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MMM Duet System: New accessible musical technology for people living with dementia

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ABSTRACT

Music offers a meaningful way for people living with dementia to interact with others and can provide health and wellbeing benefits. Enjoying shared activities helps couples affected by dementia retain a sense of couplehood and can support a spousal caregiver's mental health. This paper describes the development of the Music Memory Makers (MMM) Duet System, a prototype that has been developed as part of a qualitative, multi-phase, iterative research study to test its feasibility for use with people living with dementia and their spousal caregivers. Through the iterative process, the diverse individual needs of the participants directly led to the adding, adjusting, or removal of features and components to better fit their needs and to make the system require as little technical experience from the users as possible for quick and easy engagement. In line with our work of developing system hardware and software to meet users' needs, including 3D printed cases, coordination facilitation processes, a visual interface, and source separation tools to create familiar duets, participants found the duet system offered them an opportunity to enjoyably interact with one another by playing meaningful songs together.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility systems and tools**; *User centered design*; • **Social and professional topics** → People with disabilities; Seniors.

KEYWORDS

dementia, music technology, design, joint agency

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1 INTRODUCTION

Musical activities can provide numerous benefits for people living with dementia, ranging from enjoying music as a leisure activity to music supporting cognition, communication, social connection, and wellbeing. A particularly notable benefit of musical activities is their potential to stimulate memories of key prior life events, thereby reconnecting people to aspects of who they are and were. Music can also stimulate social interactions between people as they bond over their shared musical experiences. Despite research demonstrating the benefits of musical engagement for people living with dementia, little work is currently being done to develop accessible musical tools and technologies for people living with dementia. Furthermore, while there is a rising interest in supporting the relational worlds of people living with dementia, this is not yet being fully reflected in technological developments.

Dementia is an umbrella term for a range of progressive conditions that affect the brain. Alzheimer's disease is the most prevalent, accounting for between 60% to 80% of cases; other prominent types include vascular dementia and Lewy body disease. As many individuals have a combination of different types of dementia in addition to other comorbid conditions due to aging, individualised treatment plans are very common [1].

Dementia progression is frequently associated with an escalating impairment to an individual's ability to engage in their activities of daily life, which frequently leads to an increased burden being placed on their informal familial carer [20]. People living with dementia can often feel a loss of agency from this simultaneous loss of abilities and increased dependency on their carer, which can also erode their sense of self and cause relationship degradation [11]. Solutions are needed to manage these challenges. Enjoying shared activities where all members feel like they are contributing can help families to retain a sense of familial bond and can support the informal caregiver's mental health [28]. Music can be useful for this, as even in severe dementia the ability to engage in musical activities has been shown to be preserved [3]. Engaging with music has been linked to improved quality of life, with evidence suggesting that this is at least partly due to music providing people living with dementia an opportunity to meaningfully interact with others [2, 12, 21].

One of the ways that music has been suggested to improve the quality of life of people living with dementia is by reconnecting them to aspects of themselves by providing access to memories from their past[2]. Music has shown a strong ability to stimulate autobiographical memories in people with Alzheimer's [13, 19]. Music-evoked autobiographical memories (MEAMs) have also been found to elicit more positive memories than other methods, with social elements such as family, friends, and significant others often being included in these memories [7, 18]. Familiar music has also been shown to temporarily improve social and communicative abilities in people with Alzheimer's [8, 14]. This suggests that appropriate musical selections could serve an important function in providing affordances for reminiscence in musical activities for people living with dementia.

Another way that music is suggested to enhance the quality of life of people living with dementia is by providing opportunities for communication and connection with others. Research findings suggest that making music with others can promote social bonding and well-being [6, 30]. Musical groups and choirs often have a goal of performance precision, which can work well when everyone involved has a similar musical ability. Unfortunately, people living with dementia can often lose their ability to read and follow music notation and can easily lose their place in the music, which leads to their exclusion from many types of group music-making activities. This underscores the need for technology to be adaptable to complement the existing abilities of people living with dementia, allowing them to feel that their actions can make a meaningful contribution to the overall musical output.

Furthermore, past studies have shown that assisted living technologies designed for older adults have limited uptake and high abandonment rates [15, 24]. To address this issue, devices need to focus more on users' abilities, needs, and preferences [5]. Having participants more involved in directing the research through the use of a participatory approach is seen as a promising strategy to ensure this occurs.

