	60	Intermediate	Singing	Positive - intuitive since keys on the right always played higher notes than keys on the left	Positive - motivated to continue because they were pleasantly surprised
3	60	Advanced	Professional	Positive - Boxes play new notes which feels like a challenge	Positive - Wanted to play more
4	64	Beginner	None	Neutral - No impact	Neutral - did not listen to playback
5	68	Advanced	Singing	Neutral - The same button generating different notes was confusing as a musician but eventually improvised and followed where the music takes me which was nice	Positive - initially bad but got better with time
6	69	Intermediate	Beginner Piano	Negative - Annoying that the boxes played different notes each time - no control	Neutral - Did not listen to playback
7	62	Intermediate	None	Positive - felt easy to play	Positive - encouraging because it sounded nice

Table 5.4: Summary of Feedback from Subjective questionnaire for Research question 3

- **Interface Ease of Use**
  Participants varied in their perception of the ease of using the tablet interface. While some (Participants 2, 3, and 7) found it positive or intuitive, others (Participants 1, 5, and 6) reported difficulties or confusion. Participant 5 remarked, *"It was a wonderful experience that melodic 'fragments' are pre-programmed, which went against my expectations and also stimulated me in a certain way."* Another participant noted, *"I did discover ways to explore musical ideas within the given limits by playing several keys at the same time and discovering how they sound together with the background."* A third participant commented, *"Hard to say if it was easy due to the confusion with the pitches. But you can also 'follow' the tablet and discover where it 'leads' you."* Their experiences highlighted a potential challenge: the interface's element of surprise, where buttons generate different notes, felt counterintuitive for experienced musicians seeking precise control.

- **Impact on Creativity**
  The impact of the interface on creativity is inconclusive. Some participants (Participants 3, 5, and 7) expressed positive experiences related to exploration and improvisation and used phrases like *"boxes play new notes," "improvised,"* and *"felt easy to play"*. However, others (Participants 1 and 6) reported frustration with the interface hindering their creative expression and said *"felt like what they played was different"* and *"the interface is annoying and unreliable"*.

- **Re-listening and Motivation**
  Re-listening to the created music appeared to influence motivation in some cases. Participants 2,

3, and 5 reported positive experiences that motivated them to continue playing. The participants noted that they were *"pleasantly surprised," "wanted to play more,"* and *"got better with time"*. Participant 1 had a negative experience with re-listening and explained a dissonance between played and heard music, suggesting that the interface might not always support the user's creative intent.

5.3.2 Video Observations

The analysis of participant interactions with the music interface offers insights into its potential for fostering creative exploration. Here is a breakdown of the key observations derived from field notes and Table 5.1.

- **Exploration Levels**
  A majority (five out of seven) participants actively experimented with different features and combinations. This suggests that the interface allowed for a degree of creative exploration within its design constraints. Participants who showed minimal exploration seemed less engaged with the creative potential of the interface.
- **Challenges and Creativity**
  All of the participants embraced the challenge of using a limited color palette, demonstrating their willingness to push the boundaries of creativity with the provided tools. They used it as a springboard for creative exploration.
- **Desire for Complexity**
  While some participants found the interface engaging, others expressed a desire for more complexity. Participants who actively explored the interface often expressed a desire for more complexity and suggested a need for features that cater to advanced users.

5.4 Overall Observations

Based on the observations made through the video and the responses of the subjective and ENJOY questionnaire, we make the following observations to answer our research questions.

1. **Pepper's real-time feedback and encouragement generally has a positive influence on engagement in the music making activity among older adults.** This is particularly true for participants with some musical experience who appreciate the structure and motivation provided by the robot.The multi-sensory experience provided by the activity could be attributed to higher engagement levels. Pepper's encouragement to play, combined with the sounds and visual interface, stimulated participants' auditory and visual senses, respectively. Dialogues and guidance from Pepper required participants to pay attention and focus on the instructions, further enhancing engagement.
2. **The real-time feedback tends to act as a disruption to some older adults.** Since music is also an auditory activity, many older adults like listening to what they play. So, when Pepper provides verbal feedback, it seems to disrupt their flow and they stop playing. There seems to be a need for better paced feedback and tailoring these to the individuals' level of engagement. The feedback's effectiveness might vary depending on individual preferences and experience levels.
3. **The rhythmic accompaniment did not strongly influence perceived collaboration.** Participants seemed to use it as a guide rather than collaborating with Pepper. While some participants found Pepper's rhythm to be a positive influence on their music creation, all distinguished it from collaborating with a human on an emotional level. Most participants felt a lack of emotional connection with Pepper compared to a human collaborator. They described interactions with Pepper as "instructional" and lacking genuine reactions.
4. **Social interaction and feedback during the rhythm were enjoyable but did not foster collaboration.** Positive social cues (smiling, laughing) were observed in some participants during rhythmic sections, suggesting they enjoyed interacting with Pepper. However, it didn't necessarily translate to perceived collaboration. Some felt obligated to play rather than collaborating.

5. **Participants with intermediate to advanced musical experience find the need for an interface with more control.** The interface's element of surprise, while potentially encouraging exploration for some, was frustrating for others, particularly those with musical experience seeking more control.

6. **Participants embraced the limited options as a springboard for creative exploration.** How the interface translates user input into sound seemed to play a role in creative freedom. This highlights the idea that creativity can often thrive under constraints.

7. **The tablet interface has the potential to foster creative exploration, especially for beginners.** Some participants were pleasantly surprised and motivated to play more after re-listening to their creations. This positive reinforcement loop could be particularly encouraging for beginners. Hearing something they created themselves could boost their confidence and motivate them to keep exploring and refining their skills.

5.5 Other feedback

In addition to addressing the core research questions, the study offered participants the opportunity to provide feedback on the activity itself. This feedback encompassed suggestions for improvement in two key areas: the user interface and the interaction design. Participants were also invited to share their preferences regarding the long-term structure of the session. While participation in this feedback section was voluntary, Table 5.5 summarizes the valuable insights obtained.

Participant Details		**Musical Background**		**Preference for Future Sessions**	
Participant ID	**Age**	**Musical Experience Level**	**Specific Musical Skills**	**Preferred Session Structure**	**Additional Preferences**
1	74	Intermediate	Piano	None	Doesn't like that the robot mentions their name frequently
2	60	Intermediate	Singing	More choices of instrument - like a keyboard or drums, more agility from Pepper	repetition of information
3	60	Advanced	Professional	Would like a more complex instrument with more control over the system	None
4	64	Beginner	None	Need more guidance	None
5	68	Advanced	Singing	slower instructions and longer pauses or interaction times between instructions	Need an instrument with more control
6	69	Intermediate	Beginner Piano	None	None
7	62	Intermediate	None	Pepper provides more challenge ideas	Create a bigger note bar

Table 5.5: Summary of Suggestions for Future Sessions

By analyzing these responses, we have identified key recommendations for this activity that could be instrumental in the design of future studies.

