A Music Tangible User Interface for the Cognitive and Motor Rehabilitation of Elderly People

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Abstract: This paper proposes the combined use of tangible user interfaces, digital technologies, and musical expression in the context of cognitive and motor rehabilitation of elderly people. After analyzing the state of the art about common age impairments and tangible user interfaces in rehabilitation, we will introduce the *Kibo*, a MIDI controller based on the concept of fiducials and able to communicate with other MIDI devices via Bluetooth. The peculiar characteristics of the *Kibo* will be exploited in a Web framework aiming to foster the development or recovery of cognitive and motor abilities through 3 specially designed games. The paper will also report remarks from domain experts (music therapists and physiatrists) and the consequent redesign.

1 INTRODUCTION

According to a 2019 report by the United Nations, there were 703 million persons aged 65 years or over in the world in 2019 and the number of older persons is projected to double to 1.5 billion in 2050. These changes for individuals are mirrored in society since older persons represent a growing demographic group in society. One of the goals for sustainable development should be investing in education, health, and well-being for all, including the elder.

The target audience of the project documented in this paper is represented by elderly people who need rehabilitation sessions or are dissatisfied or inactive in their social interactions. Starting from an analysis of the most common impairments and changes in cognitive and motor abilities due to age, we designed and developed a prototype applicable to music-therapy rehabilitation sessions. Interventions can address a variety of healthcare and educational goals (e.g., promoting wellness, managing stress, alleviating pain, expressing feelings, enhancing memory, improving communication, promoting physical rehabilitation, etc.).

The result is a Web-based prototype that offers intuitive interaction with musical parameters via a specific tangible user interface, called the *Kibo*, so as to take advantage of the haptic interaction skills with the environment. In particular, three browser games have been developed in order to train rhythm, spatial, and recognition skills.

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2 STATE OF THE ART

In this section, we will review the scientific literature that is most relevant for our purposes. Due to the vastness of the subject, we cannot be exhaustive. We will limit ourselves to a few references of particular importance for our work, addressing: i) common age impairments, both cognitive and physical; ii) tangible user interfaces and their applicability to the music field; and iii) experiences of tangible user interfaces in rehabilitation.

Starting from **age impairments**, due to an increasing life expectancy, the number of elderly people has increased significantly worldwide. Thus, society will have to offer more and more products and services that meet the specific needs and desires of a geriatric age group that makes up a great percentage of the population. These people are seeking solutions to help them cope with daily life, give them the opportunity to interact socially, and find alternative ways of entertainment and learning. Moreover, health systems are dealing with the ever-increasing burden of finding solutions and cures for age-related and degenerative conditions (e.g., dementia and Alzheimer's disease) and impaired-movement pathologies (e.g.,

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Parkinson's).

Everyone experiences changes as an inevitable part of the natural degeneration associated with aging (Iversen, 2015). Concerning *changes in cognitive abilities*, aging causes a decline in spatial cognition, which is the ability to represent spatial relationships among objects. The results of a study conducted in 2008 by Iachini *et al.* show that some spatial abilities, such as the ability to mentally rotate visual images and to retrieve spatio-temporal sequences, decline with age (Iachini et al., 2008). Elderly people also struggle more with multitasking, especially if the tasks are complex (Wecker et al., 2005). Another common age impairment is the decline in fluid intelligence, which refers to the processing and reasoning components of intelligence and the natural ability to learn something new (Czaja and Lee, 2007). Because of reduced processing efficiency, the working memory, which is the ability to keep information active while processing or using it, declines with age (Salthouse, 1991). Similarly, prospective memory, which is the ability to remember to do something in the future, also declines with age (Maylor, 1995). Another issue emerging with age is the ability to select information in the environment, e.g., to attend to information on a Web page. Attention is the ability to focus on a specific task or an object in the environment while ignoring other things. This ability changes with age and older people are slower to move their attention from one thing to another (Czaja and Lee, 2007).

Another category of impairments due to aging is that of *changes in physical abilities*. Response time and accuracy of movement decline with age. Older persons' movements, reflexes, and reactions to stimuli are typically slower than younger persons' (Farage et al., 2012). Differently from the above-mentioned normal age impairments, a disease that limits movement is Parkinson's, a neurodegenerative brain disorder that progresses slowly and worsens with age. Symptoms are involuntary shaking of the hands, arms, legs, jaw, chin, and lips. Other main symptoms include slowness of movement, stiffness of arms and legs, and trouble with balance (Jankovic, 2008).