In this paper we introduce the Music Memory Makers Duet System (hereafter the MMM Duet System). The MMM Duet System is designed to allow people with no musical training to play duets created from commercial music recordings together. The MMM Duet System uses electronic versions [26] of the mechanical music boxes that were popular in the nineteenth century; these devices allow people to produce music simply by rotating the device handle. As musical behaviours continue even in severe dementia and group music making promotes social bonding, the MMM Duet System could provide a meaningful way for people living with dementia to continue interacting with others over the disease course. We developed the MMM Duet system following a multi-phase iterative design approach with an emphasis on participatory design methods, in which we encouraged participants to direct the development in a way that facilitated intuitive engagement for people living with dementia and who have no prior musical expertise. We also incorporated ideas from music reminiscence therapy [17], ensuring that couples could perform meaningful songs from their shared history. At its core, the MMM Duet System is comprised of a pair of devices that transform cyclical movements into musical output, with the rotation speed controlling the tempo of the music. Over the course of our iterative design process, we used 3D printing to create physical devices that meet the needs of people living with dementia, applied source separation tools to create duets from commercial music recordings, designed a visual interface to better support multimodal interaction, and implemented a smoothing function to support links between participants' movements and their musical outcomes. As we describe more in detail in another paper [25], we found that in using the devices many participants experienced a "we" mentality and enjoyed synchronizing their parts with each other. This system could be valuable for supporting couples living with dementia and for adding their voices to further our understanding of how people living with dementia can best collaborate with others through music.

2 RELATED WORK

In a scoping review on creative arts technologies for people living with dementia by MacRitchie et al. [23], they found that most studies reported on the feasibility of the device or intervention, suggesting that much of the current work is at the prototyping stage. Most devices were oriented for individual use, and few interfaces could be adjusted to match the needs of a user. A majority of papers only reported doing user-testing, but many others included some degree of co-design that incorporated the contributions of people living with dementia. More than half of the devices allowed people some degree of choice, but fewer allowed the incorporation of personally relevant stimuli.

Lazar et al.'s scoping review [22] focused on the use of information and communication technologies for reminiscence such as touch screen interfaces or adaptations of game devices. Many of these technologies were set up to prompt past memories through the use of multimedia such as older photos or music, with the goal of facilitating people living with dementia's involvement in social interactions and gaining self esteem. According to the review findings, people living with dementia enjoyed either listening to or viewing reminiscence materials, with reminiscence also providing them with increased opportunities for interacting with others and a greater ability to take ownership of the conversation. However, they also noted the possibility of discomfort arising from the stimulation of negative memories. Many of the included technologies were designed to capitalise on the continuing abilities of people living with dementia, such as continued musical abilities. Many devices were also designed with inclusivity in mind, accommodating for sensory and motor impairments.

The design process of the MMM Duet System began with the electronic music box introduced by Novembre et al. [26], which was created as an empirical tool to examine musical interpersonal coordination in a lab setting. In their setup, each person turns the handle of their respective music box and tones are elicited at various points along the rotation (e.g., after each quarter rotation), and partners attempt to synchronise tone onsets with their partner. Each person's movements also generate a continuous data stream that can be recorded and evaluated.

3 THE MMM DUET SYSTEM

In the MMM Duet System each music box acts as a serial controller, and whenever the music box handle is in motion it sends out its current rotational speed. This serial data is then fed into control

software implemented in Max [9] and is utilised to control the speed of the selected audio tracks. Simply put, the faster the handle is spun, the faster the music plays. To make the music boxes suitable for use as a group activity, source separation was applied to musical recordings requested by participants, so that the solo voice and some of the instruments could be assigned to one person while the rest of the parts were assigned to the other person. As a result, when each player plays alone, they only hear certain parts of the music, but when they play together, they hear the entire musical track brought back together. Because participants reported that it is more enjoyable to stay relatively in time with one another, smoothing functions and a visual interface were added to the system to help people do so, including multiple difficulty levels to accommodate people's varying abilities. During the development process, the music boxes were created in a variety of sizes and shapes to evaluate what worked best in terms of the ergonomic needs and wishes of the users. In the sections that follow, we describe each of these elements of the MMM Duet System in turn.