1. **User Interface (UI) Design**
   Control and Predictability: Several participants expressed a desire for more control over the musical output. Options like a dedicated instrument with a wider range of *controllable notes* or a

larger note bar could address this need.
Clarity and Predictability: Participant 5's comment about the confusing nature of buttons generating different notes highlights the need for a clear and predictable UI.

2. **Interaction Design**
   Instruction Repetition: Feedback from two participants (2 and 5) suggests that the current pace of instructions might be too fast for some participants.
   Challenge and Guidance: Balancing challenge and guidance is crucial. While some participants (3) desired more complexity, others (4) expressed a need for more initial guidance.
   Pepper's Role and Behavior: Participant 1 found Pepper's frequent use of their name distracting. Additionally, incorporating suggestions for increased "agility" from Pepper (2) could involve exploring options for more dynamic and engaging robot behavior.

3. **Session Structure**
   Participant Preferences: While some participants expressed no preference for changes to the session structure, others offered suggestions such as a longer guided-session.

5.6 Design Recommendations

Drawing on the key observations and participant feedback, the following recommendations are proposed for improving future design and user experience. These recommendations aim to make the system more intuitive and the interface more user-friendly while fostering more meaningful human-robot interaction.

1. **Enhanced Control in the Intelligent Interface**: The majority of participants, being intermediate to advanced musicians, highlighted a significant challenge: a mismatch between the expected and actual sounds produced when playing notes. This occurred because the system's neural network prioritizes in-melody sounds, which might benefit beginners. However, to empower advanced users, implementing features for greater control over musical output is crucial. This could involve a dedicated instrument offering a wider range of selectable notes or an expanded note bar on the tablet interface. Importantly, ensuring a clear and consistent mapping between user input and sound output is essential. This predictability is especially important for participants with musical experience who might find the current element of surprise frustrating.

2. **Pacing and repetition of instructions and dialogues.** Participants frequently did not understand or asked Pepper to rephrase what it said because they couldn't hear it or found the dialogue unclear. Therefore, the pace of instructions needs to be adjusted based on user needs. We could consider incorporating slower delivery, longer pauses, and repetition of key information to improve comprehension and engagement.

3. **Tailored Challenge and Guidance** Some participants with less musical experience expressed the need for a longer guided session. Conversely, intermediate to advanced participants wanted different challenges and a more difficult rhythm. Offering tiered difficulty levels or adaptive features that adjust the level of guidance based on the user's skill and experience would cater to both beginners seeking structure and more advanced users desiring greater complexity.

4. **Refined Dialogues** When it comes to Pepper's role, there was a need for more nuanced interaction seen through the observations. The frequent use of names were distracting for some participants. To address this, we could consider utilizing Large Language Models (LLMs) to generate more dynamic and engaging responses for Pepper. The LLM could analyze the situation and generate responses that go beyond simply using the participant's name. This might involve offering creative prompts, suggesting musical styles based on the user's input, or even telling short, relevant anecdotes related to music or the emotions the music evokes.

5. **Refined Interaction** The feedback mentions a desire for increased agility in Pepper's behavior. To address this, we could make Pepper's interactions more dynamic and engaging by incorporating non-verbal cues like gestures or body language to acknowledge user actions. This might involve incorporating more expressive movements during feedback or transitioning between activities more smoothly. By making Pepper's behavior more responsive and adaptable, we could create a more interactive and enjoyable experience for users.

6. **Individualised Feedback**While Pepper's real-time feedback is generally appreciated, participants reported concerns about its perceived inauthenticity and excessive praise. To foster a more genuine emotional connection, we propose a system that adapts feedback to individual preferences and engagement levels. This could include offering an option to disable verbal feedback for users who find it disruptive. Additionally, Pepper's tablet could display textual feedback that provides constructive criticism alongside encouragement, creating a more balanced and personalized experience.

6 Conclusions and Future Work

6.1 Conclusions

In this thesis, we designed and developed a robotic intervention for individuals with cognitive impairment. The intervention incorporates an intelligent music-making interface and an interactive robot that provides real-time feedback, guidance, and rhythmic accompaniment. The system is intended for individuals with early-onset dementia or similar levels of cognitive decline, for use in care homes or at home. Its goals are to slow cognitive decline, promote creative expression, engage older adults in stimulating activities, and improve their mood.

We propose a new end-to-end approach for detecting engagement and providing a platform for creative collaboration through music-making with a robot. The intelligent music interface is designed to focus on creative exploration for individuals with cognitive decline, providing a balance of control and competence. This allows users to freely explore the interface while playing notes that sound melodious together, reinforcing their confidence. The proposed system connects a robot to the intelligent music interface to understand user engagement, interact, and provide feedback based on their engagement. To foster a sense of collaboration, the robot also provides rhythmic accompaniment as users play the tap-to-play melody interface. An additional optional feature was added: participants could listen to the playback of their musical creation if they wished. An exploratory study was conducted to evaluate the effectiveness of each element of this end-to-end system, as well as the system as a whole. The findings provided valuable insights into the effectiveness of the system's components, addressing each of the three research questions of this thesis.The approach shows promise for future research, offering potential for robust interactions and detailed user studies.

The first research question (RQ1) aims to understand the impact of real-time feedback and interaction from the robot on engagement. The results indicate that users with less musical experience desire and prefer real-time guidance from the robot. Real-time feedback from the robot, Pepper, generally enhances engagement in the music-making activity among older adults. Participants who valued the feedback, particularly those with musical backgrounds, found it provided structure, motivation, and a sense of achievement. This underscores the potential of real-time feedback to foster participation and sustain interest in music creation, especially beneficial for those needing additional guidance. Some participants paused playing when the robot provided positive feedback, yet still appreciated the acknowledgment because it conveyed attentive listening. This highlights the importance of appropriately timing feedback.

The second research question (RQ2) aims to understand the influence of rhythmic accompaniment on perceived collaboration, yielding mixed results. While some participants found the rhythm helpful as a prompt for musical exploration, others expressed a lack of connection or felt that the robot couldn't replicate human interaction. These findings suggest that participants desire an emotional connection to foster a sense of collaboration, and rhythmic accompaniment might be more effective as a tool for stimulating musical ideas rather than fostering true collaboration.

The third research question (RQ3) investigates the impact of the intelligent music interface on creativity. Observations indicated that the interface has potential to support creative exploration, especially for beginners in music and users who actively experiment with its features. However, the interface could be improved to address challenges encountered by advanced musical participants. The element of surprise (buttons generating different notes) proved counter-intuitive for experienced musicians seeking precise control. Ensuring a clear and predictable relationship between user input and sound output appears crucial for fostering a sense of agency and creative expression. The playback feature revealed that participants felt a sense of creative ownership over their compositions. Those who chose to listen to their creations were highly engaged, tapping along with the playback. This suggests that having a tangible output can enhance the user's sense of creative ownership. People enjoy experiencing their art through seeing or hearing playback, which in turn encourages creativity and motivates them to play more and improve their skills.