Even if not an impairment, another phenomenon relevant for our work is anxiety towards technology. In a study by Czaja and Sharit dating back to 1998, older people saw themselves as having less control over computers than younger people (Czaja and Sharit, 1998). They had significantly less efficacy in completing computer tasks, but, surprisingly, they also perceived computers as being more useful compared to younger people. Another study revealed that older subjects reported higher levels of computer anxiety than younger persons and that the anxiety level was related to the decision time on the computer when performing a test (Laguna and Babcock, 1997). The elderly may have a harder time using new technology, but it helps with practice (Chu, 2010). These considerations pushed us to develop a solution based on a computing system but relying on a tangible interface to ease user interaction.

Focusing on **tangible user interfaces (TUIs)**, they are intended to replace the graphical user interfaces (GUIs), more common in computing systems, with real physical objects the user can interact with. The key idea is to give digital information a physical form and let these physical forms serve as a representation and control for digital information. A TUI lets users manipulate digital information with their hands and perceive it with their senses. One of the pioneers in tangible user interfaces is Hiroshi Ishii, a professor at MIT who heads the *Tangible Media Group* at the MIT Media Lab. His particular vision for TUIs, called *Tangible Bits*, is to give physical form to digital information, making bits directly manipulable and perceptible (Ishii, 2008b). *Tangible Bits* pursues the seamless coupling between physical objects and virtual data. "*TUIs will augment the real physical world by coupling digital information to everyday physical objects and environments*" (Ishii and Ullmer, 1997). All physical objects can potentially be a part of a digital user interface (Ishii, 2008a). For example, if an object, which is a part of a TUI, is moved or put in a specific position, a digital signal will be sent from either the tangible object itself or from another device that senses the object. Currently, there are different research areas and applications related to TUIs. For instance, tangible augmented reality implies that virtual objects are "attached" to physically manipulated objects; in tangible tabletop interaction, physical objects are moved upon a multi-touch surface; moreover, physical objects can be used as ambient displays or integrated inside embodied user interfaces.

TUIs have been used considerably in musical performances and music-therapy treatments. A tangible interface – implying something "real", "concrete" – offers a physical way to interact with music and sound parameters. Most traditional musical instruments are played through this kind of interaction, but the advent of digital technologies paved the way for innovative and original approaches. Concerning technology-enhanced TUIs for music, the scientific literature describes a number of theoretical approaches, prototypes, and available products. Music TUIs can play a number of roles: for example, synthesizers to generate sound, sequencers that perform audio samples and mix them together, remote controllers for music and sound parameters, or interfaces for music-related games. To cite but a few references, Paradiso *et al.* review TUIs based on magnetic tags (Paradiso et al., 2001), Newton-Dunn *et al.* describe a way to control a dynamic polyrhythmic sequencer using physical artifacts (Newton-Dunn et al., 2003), and Schiettecatte and Vanderdonckt present a distributed cube interface based on interaction range for sound design (Schiettecatte and Vanderdonckt, 2008). A noticeable example of commercially available music TUI is the *reacTable* (Jordà et al., 2007), used by renowned artists such as Björk in their live performances. Our solution adopts a low-cost device called the *Kibo*, whose features will be described in detail in Section 3.

Finally, let us address the applicability and role of **tangible user interfaces in rehabilitation**. Motivation is one of the main problems evidenced in traditional therapy sessions, often hampered by the repetitive nature of exercises. Most studies show that an effective rehabilitation must be early, intensive and repetitive (Rego et al., 2014; Burke et al., 2010). As such, these approaches are often considered repetitive and boring by the patients, resulting in difficulties in maintaining their interest and in assuring that they complete the treatment program (Rego et al., 2014). On the other hand, due to their nature, games can motivate and engage the patients' attention and distract them from their rehabilitation condition. On one side, they require some motor and cognitive activity, but, on the other, they have a story and can offer feedback and levels of challenge and difficulty that can be adapted to the patients' skills.