3.1 3D printed devices

Figure 1 depicts the present version of the music box, which has a wide base and a 50mm crank arm. People have held the music boxes in a variety of ways, including placing it on a tabletop surface or on their lap, as well as holding it in one arm while spinning it with the other. The present model was designed to attempt to address all of these use cases. The crank arm is currently long enough to require little power to rotate and to better allow people living with dementia to know where they should hold it without explanation. It is also short enough to reduce the likelihood of tipping over the music box when spinning it. The relatively wide base of the music box was selected to further reduce this possibility. The music box is made up of a number of 3D printed parts: base bottom, base top, handle base, handle, and knob.

Although the present version accommodates multiple use cases, further exploration of alternative designs is also possible. For instance, the height of the main cylinder could be extended to create a shaft that could be grasped. Additionally, the handle knob could be modified into different shapes to evaluate its performance and accommodate different abilities. The base could be adjusted to be larger, transforming it into a tabletop platter design. Alternative designs could also be developed to accommodate participants with other types of movement disorders.

Figure 2 presents a view of the inside of a music box, which includes A: capacitive rotary encoder, B: Adafruit Huzzah32 Feather Board with ESP32 chip and Bluetooth module C: 1000 mAh Lipo battery, D: "Awake" button to disengage from sleep mode, E: "Awake/Sleep" indicator light.

3.2 Source separation

Rather than having each participant play the complete original recording and attempt to synchronise these with each other, we chose to split up the vocal and instrumental parts between two separate tracks. We chose this implementation because a number of people complained about feeling off or wrong when attempting to synchronise while each of them played the entire original track. This could have occurred because they can more easily judge the asynchrony between, say, the drum beat in their part and that of their partner when they are both playing the drum part, whereas the up to 80 milliseconds asynchrony that is often already present between different parts (e.g. drums vs guitar) in many types of pop music recordings could make this type of asynchrony more difficult to recognise [10].

Figure 1: Music box with wide square base and medium length crank arm

In order to split our recordings into duets, we used the open source Open-Unmix source separation tool [29]. Employing a three-layer bidirectional deep recurrent neural network, it predicts target sources from a mixed input to separate pop music into four stems: vocals, drums, bass, and remaining components. As its models were pre-trained using the freely available MUSDB18 dataset [27], they perform better on more recent pop music, with slightly less success on popular music from the 1940s or 50s, which is likely due to changes in recording practices since that time period [31]. When we mixed these four stems back together to create two duet parts, we found that most of the songs we source-separated from the 1940s or 50s also performed well enough. However, mixing the stems back together can take some trial and error to avoid artifacts present in some of the stems made from this period. Future work is needed to be able to include classical music as well as folk or popular music from non-western contexts, as these are often not handled adequately at present with the models that we used.

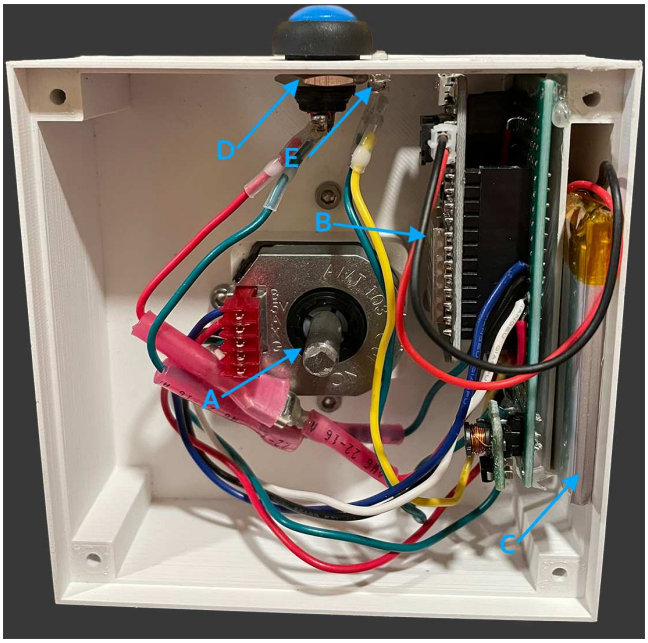

Figure 2: Image of the inside of a music box. It includes A: capacitive rotary encoder, B: Adafruit Huzzah32 Feather Board with ESP32 chip and Bluetooth module C: 1000 mAh Lipo battery, D: "Awake" button to disengage from sleep mode, E: "Awake/Sleep" indicator light