This research offers promising results for the end-to-end music-making system with a robot. Notably, the findings suggest positive outcomes for specific elements like real-time interaction, feedback, and music playback. Additionally, the study sheds light on the importance of balancing user control with achieving musical results within the intelligent music interface. Furthermore, valuable insights are gained regarding the limitations of using robotic rhythm to solely foster collaboration. These findings suggest that rhythm may be more effectively utilized as a complementary tool. Overall, the research provides a foundational framework for the design of such systems, along with valuable information on specific Human-Robot Interaction (HRI) elements that can be further explored and potentially incorporated into future research endeavors.

6.2 Limitations

Reflecting on the implementation and methodology, this study acknowledges several limitations that should be considered when interpreting the findings. Due to time constraints, the sample size of participants in the study was only 7. This meant that no quantitative analysis could be done conclusively and the qualitative analysis was done on a small sample size. This affects the generalisability of the results. With a larger and more diverse group, we could gain a broader understanding of user experience across different demographics. Additionally, the study itself was conducted in a controlled laboratory environment which may not fully reflect real-world usage. In their own homes or familiar settings, participants might interact with the system differently. The short duration of the study posed a limitation in two ways. Firstly, a longer timeframe might have allowed for more in-depth exploration of the system by participants, potentially leading to richer data. Additionally, the time constraint hampered the implementation of a long-term study to assess sustained engagement and potential changes in user behavior over time.

Participants were recruited by distributing posters to communities of older adults, with a significant number being members of a choir. This selection method introduced a bias, as these participants were already familiar with music-related activities and more likely to engage with the system. The system was designed to be user-friendly for individuals with cognitive impairments; however, since it was primarily tested with healthy older adults who enjoy music, the sample was skewed towards this demographic. Thus, while valuable insights were gained into the effectiveness of the system with older adults familiar with music, there is a lack of sufficient insight into a more diverse adult population.

Furthermore, healthy older adults are not the primary target demographic of the system, which is designed for individuals with dementia or cognitive impairment. While there may be overlap between these groups due to age-related cognitive decline, there could be differences in how each group interacts with the system.

Apart from this, the conversations and robot dialogues were scripted, allowing little to no deviation from the predetermined script. All robot responses, both verbal and non-verbal, were pre-written, which restricted the robot's autonomy. This rigid approach made the robot appear inflexible, leading participants to perceive it as lacking genuineness. The lack of flexibility likely contributed to the perceived lack of collaboration. Additionally, while the experiments were conducted in both Dutch and English, the primary researcher primarily spoke English. As the human operator/primary researcher had limited proficiency in Dutch, there was a language barrier with some Dutch-speaking participants. This barrier may have affected their comfort level and the clarity of their responses in questionnaires and video recordings. The analysis of observational data and questionnaire responses involves a degree of subjectivity in interpretation. While we utilized a predefined coding scheme and interrater reliability to minimize bias, some aspects like body language or facial expressions might be open to interpretation. Finally, our intention was to use captions on the tablet attached to Pepper to assist participants who might struggle with understanding the robot's accent or speaking pace. However, the SIC framework was still under development with limited documentation on existing features, which caused issues when attempting to operate the tablet on Pepper. Regrettably, due to compatibility issues between the tablet and the study framework (SIC), this feature could not be implemented. Time constraints also hindered our ability to resolve this technical challenge.

6.3 Future Work

This study serves as a springboard for further exploration of robotic interventions for cognitive support through music making. While the current research offers valuable insights, several aspects can be improved in future iterations. The above identified limitations should be addressed in these future iterations to enhance the generalizability, ecological validity, and robustness of the findings. Building on these findings, future research can explore several avenues.

Firstly, expanding the participant pool is crucial. The limited sample size, skewed towards Dutch-speaking choir members, restricts the generalizability of the findings. Recruiting a larger and more diverse group, encompassing individuals with varying levels of cognitive decline and musical experience, will provide a more comprehensive picture of user experience. Additionally, conducting the study in participants' home environments could yield valuable insights into real-world interactions with the system. A longer study timeframe would also be beneficial. A more extended period would allow users to explore the system in-depth, potentially leading to richer data and facilitating a long-term assessment of user engagement and behavioral changes.

Secondly, the robot's interaction style could be developed further. Moving beyond scripted dialogues and incorporating more natural language processing capabilities would enable the robot to respond more dynamically and authentically to user actions and emotions. Integrating a large language model (LLM) into the system would enhance the dialogue flow with Pepper. This would enable Pepper to manage follow-up questions more effectively. An LLM could analyze the conversation context, understand the participant's intent, and respond with relevant information or guidance. To support a more natural dialogue, we could consider incorporating a memory model. This would allow the system to retain previous interactions with the participant, enabling references to past discussions and a more personalized experience. This could significantly enhance the perceived collaboration between user and robot.

Additionally, improving the user interface's ease of use and catering to a wider range of musical experience levels could be done by offering options for more control over musical output and a clearer cause-and-effect relationship between user input and sound. Exploring options for user-controllable or adaptive rhythmic accompaniment that can adjust to individual preferences and skill levels could enhance the perceived value of the accompaniment as a tool for creative exploration.

Furthermore, addressing the technical limitations identified in this study is crucial for future deployments. Investing further time and resources into refining the compatibility between the tablet interface and the overall framework would allow for the successful implementation of features like captions, potentially improving accessibility for users with auditory processing difficulties.

Finally, several ongoing research studies explore the relationship between music and memory, investigating how music can stimulate memory and evoke emotions associated with specific pieces [47][49]. In the future, we could integrate these findings into the current thesis and its methodology. Training an intelligent music interface with specialized playlists tailored to the individual's preferences can personalize the experience and evoke emotional responses. Future iterations of this robotic intervention have the potential to become a truly engaging and effective tool for promoting creative expression, slowing cognitive decline, and improving the overall well-being of individuals with cognitive impairments.

References

[1] Natsuki Asakura et al. “A Novel Electronic Musical Instrument Used as an Aid in the Prevention of Dementia”. In: *Advanced Biomedical Engineering* 12 (Dec. 2023), pp. 253–260. DOI: 10.14326/abe.12.253.

[2] S. Baisch, T. Kolling, and A. et al. Schall. “Acceptance of Social Robots by Elder People: Does Psychosocial Functioning Matter?” In: *International Journal of Social Robotics* 9 (2017), pp. 293–307. DOI: 10.1007/s12369-016-0392-5.

[3] Adriano Baratè., Helene Korsten., and Luca A. Ludovico. “A Music Tangible User Interface for the Cognitive and Motor Rehabilitation of Elderly People”. In: *Proceedings of the 6th International Conference on Computer-Human Interaction Research and Applications - CHIRA*. INSTICC. SciTePress, 2022, pp. 121–128. ISBN: 978-989-758-609-5. DOI: 10.5220/0011395900003323.