Serious games are an option that provides learning combined with entertainment. The locution "serious games" refers to playful activities that provide training and physical or mental exercise in a fun and enjoyable way (Dörner et al., 2016). These games can be not only a way to prevent the feeling of loneliness (De Carvalho et al., 2012), but they can also enable social interaction (Fonseca et al., 2021). During the last decades, digital games have become a popular leisure activity. Ijsselsteijn *et al.* claim that digital games can be considered a promise to improve the lives of seniors. To this end, it is important to develop interesting and accessible games which could provide an option to spend quality time with clear benefits (Ijsselsteijn et al., 2007). Pearce reports that the studies of digital games with an emphasis on older people are still rare because this need is relatively new (Pearce, 2008). This perception may be justified by the fact that the current elderly population did not have much access to technology at their earlier age.

Many rehabilitation games based on TUIs are already available. For example, *Handly* is an integrated upper-limb rehabilitation system for persons with a neurological disorder (Vandermaesen et al., 2016). *Handly* consists of tangibles for training four-hand tasks with specific functional handgrips and a motivational game. The system consists of four tangible training boxes, which each present one essential grip and associated hand task: push-pull, squeezing, knob turning, and key turning. *Handly* combines tangibles specifically designed for repetitive task-oriented motor skill training of typical daily activities with serious gaming, thus offering a comprehensive approach.

Segara is an integrated hand rehabilitation system for patients with rheumatoid arthritis (Zhao et al., 2021). *Segara* consists of tangibles for training six tasks with interactive functional handgrips and a motivational serious game. It shows that a system combining games and tangibles to enhance hand rehabilitation is feasible and highly appreciated by patients.

Resonance is an interactive tabletop artwork that targets upper-limb movement rehabilitation for patients with an acquired brain injury (Duckworth et al., 2015). The artwork consists of several interactive game environments, which enable artistic expression, exploration, and play. *Resonance* provides uni-manual and bi-manual game-like tasks and exploratory creative environments of varying complexity geared toward reaching, grasping, lifting, moving, and placing tangible user interfaces on a tabletop display. Each environment aims to encourage collaborative, cooperative, and competitive modes of interaction for small groups of co-located participants.

NikVision is a tangible tabletop based on a user-centered design approach for the cognitive stimulation of older people with cognitive impairments and dementia problems in nursing homes (Cerezo et al., 2020). The general experiences of the users when working with the tangible tabletop were assessed and applied to the design of new cognitive and physical stimulation activities. Game activities are specially designed for the elderly, including daily tasks such as getting dressed, cognitive assignments, and upper-half motor skills training. Activities present different levels of difficulty and audio feedback.

3 EMPLOYED TECHNOLOGIES

In this paper, we want to take advantage of real physical objects and the benefits that TUI technologies offer in order to provide the elder with a playful way to interact in rehabilitation therapies. As mentioned before, one of the advantages of a TUI is the user experience, because a physical interaction occurs between the user and the interface itself. Another advantage is usability since the user intuitively knows how to manipulate the interface by knowing the function of the physical object; consequently, the user does not need to learn the functionality. That is why TUIs are often used to make technology more accessible for elderly people.

In this section, we will address the key technologies employed in the project: a music TUI called the *Kibo* (Amico and Ludovico, 2020), the way it is connected to a Web application, and the Web languages and formats used to implement the browser games described later.

The *Kibo* is a wooden board produced by Kodaly that presents eight distinct, easy-to-recognize tangibles.[1] These geometric shapes can be inserted into and removed from the corresponding slots, thus triggering events encoded in the form of MIDI messages. The device is also sensitive to pressure variations on single tangibles and individual dynamic responses can be communicated via MIDI messages. As an additional controller, there is a knob that can be rotated clockwise and counterclockwise. Finally, the device is equipped with a gyroscope.

The *Kibo* can be connected via Bluetooth or USB to iOS and macOS devices running a proprietary app that acts as both a synthesizer and a configuration center. Windows and Android operating systems are also supported via third-party drivers. The communication between the controller and the app occurs by exchanging standard MIDI 1.0 messages. The MIDI engine integrated into the app supports up to 7 *Kibo* units simultaneously, without perceivable latency. This aspect is particularly interesting for collaborative experiences (Baratè et al., 2021). Being a fully compatible controller, *Kibo* can also be integrated into any MIDI setup without the intervention of the app as a mediator, as we will do in our proposal.