3.3 Max project

We implemented the control software for the MMM Duet System in Max. To assist future developers, the Max project has been divided into several smaller Max Patchers, each handling their own function. The diagram of how these Patchers are linked together can be seen in Figure 3. The 'Game controller script' at top of the image denotes the input from the Arudino sketch that is loaded on the ESP32. The main role of the Arduino sketch is to measure the time difference between changes in angular positioning of the rotary encoder, which it then sends on to Max where it is translated into a usable form in the Bluetooth parsing Patcher. This information is then passed through the Speed Correction and Smoothing Correction Patchers (described in subsection 3.4) before it is passed on to the Signal Processing Patcher to control the speed of the Wav file. The parsed information is separately sent on to control the animation in the Visualization patch. In the Session Recording Patcher, the behavioral movement data can be recorded from when people perform on the music boxes. This Patcher records two types of data: the incoming raw behavioral data immediately after it has been parsed, and a series of regular snapshots that indicates the current digital sample of the Wav file being played.

3.4 Smoothing Correction function

As dementia most commonly affects older adults, people living with dementia may also have age-related mobility issues that limits their psychomotor performance and dexterity. Music has a variety of qualities that have been found to provide value to people living with

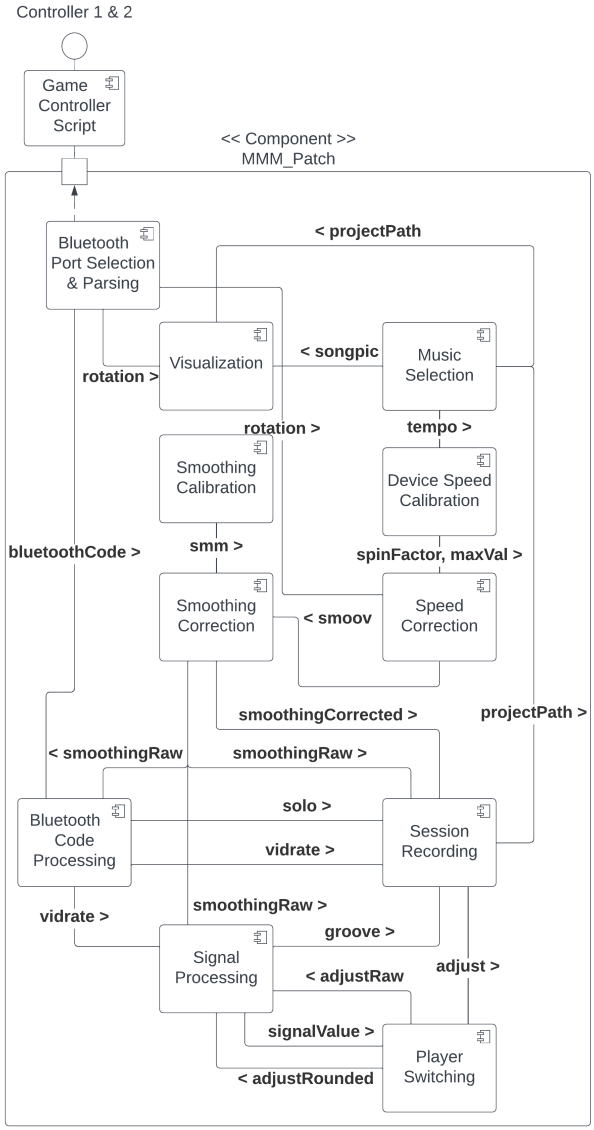

Figure 3: MMM Duet System Component Diagram

dementia, such as it being engaging, conveying emotional meaning, stimulating movement, affording synchronisation, reinforcing identity and sense of self, being a catalyst for social cohesion, and being persuasive [4]. The MMM Duet System has been developed to take advantage of many of these musical qualities, with the hope that people will engage with their music in a way that is important and meaningful to them. For some, synchronising is a part of music that acts as a catalyst for bonding with their partner, stimulating them to engage with the music in a playful and open way, and sparking discussion. Others are less concerned with synchronisation, but having a way to move along with music that supports their sense of identity is important, as is being able to hear the music 'correctly' as it is in their memories. For this reason, we felt it was critical to be

able to adjust the challenge level not only to match people's current skill level, but also their motivation for engaging with music.