[4] M. S. Barrett, A. Creech, and K. Zhukov. “Creative Collaboration and Collaborative Creativity: A Systematic Literature Review”. In: *Frontiers in Psychology* 12 (2021), p. 713445. DOI: 10.3389/fpsyg.2021.713445.

[5] Christoph Bartneck, Elizabeth Croft, and Dana Kulic. “Measurement instruments for the anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety of robots”. In: *International Journal of Social Robotics* 1.1 (2009), pp. 71–81.

[6] Malak Bleibel et al. “The effect of music therapy on cognitive functions in patients with Alzheimer’s disease: a systematic review of randomized controlled trials”. In: *Alzheimer’s Research Therapy* 15.1 (2023). DOI: 10.1186/s13195-023-01214-9.

[7] Elizabeth Broadbent, Rebecca Stafford, and Bruce Macdonald. “Acceptance of Healthcare Robots for the Older Population: Review and Future Directions”. In: *I. J. Social Robotics* 1 (Nov. 2009), pp. 319–330. DOI: 10.1007/s12369-009-0030-6.

[8] Joost Broekens, Marcel Heerink, Henk Rosendal, et al. “Assistive social robots in elderly care: a review”. In: *Gerontechnology* 8.2 (2009), pp. 94–103.

[9] John Brooke. “SUS: A quick and dirty usability scale”. In: *Usability Eval. Ind.* 189 (Nov. 1995).

[10] Bob Bruer, Edward Spitznagel, and Robert Cloninger. “The Temporal Limits of Cognitive Change from Music Therapy in Elderly Persons with Dementia or Dementia-Like Cognitive Impairment: A Randomized Controlled Trial”. In: *Journal of music therapy* 44 (Dec. 2007), pp. 308–28. DOI: 10.1093/jmt/44.4.308.

[11] Cristian A. Cifuentes et al. “Social Robots in Therapy and Care”. In: *Current Robotics Reports* 1 (2020), pp. 59–74. DOI: 10.1007/s43154-020-00009-2.

[12] Joyce Cohen-Mansfield, Maysaa Dakheel-Ali, and Melissa S Marx. “Engagement in persons with dementia: the concept and its measurement”. In: *The American journal of geriatric psychiatry : official journal of the American Association for Geriatric Psychiatry* 17.4 (2009), pp. 299–307. DOI: 10.1097/JGP.0b013e31818f3a52. URL: https://doi.org/10.1097/JGP.0b013e31818f3a52.

[13] Andrea Creech et al. “Creativity, music, and quality of later life: A systematic review”. In: *Psychology of Music* 51.4 (2023), pp. 1080–1100. DOI: 10.1177/0305735620948114. eprint: https://doi.org/10.1177/0305735620948114. URL: https://doi.org/10.1177/0305735620948114.

[14] Shayn S. Davidson, Joseph Roland Keebler, Tianxin Zhang, et al. “The development and validation of a universal enjoyment measure: The enjoy scale”. In: *Current Psychology* 42 (2022), pp. 17733–17745. DOI: 10.1007/s12144-022-02967-6. URL: https://doi.org/10.1007/s12144-022-02967-6.

[15] Norma Daykin et al. “The role of participatory music making in supporting people with dementia in hospital environments”. In: *Dementia* 17.6 (2018). PMID: 29096539, pp. 686–701. DOI: 10.1177/1471301217739722. eprint: https://doi.org/10.1177/1471301217739722. URL: https://doi.org/10.1177/1471301217739722.

[16] Roos De Kok et al. "Combining Social Robotics and Music as a Non-Medical Treatment for People with Dementia". In: *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. 2018, pp. 465–467. DOI: `10.1109/ROMAN.2018.8525813`.

[17] Connor Dodd, Rukshan Athauda, and Marc Adam. "Designing User Interfaces for the Elderly: A Systematic Literature Review". In: Dec. 2017.

[18] Chris Donahue, Ian Simon, and Sander Dieleman. "Piano Genie". In: *Proceedings of the 24th International Conference on Intelligent User Interfaces*. IUI '19. ACM, Mar. 2019. DOI: `10.1145/3301275.3302288`. URL: `http://dx.doi.org/10.1145/3301275.3302288`.

[19] Jennie L. Dorris et al. "Effects of music participation for mild cognitive impairment and dementia: A systematic review and meta-analysis". In: *Journal of the American Geriatrics Society* 69.9 (2021), pp. 2659–2667. DOI: `https://doi.org/10.1111/jgs.17208`. eprint: `https://agsjournals.onlinelibrary.wiley.com/doi/pdf/10.1111/jgs.17208`. URL: `https://agsjournals.onlinelibrary.wiley.com/doi/abs/10.1111/jgs.17208`.

[20] Becky Dowson et al. "Digital Approaches to Music-Making for People With Dementia in Response to the COVID-19 Pandemic: Current Practice and Recommendations". In: *Frontiers in Psychology* 12 (2021). ISSN: 1664-1078. DOI: `10.3389/fpsyg.2021.625258`. URL: `https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2021.625258`.

[21] United Nations Department of Economic and Population Division Social Affairs. *World Population Prospects 2022: Summary of Results*. 2022. URL: `https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf`.

[22] Jing Fan et al. "SAR-Connect: A Socially Assistive Robotic System to Support Activity and Social Engagement of Older Adults". In: *IEEE Transactions on Robotics* 38.2 (2022), pp. 1250–1269. DOI: `10.1109/TRO.2021.3092162`.

[23] Emma Frid. "Accessible Digital Musical Instruments—A Review of Musical Interfaces in Inclusive Music Practice". In: *Multimodal Technologies and Interaction* 3.3 (2019). ISSN: 2414-4088. DOI: `10.3390/mti3030057`. URL: `https://www.mdpi.com/2414-4088/3/3/57`.

[24] C. Victor Fung and Lisa J. Lehmberg. *Music for Life: Music Participation and Quality of Life for Senior Citizens*. Oxford University Press, June 2016. ISBN: 9780199371686. DOI: `10.1093/acprof:oso/9780199371686.001.0001`. URL: `https://doi.org/10.1093/acprof:oso/9780199371686.001.0001`.

[25] Susel Góngora Alonso et al. "Social Robots for People with Aging and Dementia: A Systematic Review of Literature". In: *Telemedicine and e-Health* 25 (May 2018). DOI: `10.1089/tmj.2018.0051`.

[26] Mitzi M. Gonzales et al. "Biological aging processes underlying cognitive decline and neurodegenerative disease". In: *The Journal of Clinical Investigation* 132.10 (May 2022). DOI: `10.1172/JCI158453`. URL: `https://doi.org/10.1172/JCI158453`.