The control over music parameters is mainly based on the 8 tangibles shown in Figure 1. Each object has a different shape fitting in a single slot and presents symmetry properties so that it can be rotated and flipped before being inserted. Tangibles have a magnetic core; they can be stacked one on top of the other and interact through magnetic fields. The body of the *Kibo* contains a multi-point pressure sensor that allows for the detection of the insertion and removal of tangibles. The characteristics of the sensor make the instrument extremely sensitive and, simultaneously, very resistant.

Even if our proposal bypasses the native *Kibo*'s app, it is interesting to analyze the three original operating modes and shed some light on rehabilitative and therapeutic scenarios:

[1] https://www.kodaly.app/

Figure 1: The *Kibo*'s body and tangibles.

1. *Musical Instrument Mode* — In this scenario, *Kibo*'s tangibles are mapped onto pitches. Associations between shapes and notes can be customized, even triggering multiple notes through a single tangible. The device is able to detect *aftertouch* effects, namely the possibility to track pressure variations over tangibles after note attacks;
2. *Beat Mode* — In this scenario, tangibles are mapped onto single percussive instruments. The pressure sensor, presenting a high level of resistance to strong mechanical stresses but also a noticeable sensitivity, allows effects ranging from hard mallet beats to delicate brush rubbing;
3. *Song Mode* — In this scenario, *Kibo* is employed as a controller to trigger already available music loops. Tangibles are associated with mutually synchronized but independent tracks, like in a multi-track environment. When tangibles are inserted, the corresponding tracks are activated; when they are removed, tracks are muted.

The configurability of *Kibo*, coupled with the adoption of standard communication protocols, enables numerous and heterogeneous scenarios. Multiple *Kibo* units in an ensemble can be configured to cover distinct note ranges and timbres, or even to work in different operating modes, thus providing the therapist with great flexibility. Moreover, the standard MIDI output of the *Kibo* allows the implementation of additional operating modes where other meanings, even extra-musical ones, can be assigned to user gestures. Our proposal, described in detail in Section 4, explores this possibility.

Even if originally conceived as a general-purpose tangible MIDI controller, when used in a suitable scenario the *Kibo* can also be considered an *assistive* technology falling in the category of communication boards. Under this perspective, it has a *therapeutic* function since it encourages upper-limb movements and challenges cognitive skills. Moreover, it is *compensatory* both from a motor point of view, being able to translate even small movements into sound, and from a cognitive point of view, enabling intuitive musical expression by lowering the barriers of a traditional instrument.

In this project, the *Kibo* has to be directly connected via Bluetooth to the computing system that hosts the browser. A specific protocol – called MIDI over Bluetooth or, simply, Bluetooth MIDI – is specially conceived to exchange MIDI messages over Bluetooth connections (Bartolomeu et al., 2005). The *Kibo* adopts Bluetooth Low Energy (BLE), a wireless personal-area network technology that, compared to the original Bluetooth protocol, is intended to provide considerably reduced power consumption and cost while maintaining a similar communication range. A BLE MIDI device will transparently operate with a MIDI-compatible application on most mobile and desktop platforms with no additions and provides "out of the box" support for most use cases compared with any wired or wireless alternative.

The visual feedback of the system is implemented in the form of a Web page by adopting W3C standard languages and formats. As a result, the browser games can be experienced using any HTML5 browser. The project was realized using HTML, CSS, and JavaScript.

Please note that all the mentioned technologies are client-side, so the platform could also be enjoyed locally on the user's client, with no need to connect to a server. Nevertheless, we have publicly released it over the Web in order to distribute it easily at no cost for the user and to keep it up-to-date in the case of a new release.

4 KIBO WEB GAMES

The goal of linking music therapy, rehabilitation exercises, and technology through the *Kibo* brought to the design and implementation of a Web platform that proposes three serious games. The name of the platform is *Kibo Web Games*. All game activities allow working the association between physical elements (geometric tangibles) and the concepts they represent (e.g., notes, tracks, hit buttons). The platform is available at https://kibogames.lim.di.unimi.it/ and its original Web interface is shown in Figure 2. *Kibo Web Games* need a *Kibo* device connected via BLE.