The Smoothing Correction functions reduce the unsteadiness of movements made, also pushing the speed of the performance towards the original tempo of the song even if the person's spinning speed is somewhat faster, slower, or less smooth than the music's original steady pace. The Smoothing Correction functions, as shown in Figure 4, do this by creating a non-linear warping of the spinning speed input by using 7 variations of a basic cubic function $y = n(x-1)^m + 1$ centred around (1,1), thus having a gentle slope (rise over run smaller than 1) of x in the region around the (1,1) inflection point. Each of the cubic functions' positive exponential tails have also been capped to eliminate the possibility of large exponential changes as one moves positively further away from the central inflection point. The higher degree of smoothing, the lower this upper boundary has been placed, making it easier for people on the higher levels of smoothing to return to the inflection point.

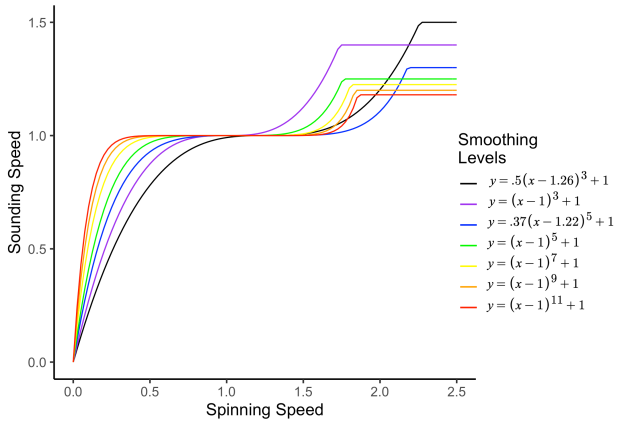

Figure 4: Seven stages of smoothing made to assist people to spin at original song tempo

As people sometimes struggled with their very first attempts to use the MMM Duet System, we added another higher degree of 'smoothing'. This highest level of smoothing (level 8) is not reflected in Figure 4 as it functions more as an on/off control. For this level, as long as a person spins the music box, the music plays at the correct tempo, and the music stops shortly after they stop spinning (around 1/2 second afterwards). This affords people a degree of control in terms of choice but not of speed control, as they choose when the music starts and stops. We have found that this can give participants a success to build on from, and can be a good starting point for many people living with dementia, as it is important for them to be able to see themselves succeeding in order to stay motivated to continue engaging with the task.

The higher levels of smoothing (levels 3-7) only give people the ability control the speed, and the lower levels (1-3) allow people to control both the pitch and speed of the music, so that the faster people spin, the faster and higher-pitched the music sounds. Originally, this combined control of pitch and speed was applied to all levels of smoothing, but some people living with dementia found this to be confusing, and it also does not match the wishes of people who want to hear the music played correctly. We would like to isolate this into its own musical pitch/spinning speed feature in the future, but we currently felt it was more important to minimise the number of options users had to select among every time they play a song.

We found that natural spinning rates vary greatly between individuals. People with mobility impairments might also spin more slowly as it is more comfortable for them. For these reasons, we implemented the function Speed Correction with 10 speed levels so that the correct spinning speed (the speed that plays a recording at its original tempo) can be manually adjusted to be close to a person's natural spinning speed. This was also done because of how the smoothing function works in nudging people towards the correct speed. Unfortunately, if a person's spinning speed falls too far away from the inflection point, the sounding result is even more unstable than if there is no smoothing at all (e.g., the rise over the run of the function is greater than 1 as a person approaches zero, which results in an amplification of the unsteadiness in the spinning speed rather than a smoothing process), so it is important that the spinning level is adjusted so that it is close to a person's natural spinning rate.

As we found that people tend to adjust their natural speed a bit for music of different tempos, spinning slightly faster for fast music than for slow songs, we implemented a tempo correction function that adjusts to the indicated tempo of the recording (reported in the Song List text files), requiring a slightly quicker spinning speed to match the original song tempo of a fast song. To increase people's sense of control over their actions, users also slightly control the loudness of the audio output, such that when they spin faster, the music is very slightly louder. The amplitude change is just enough so that a person can create small accents in the audio output from rapid movements, translating some of their sense of control over the speed of the music into a control over the dynamics of the song.