[27] Dianne Gregory. "Music Listening for Maintaining Attention of Older Adults with Cognitive Impairments". In: *Journal of Music Therapy* 39.4 (Dec. 2002), pp. 244–264. ISSN: 0022-2917. DOI: `10.1093/jmt/39.4.244`. eprint: `https://academic.oup.com/jmt/article-pdf/39/4/244/5145537/39-4-244.pdf`. URL: `https://doi.org/10.1093/jmt/39.4.244`.

[28] Beat Ted Hannemann. "Creativity with Dementia Patients: Can Creativity and Art Stimulate Dementia Patients Positively?" In: *Gerontology* 52.1 (Jan. 2006), pp. 59–65. ISSN: 0304-324X. DOI: `10.1159/000089827`. eprint: `https://karger.com/ger/article-pdf/52/1/59/2834453/000089827.pdf`. URL: `https://doi.org/10.1159/000089827`.

[29] Curtis Hawthorne et al. "Enabling Factorized Piano Music Modeling and Generation with the MAESTRO Dataset". In: *International Conference on Learning Representations*. 2019. URL: `https://openreview.net/forum?id=r1lYRjC9F7`.

[30] Riitta Hellman. "Ambient Assisted Living". In: Springer, 2012. Chap. Usable User Interfaces for Persons with Memory Impairments.

[31] Guy Hoffman and Cynthia Breazeal. "Effects of anticipatory perceptual simulation on practiced human-robot tasks". In: *Autonomous Robots* 28.4 (May 2010), pp. 403–423. ISSN: 1573-7527. DOI: `10.1007/s10514-009-9166-3`. URL: `https://doi.org/10.1007/s10514-009-9166-3`.

[32] Erika Ito et al. "The Effect of Music-Based Intervention on General Cognitive and Executive Functions, and Episodic Memory in People with Mild Cognitive Impairment and Dementia: A Systematic Review and Meta-Analysis of Recent Randomized Controlled Trials". In: *Healthcare* 10.8 (2022). ISSN: 2227-9032. DOI: 10.3390/healthcare10081462. URL: https://www.mdpi.com/2227-9032/10/8/1462.

[33] Andrew J. Milne John R. Taylor and Jennifer Macritchie. "New musical interfaces for older adults in residential care: assessing a user-centred design approach". In: *Disability and Rehabilitation: Assistive Technology* 18.5 (2023). PMID: 33784921, pp. 519–531. DOI: 10.1080/17483107.2021.1881172. eprint: https://doi.org/10.1080/17483107.2021.1881172. URL: https://doi.org/10.1080/17483107.2021.1881172.

[34] Maximos Kaliakatsos-Papakostas, Andreas Floros, and Michael N. Vrahatis. "Chapter 13 - Artificial intelligence methods for music generation: a review and future perspectives". In: *Nature-Inspired Computation and Swarm Intelligence*. Ed. by Xin-She Yang. Academic Press, 2020, pp. 217–245. ISBN: 978-0-12-819714-1. DOI: https://doi.org/10.1016/B978-0-12-819714-1.00024-5. URL: https://www.sciencedirect.com/science/article/pii/B9780128197141000245.

[35] Eisuke Kondo et al. "Case Report: Accessible Digital Musical Instrument Can Be Used for Active Music Therapy in a Person With Severe Dementia and Worsening Behavioral and Psychological Symptoms: A Case Study Over a Year and a Half". In: *Frontiers in Neurology* 13 (2022). ISSN: 1664-2295. DOI: 10.3389/fneur.2022.831523. URL: https://www.frontiersin.org/journals/neurology/articles/10.3389/fneur.2022.831523.

[36] Aysan Mahmoudi Asl et al. "Methodologies Used to Study the Feasibility, Usability, Efficacy, and Effectiveness of Social Robots For Elderly Adults: Scoping Review". In: *J Med Internet Res* 24.8 (Aug. 2022), e37434. ISSN: 1438-8871. DOI: 10.2196/37434. URL: http://www.ncbi.nlm.nih.gov/pubmed/35916695.

[37] Yotam Mann. *AI Duet*. 2017. URL: https://experiments.withgoogle.com/ai-duet.

[38] *Mayo Foundation for Medical Education and Research - Dementia*. https://www.mayoclinic.org/diseases-conditions/dementia/symptoms-causes/syc-20352013. 2023.

[39] M. L. McHugh. "Interrater Reliability: The Kappa Statistic". In: *Biochemia Medica* 22.3 (2012), pp. 276–282. ISSN: 0350-5147.

[40] *Meet Pepper: The Robot Built for People*. https://us.softbankrobotics.com/pepper. 2024.

[41] OpenUp Music and Use All Five. *Clarion Lite*. 2018. URL: https://experiments.withgoogle.com/clarion-lite.

[42] Samuel Olatunji et al. "Immersive participatory design of assistive robots to support older adults". In: *Ergonomics* (Feb. 2024), pp. 1–15. DOI: 10.1080/00140139.2024.2312529.

[43] Amit Kumar Pandey and Rodolphe Gelin. "A Mass-Produced Sociable Humanoid Robot: Pepper: The First Machine of Its Kind". In: *IEEE Robotics Automation Magazine* PP (July 2018), pp. 1–1. DOI: 10.1109/MRA.2018.2833157.

[44] Tero Parviainen. *Connecting with Music Through Magenta.js*. 2018. URL: https://magenta.tensorflow.org/blog/2018/05/03/connecting-with-magenta-js.

[45] Giancarlo Perugia et al. "ENGAGE-DEM: A Model of Engagement of People With Dementia". In: *IEEE Transactions on Affective Computing* 13.2 (2022), pp. 926–943. DOI: 10.1109/TAFFC.2020.2980275.

[46] Jon Pigrem et al. "Agency and Creativity in Musical Interaction for those living with Dementia and Cognitive Decline". In: (2024).

[47] Herve Platel et al. "Semantic and episodic memory of music are subserved by distinct neural networks". In: *NeuroImage* 20 (Oct. 2003), pp. 244–56. DOI: 10.1016/S1053-8119(03)00287-8.

[48] Martin Kuška Radek Trnka Inna Cabelkova and Tomas Nikolai. "Cognitive Decline Influences Emotional Creativity in the Elderly". In: *Creativity Research Journal* 31.1 (2019), pp. 93–101. DOI: 10.1080/10400419.2019.1577205. URL: https://doi.org/10.1080/10400419.2019.1577205.

[49] Alfredo Raglio and Osmano Oasi. "Music and health: what interventions for what results?" In: *Frontiers in Psychology* 6 (2015). ISSN: 1664-1078. DOI: 10.3389/fpsyg.2015.00230. URL: https://www.frontiersin.org/journals/psychology/articles/10.3389/fpsyg.2015.00230.