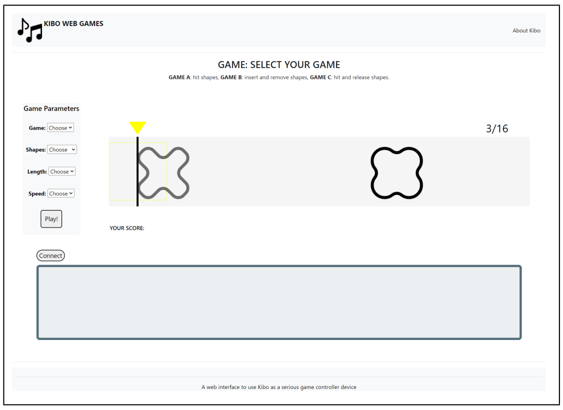

Figure 2: The interface of *Kibo Web Games*.

A number of game parameters have been introduced to allow flexibility in usage and adaptation to gradual improvements without causing frustration in the player. The user or therapist can set different types of activities and levels of difficulty according to the following parameters: i) the **game** to play, that is basically a rhythm-based activity where given shapes are proposed to the player and must be timely touched, inserted, removed, or continuously pressed depending on the game mode, as explained in the following; ii) the **number of shapes** (1 to 8 out of the 8 available) that can randomly be involved during the game experience; iii) the **total length** of the game sequence, i.e. the number of actions a user should carry out in a game session; and iv) the **speed** of the shape generation and scroll animation.

The central part of the interface is taken by the *Game field*, which displays the moving shapes during a game session. Shapes move from right to left, and the perfect timing for user's actions is when they hit the black vertical line. Another relevant part of the interface in Figure 2 is the *MIDI message console*, namely the lower rectangle that displays the MIDI messages received from the *Kibo*. Finally, the *Play* button starts the selected game with the parameters set by the user.

The second game expects the user to insert or remove the shapes from their slots in synchronization to the game's graphic scenario is able to train precision in performing movements. The third game asks the user to simultaneously press and release the recognized shapes. The scores, levels of difficulty, and feedback given to the player depend on her/his temporal precision in performing the movement.

Concerning the gameplay, *Kibo Web Games* focus on the interactions occurring between the player and the *Kibo*, i.e. simple motor movements like hitting, tapping, grabbing, holding, releasing, placing, and removing the geometrical tangibles. Furthermore, recognition and listening skills are trained to help restore or keep active cognitive functions. The *Kibo* gives tactile and musical feedback to every action that is performed and allows the user to proceed in small steps. It also allows users to manipulate objects giving the clearer image of the connection between physical interaction and the response that it triggers.

All games share the same game field and functional concepts. The system generates shapes scrolling across the screen from right to left and the goal is to timely recognize the shape by hitting, pressing, inserting, or removing the corresponding tangible from the *Kibo* physical body when it reaches the vertical line in the delimiter box (Figure 2). Throughout the duration of a game session, the arrow, square, and vertical line in the *Game field* animate to facilitate the game experience. Arrow and square flash when the user is supposed to perform a task. The vertical line turns either red or green according to the accuracy of the performance. The score field keeps track of the points gained while playing and remains displayed until the next game session is started.

Perfect hits are those performed in a very small range around the computed timing. Good hits occur in a slightly wider timing range. The exact values depend on the game speed set by the user, but they are in the order of tenths of a second. Currently, score penalties for wrong shape recognition or missed hits are not implemented to avoid frustration in players, but this feature could be easily integrated.

Please note that the *Kibo Web Games* interface allows users to play with the *Kibo* instrument as a simple musical controller, regardless a game session is active or not, after connecting it to the Web page. This provides sound feedback (C-major scale) and console messages only, but it might help to gain confidence and increase motivation. As another remark, the three games help gain rhythm awareness and present musical feedback, but they never imply a music-education background nor make use of any kind of music-related concept.

Game A – Tap the Shapes is based on the *Kibo*'s *Beat Mode* (see Section 3). Tangibles are mapped onto single notes of a C-major scale, one grade per shape. Pressing, hitting, or tapping a shape sends a Note On message immediately followed by a Note Off. MIDI messages are interpreted by the interface and played back thanks to an embedded audio synthesizer. Difficulty varies according to speed, number of shapes involved, game length, and score precision. The rhythm game expects the user to simply activate a midi ON message by pressing the expected tangible in the right timing range, namely when the arrow and delimiter box turn yellow. In order to play this game, all tangibles must be inserted.