Additionally, as it is very difficult to get individuals back together if they get off by more than a certain amount, we implemented an automated correction feature that brings people back together. People are automatically brought back together if they are ever off by more than 1 second, separated by more than 1/2 second for more than 1/2 second, or separated by more than 1/4 second for more than a second. Currently, the accompaniment part is brought back together with the melody part in all circumstances to make this transition more seamless. This is also done because we found that people living with dementia performed better and enjoyed the task more when they were given the lead vocals part to play, and automatically correcting the part they are not controlling might cause less confusion for them.

With these various smoothing and spinning speed levels, we have found that the MMM Duet System is more enjoyable for more people. Some people are very happy to stay on the highest smoothing level, while others, once they have been successful at their current level, want to have a greater challenge on their next go. Introducing these differing smoothing levels has supported individualised ways of using the system.

3.5 Visual interface

As shown in Figure 5, we developed a screen interface to help people to visually coordinate with one another. We wanted a visual

representation that would require as little explanation as possible in order for people to understand if they were spinning too slowly or too quickly for the music. For this reason, we chose to visualise the speed of their spinning with cars moving forwards or backwards on a road to suggest their spinning speed being either faster or slower than the correct speed. We have designed the visual interface to try to present only the necessary information on screen, with the more relevant items in larger font size to make it easier to see for people whose vision is diminishing due to aging or dementia. The songs can be sorted by year, tempo, or alphabetically by performer or band name. We found that selecting the correct song for a given couple was important for stimulating reminiscence and conversation between the players, so this part of the visual interface is among the larger font sizes. On the screen, dropdown menus allow users to select the appropriate Bluetooth ports, spinning speed, smoothing level, and how the vehicles travel on screen. There is a help option at the top right of the screen that takes users to the most recent online documentation on how to set up and use the Max software and music box devices. Because not everyone wants to have visual feedback when they are playing, there is also a function to hide the animation of the cars traveling on the road and instead place onscreen an image of the artist or band performing the music. There are two options for how each car responds to spinning: Direct Rotation mode and Cadence mode. In the Direct Rotation mode, the vehicle's position is determined by the speed with which the player rotates the device. Faster rotations cause the vehicle to move to the right, while slower rotations cause the vehicle to move to the left. In the Cadence mode, the vehicle's position remains at the center when the player rotates the device at a consistent speed. If the player rotates greater than one standard deviation from than their average speed the player will move to the right (slower will go to the left). If the player remains at that higher speed the average is adjusted and the player will be re-centered.

Figure 5: MMM Duet System Visual Interface

4 DISCUSSION AND CONCLUSIONS

This paper presents the MMM Duet System, designed for couples living with dementia to better allow them to engage in group music-making with each other in a way that can support feelings of togetherness and relationship continuity. People living with dementia perform better at daily tasks when they collaborate with others, and these collaborations allow them a way to more actively participate in their daily life [16]. Despite these successes that people living with dementia find in cooperating with others, there is currently a lack of creative arts technologies that support collaborative activities for people living with dementia. As it has been made to be easy and flexible enough for people with no musical training to make music together, The MMM Duet System may provide a meaningful way for couples to continue interacting through dementia disease progression.

The participants have been valued partners in this work, and using a multi-phase iterative design approach with an emphasis on participatory design methods has allowed us to hear their voices more clearly. The involvement of the participants from early on has helped shape the development and the result.

In future work, we would like to automate certain elements of the Max Project. We would like to include a function that automatically adjusts to a person's natural spinning speed, as well as for the system to have better ways of adjusting to specific mobility needs. As many people like to sing along when using the music boxes, we would like to add the option of displaying lyrics on the screen. We would like to port the software to other platforms, such as for iPads or tablets, to make it more accessible for those who are less tech-savvy. We used Open-Unmix to load songs onto the MMM Duet System, which requires knowledge of how to code in Python. We would like to have a more integrated system in which users can load purchased audio tracks into the Max project and have the software separate and arrange the music for them. We believe that such developments will continue to make this system more dementia-friendly.

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A ONLINE RESOURCES

To download the current documentation, 3D printing files, Arduino sketch, and Max project, please go to: https://github.com/LoehrLab/MMM_Duet_System.

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