[50] Harleen Rai, Lauren Yates, and Martin Orrell. “Cognitive Stimulation Therapy for Dementia”. In: *Clinics in Geriatric Medicine* 34.4 (2018). Alzheimer Disease and Other Dementias, pp. 653–665. ISSN: 0749-0690. DOI: https://doi.org/10.1016/j.cger.2018.06.010. URL: https://www.sciencedirect.com/science/article/pii/S0749069018310036.

[51] James L. Jr. Reifinger. “Age-related changes affecting the learning of music performance skills for older adults”. In: *Psychomusicology: Music, Mind, and Brain* 26.3 (2016), pp. 211–219. DOI: 10.1037/pmu0000144.

[52] Rajiv Khosla Reza Kachouie Sima Sedighadeli and Mei-Tai Chu. “Socially Assistive Robots in Elderly Care: A Mixed-Method Systematic Literature Review”. In: *International Journal of Human–Computer Interaction* 30.5 (2014), pp. 369–393. DOI: 10.1080/10447318.2013.873278.

[53] Falko Rheinberg et al. “FSS - Flow Short Scale (English Version)”. In: (Sept. 2023).

[54] Philippa Riley, Norman Alm, and Alan Newell. “An interactive tool to promote musical creativity in people with dementia”. In: *Computers in Human Behavior* 25.3 (2009). Including the Special Issue: Enabling elderly users to create and share self authored multimedia content, pp. 599–608. ISSN: 0747-5632. DOI: https://doi.org/10.1016/j.chb.2008.08.014. URL: https://www.sciencedirect.com/science/article/pii/S0747563208001672.

[55] Frank A. Russo et al. “Developing a music-based digital therapeutic to help manage the neuropsychiatric symptoms of dementia”. In: *Frontiers in Digital Health* 5 (2023). ISSN: 2673-253X. DOI: 10.3389/fdgth.2023.1064115. URL: https://www.frontiersin.org/journals/digital-health/articles/10.3389/fdgth.2023.1064115.

[56] Ruben Schlagowski et al. “Flow with the Beat! Human-Centered Design of Virtual Environments for Musical Creativity Support in VR”. In: *Proceedings of the 14th Conference on Creativity and Cognition*. CC ’22. Venice, Italy: Association for Computing Machinery, 2022, pp. 428–442. ISBN: 9781450393270. DOI: 10.1145/3527927.3532799. URL: https://doi.org/10.1145/3527927.3532799.

[57] M. Schuster and K.K. Paliwal. “Bidirectional recurrent neural networks”. In: *IEEE Transactions on Signal Processing* 45.11 (1997), pp. 2673–2681. DOI: 10.1109/78.650093.

[58] Changhee Seo, Jin Suk Lee, and Jieun Kwon. “Development of Application Usability Evaluation Scale for Seniors”. In: *Intelligent Human Computer Interaction*. Ed. by Jong-Hoon Kim et al. Cham: Springer International Publishing, 2022, pp. 150–162. ISBN: 978-3-030-98404-5.

[59] João S. Sequeira. “Robots in Healthcare”. In: Springer Cham, 2020. Chap. Developing a Social Robot – A Case Study. DOI: https://doi.org/10.1007/978-3-030-24230-5.

[60] P. Frazer Seymour et al. “AMI: An Adaptable Music Interface to Support the Varying Needs of People with Dementia”. In: *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility*. ASSETS ’17. Baltimore, Maryland, USA: Association for Computing Machinery, 2017, pp. 150–154. ISBN: 9781450349260. DOI: 10.1145/3132525.3132557. URL: https://doi.org/10.1145/3132525.3132557.

[61] *Smithsonian Launches Pilot Program with Pepper Robots*. 2018. URL: https://www.si.edu/newsdesk/releases/smithsonian-launches-pilot-program-pepper-robots.

[62] Heqiu Song et al. “Learning Musical Instrument with the Help of Social Robots: Attitudes and Expectations of Teachers and Parents”. In: *2022 31st IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*. 2022, pp. 351–357. DOI: 10.1109/RO-MAN53752.2022.9900727.

[63] Heqiu Song et al. “The impact of social robots’ presence and roles on children’s performance in musical instrument practice”. In: *British Journal of Educational Technology* 55.3 (2024), pp. 1041–1059. DOI: https://doi.org/10.1111/bjet.13416. eprint: https://bera-journals.onlinelibrary.wiley.com/doi/pdf/10.1111/bjet.13416. URL: https://bera-journals.onlinelibrary.wiley.com/doi/abs/10.1111/bjet.13416.

[64] R. A. Søraa, G. Tøndel, and M. et al. Kharas. “What do Older Adults Want from Social Robots? A Qualitative Research Approach to Human-Robot Interaction (HRI) Studies”. In: *International Journal of Social Robotics* 15.3 (2023), pp. 411–424. DOI: 10.1007/s12369-022-00914-w. URL: https://doi.org/10.1007/s12369-022-00914-w.

[65] *Understanding Cognitive Impairment and Dementia*. https://www.nia.nih.gov/health/alzheimers-and-dementia. 2020.

[66] Lotte Veling and Cathal McGinn. “Qualitative Research in HRI: A Review and Taxonomy”. In: *International Journal of Social Robotics* 13.6 (2021), pp. 1689–1709. DOI: `10.1007/s12369-020-00723-z`. URL: `https://doi.org/10.1007/s12369-020-00723-z`.

[67] Tessa Watson. *Music Therapy with Adults with Learning Disabilities*. Routledge, Taylor & Francis Group, 2007.

[68] Astrid Weiss et al. “Addressing User Experience and Societal Impact in a User Study with a Humanoid Robot”. In: 2009. URL: `https://api.semanticscholar.org/CorpusID:8796641`.

[69] *What is Dementia?* `https://www.alz.org/alzheimer_s_dementia`. 2023.

[70] Wikipedia contributors. *Dementia — Wikipedia, The Free Encyclopedia*. `https://en.wikipedia.org/w/index.php?title=Dementia&oldid=1228327401`. [Online; accessed 11-November-2023]. 2023.

[71] Wikipedia contributors. *Music therapy — Wikipedia, The Free Encyclopedia*. `https://en.wikipedia.org/w/index.php?title=Music_therapy&oldid=1216647586`. 2023.

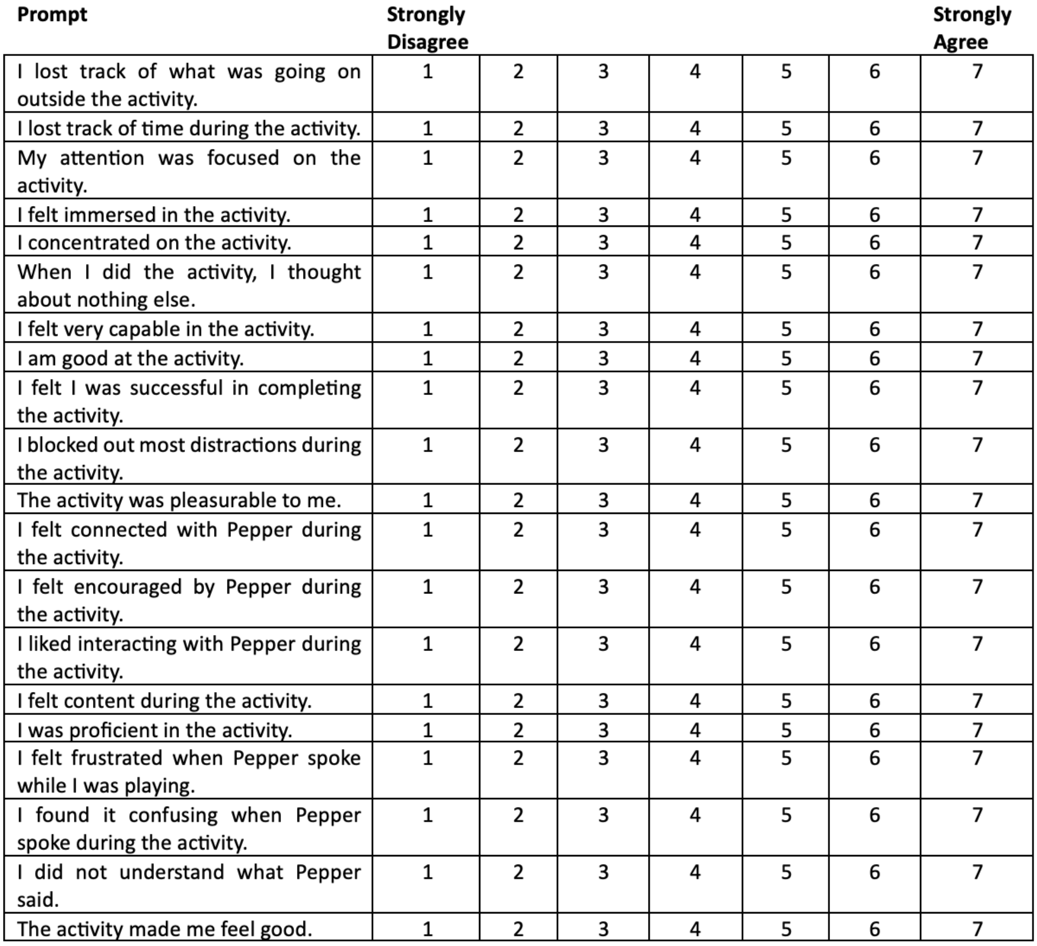
[72] Minmin Zhou, Kamal Sabran, and Zuriawati Ahmad Zahari. “Designing User Interface for People with Dementia: A Systematic Literature Review”. In: Jan. 2022. DOI: `10.4108/eai.24-8-2021.2315094`.

Appendix

1 ENJOY Scale based Questionnaire

Delft University of Technology
Questionnaire 1 – Understanding Engagement through Interaction

The following questionnaire is a validated questionnaire to assess social perception of robot feedback on engagement in a joint activity. We aim to understand how feedback influences a person's motivation and participation in the collaborative activity. There are 21 prompts for which the activity with the robot can be rated on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree). You must rate the statements based on your experience in the activity. Using the scale provided, how much do you agree/disagree with the following statements?



Prompt	Strongly Disagree						Strongly Agree
I lost track of what was going on outside the activity.	1	2	3	4	5	6	7
I lost track of time during the activity.	1	2	3	4	5	6	7
My attention was focused on the activity.	1	2	3	4	5	6	7
I felt immersed in the activity.	1	2	3	4	5	6	7
I concentrated on the activity.	1	2	3	4	5	6	7
When I did the activity, I thought about nothing else.	1	2	3	4	5	6	7
I felt very capable in the activity.	1	2	3	4	5	6	7
I am good at the activity.	1	2	3	4	5	6	7
I felt I was successful in completing the activity.	1	2	3	4	5	6	7
I blocked out most distractions during the activity.	1	2	3	4	5	6	7
The activity was pleasurable to me.	1	2	3	4	5	6	7
I felt connected with Pepper during the activity.	1	2	3	4	5	6	7
I felt encouraged by Pepper during the activity.	1	2	3	4	5	6	7
I liked interacting with Pepper during the activity.	1	2	3	4	5	6	7
I felt content during the activity.	1	2	3	4	5	6	7
I was proficient in the activity.	1	2	3	4	5	6	7
I felt frustrated when Pepper spoke while I was playing.	1	2	3	4	5	6	7
I found it confusing when Pepper spoke during the activity.	1	2	3	4	5	6	7
I did not understand what Pepper said.	1	2	3	4	5	6	7
The activity made me feel good.	1	2	3	4	5	6	7

Figure 1: PROMPTS in the ENJOY Questionnaire

2 Subjective Questionnaire

Delft University of Technology
Subjective Questionnaire to evaluate perceived Creativity and Collaboration.

The following questionnaire has been developed to gain initial feedback on the feeling of creative collaboration. It includes questions about the social, emotional, and cognitive experience with the activity and some general feedback. We are interested in understanding your perspective so feel free to provide specific examples or details to support your answer.

1. How would you rate your level of proficiency with music and music-making on a scale of 1 to 10? Please share your personal experience with playing instruments, singing, and understanding rhythm.
   Example response: "I would rate my musical experience at 8. I can sing, understand pitch and rhythm, and play one instrument—the piano."
2. Did Pepper's encouragement make the activity more enjoyable for you? Why/Why not?
3. How did Pepper's feedback (positive/negative) impact your desire to continue creating music?
4. Explain how Pepper's rhythmic accompaniment influenced your musical choices during the activity.
5. How similar or different was interacting with Pepper compared to creating music with another person?
6. Through the music-making activity with Pepper, did you discover ways to explore your own musical ideas? If so, how?
7. Did the tablet make it easy for you to try out different musical ideas and sounds? How?
8. Did you choose to listen to the music you created? If yes, did it make you want to continue creating more music?
9. Imagine using Pepper to make music on a regular basis. What kind of structure or format would you prefer for these sessions? Would you like more guidance from Pepper, more freedom to explore, or a combination?
10. Is there anything you would change or improve about the music-making activity with Pepper? (optional)

3 Coding Scheme for Video Observations

Focus: This scheme emphasizes observable and behavioral aspects of engagement during music making and is based on the ENGAGEDEM model. In the context of the coding scheme, YES and NONYES stand for:
YES: This refers to behaviors that indicate positive engagement and enjoyment during the music making activity. It reflects a higher level of energy and enthusiasm.
NO: This refers to behaviors that indicate lower engagement or disinterest in the music making activity. It can include neutrality or negative expressions like boredom or frustration.

3.1 Participant Information

- Participant ID

3.2 Introduction and Setup(YES/NO)

- Introduction Length (in minutes)
- Interest in music expressed (YES/NO): Positive (YES) if participant shows enthusiasm for music or Negative (NO) if they show disinterest.

3.3 Music Making session

1. Participation Level (YES)
    - **Initiates exploration (YES):** Participant independently explores the music interface.
    - **Responds to prompts (YES):** Participant actively participates in response to robot's prompts or suggestions.
    - **Passively observes (NO):** Participant watches the robot's music making but doesn't actively participate.
    - **Disengaged (NO):** Participant shows disinterest and withdraws from the activity.
2. Choice of Guidance (YES/NO)
    - **Chooses Guided Play (YES):** Participant actively seeks or accepts the robot's guidance during music making.
    - **Chooses Self-Play (YES/NO):** Participant prefers to explore the music interface independently. This can be coded as YES if the participant actively explores, or NONYES if they show minimal exploration.
3. Exploration of Music Interface (YES)
    - **High Exploration (YES):** Participant tries a variety of buttons and combinations, showing active engagement with the interface
    - **Moderate Exploration (YES/NO):** Participant explores the interface to some extent but not extensively.
    - **Low Exploration (NO):** Participant shows minimal exploration of the interface, suggesting limited engagement.
4. **Challenge Selection (YES/NO):** Accepted Challenge (YES) or Declined Challenge (NO).
5. **Limited Color Palette Use (YES/NO):** Embraced limited colour palette (YES) or Did not stick to the challenge(NO) based on engagement during the limited palette segment.
6. **Social Interaction (YES)**

   - **Focuses on robot (YES):** Participant directs most attention towards the robot during music making.
   - **Shared interaction (YES):** Participant interacts with both the robot and interface during music making, without letting the robot distract them from playing.
   - **Minimal social interaction (NO):** Participant shows minimal interaction with the robot during music making.

7. **Non-verbal Cues (YES/NO)**
   - **Positive expressions (YES):** Participant smiles, laughs, or shows other signs of enjoyment during music making.
   - **Neutral expressions (YES/NO):** Participant has a neutral expression throughout the activity.
   - **Negative expressions (NO):** Participant frowns, looks away, or shows signs of boredom or frustration during music making.
8. **Body Language (YES/NO)**
   - **Active body movements (YES):** Participant claps, sways, taps feet, or shows other signs of physical engagement with the music.
   - **Minimal body movements (YES/NO):** Participant shows minimal physical movement during music making.
   - **Restlessness (NO):** Participant fidgets, looks around, or shows signs of disengagement from the activity.
9. **Frequency of Feedback and Encouragement (YES/NO):** Retained for analysis but categorized as Positive Feedback(YES) or Encouraging Feedback (through asking them to try something (NO) based on participant's reaction.
10. **Participant Initiated Pauses (Number):** (Retained)

3.4 Post session

1. **Playback Participation**
   - **Engaged with playback (YES):** Participant actively watches or listens to the playback.
   - **Passively observes playback (NO):** Participant shows minimal interest in the playback
2. **Response to Pepper's questions (YES)**
   - **Enthusiastic response (YES):** Participant actively responds to the robot's questions.
   - **Subdued response (NO):** Participant shows limited interest in responding to the robot's questions.
3. **Technical Issues (Yes/No):** (Retained)
4. **Participant Conversation with researcher (Yes/No)**:
   - **Had a conversation that was more critical than enthusiastic (NO)**
   - **Had a conversation that was enthusiastic/curious - understood potential of the system (YES)**

4 Coding Scheme for Perceived Creativity and Collaboration Questionnaire

4.1 Demographics

Age: Numerical responses (e.g., 18-25, 26-35, etc.)

4.2 Musical Background

- Code 1: Musical Experience Level (1-10): Categorize responses based on the self-reported rating (e.g., Beginner: 1-3, Intermediate: 4-7, Advanced: 8-10)
- Code 2: Musical Skills: Identify specific skills mentioned (e.g., Singing, Playing Instrument, Music Theory)

4.3 Perceived Creativity and Collaboration with Pepper

Social Experience

- Code 3.1: Impact of Pepper's Encouragement (Positive/Negative)
- Code 3.2: Impact of Pepper's Feedback (Positive/Negative) on Desire to Create Music

Cognitive Experience

- Code 4: Influence of Pepper's Rhythm on Musical Choices
- Code 6: Exploration of Musical Ideas through Pepper Interaction

Collaboration vs. Solo Experience

- Code 5: Comparison of Interaction with Pepper vs. Human in Music Making

Technology and Exploration

- Code 7: Ease of Using Tablet for Exploring Ideas
- Code 8: Re-listening to Created Music and Motivation

4.4 Preferences for Future Sessions

- Code 9.1: Preferred Session Structure: (Guidance, Exploration, Combination)
- Code 9.2: Additional Preferences: Capture specific suggestions for improvement

5 Interrater Reliabilty Evaluations

The following tables contain the ratings provided by 2 external researchers and the percent agreement computation for interrater reliability [39]. To obtain the measure of percent agreement, we created a matrix in which the columns represented the different raters, and the rows represented variables for which the raters had collected data (Table 1 an Table 2). The cells in the matrix contained the scores the data collectors entered for each variable. Table 1 contains the scores for participant 4 and table 2 contains the scores for participant 5. To obtain percent agreement, we calculate it for each row and take the average.

Code	**Primary Researcher**	**External Researcher 1**	**External Researcher 2**	**Percent Agreement**
3.2.2	0	0	0	1
3.3.1	0	1	1	0.66
3.3.2	1	1	1	1
3.3.3	0	0	0	1
3.3.4	1	1	1	1
3.3.5	0	1	1	0.66
3.3.6	0	0	0	1
3.3.7	0	0	0	1
3.3.8	0	0	0	1
3.3.9	0	1	0	0.66
3.3.10	3	3	6	0.66
3.4.1	0	0	0	1
3.4.2	0	0	0	1
3.4.3	0	0	0	1
3.4.4	0	0	0	1

Table 1: External rater observations based on the coding scheme in Appendix 3 for Participant 4

From the above table, the average percent agreement for participant 4 is 0.909.

Code	**Primary Researcher**	**External Researcher 1**	**External Researcher 2**	**Percent Agreement**
3.2.2	1	1	1	1
3.3.1	1	1	1	1
3.3.2	1	1	1	1
3.3.3	1	1	1	1
3.3.4	1	1	1	1
3.3.5	1	1	1	1
3.3.6	0	1	1	0.66
3.3.7	1	1	1	1
3.3.8	0	0.5	1	0.33
3.3.9	1	1	1	1
3.3.10	2	2	3	0.66
3.4.1	1	1	1	1
3.4.2	0	1	1	0.66
3.4.3	0	0	0	1
3.4.4	1	1	1	1

Table 2: External rater observations based on the coding scheme in Appendix 3 for Participant 5

From the above table, the average percent agreement for Participant 4 is 0.887. By averaging the percent agreements of Participants 4 and 5, we obtain a percent agreement of 0.898.