Game B – Insert and Remove Shapes recalls the *Kibo*'s *Song Mode* (see Section 3). Tangibles are associated with independent synchronized tracks within a multi-track environment realized with Pro Tools [2] for this purpose. The multi-track starts playing when the game is initialized but has no volume. Each track is associated with a shape and is unmuted when the corresponding tangible is inserted into the device's wooden base. Conversely, removing the shape will mute the track. All tangibles must be removed and placed in front of the player or at a reachable distance before starting the game. For a better user experience, long game sequences must be set. The aim of Game B is to score points by inserting or extracting the *Kibo*'s tangibles once the randomly generated shapes touch the hit-line or perfectly fit the delimiter box before the animation ends and the shape disappears. The random algorithm should assure that, in the case of right user performance, at the end of the session no shapes are left inside *Kibo*'s body. This game mode solicits the development or recovery of some cognitive abilities, including memory (shapes have to be quickly recognized, found in the space around the *Kibo*, and inserted into the right slot) and creative reasoning (e.g., finding the best initial layout for the pieces around the *Kibo*'s body).

Game C – Hold and Release Shapes recalls the *Kibo*'s *Musical Instrument Mode* and takes benefits from the polyphonic aftertouch feature. Tangibles are mapped once again onto the grades of a C-major scale. Somehow similar to Game A, when a shape touches the vertical line or enters the delimiter box, the user is expected not only to tap the corresponding tangible but also to keep it pressed until the same shape appears again. Pressing a tangible sends a MIDI Note On message, and releasing it sends the corresponding Note Off message. This game mode is probably the most challenging one, from both a motor and a cognitive point of view. For example, some combinations of shapes require not only the ability to have them selected simultaneously but also a good strategy to have a hand free for the next insertion.

5 EARLY EXPERIMENTATION

Due to the restrictions imposed on society during the COVID-19 pandemic and the impact it had on the elderly and fragile populations, it has not been possible to test this prototype in a real-life setting so far. Nonetheless, the games were proposed to elder family members, colleagues, and domain experts to get objective feedback on their benefits and usefulness.

Overall, *Kibo Web Games* were appreciated and described as an enjoyable form of entertainment, yet challenging enough to possess rehabilitative properties. Differentiating between similarly shaped tangibles (e.g., star and flower) was initially perceived as demanding by many but overcome with practice. Another challenging aspect was maintaining the level of performance with the speed increment.

An early prototype was presented to music thera-

[2] https://www.avid.com/pro-tools

pists and physiatrists of *Fondazione Don Carlo Gnocchi*, Milan. Many useful remarks emerged about the games' structure and the user interface. Game A was particularly appreciated due to its simplicity, but the interface was considered too complex for users with impairments, above all cognitive ones. A first suggestion was to move the parameter configuration and the MIDI console away from the game screen, thus introducing a sort of back-office area to set game sessions; in fact, in a standard scenario, the parameter configuration on one side and the gameplay on the other involve two distinct actors, and the presence of side controls and messages can be a source of distraction. Similarly, the use of colors should be limited as much as possible, just to differentiate the actions required (e.g., either insert or remove a tangible). The numeric score, too, should be turned into a more direct and comprehensible representation, such as a given number of stars, a growing bar, or something similar. Games B and C involve persistent actions (i.e. shapes to keep inserted or pressed for a given time). In this case, the experts' objections focused on the graphical representation itself of the game field. In fact, in their opinion, having 8 scrolling areas corresponding to the 8 tangibles could help, above all in the case of cognitive impairment. Actually, a colored multi-track representation for Game C would recall the piano-roll visualization typically adopted by MIDI sequencers. Moreover, experts agreed that the last two games are more challenging from any point of view and, for this reason, they suggested a step-by-step process before playing the final version (e.g., first locate given shapes with no time constraint, then test the physical actions by moving shapes into their slots, etc.). Early experimentation of the revised interface should start at *Fondazione Don Carlo Gnocchi* in October 2022. Thanks to the positive feedback received, it is likely that *Kibo Web Games* have the requisites to be utilized among the elderly population. Future testing on this specific population will be necessary to fine-tune the development of a truly suitable device that can be used in the rehabilitative space. Connecting performance results to a database or exporting them into a CSV file could provide a more accurate track of progress.

The approach of *Kibo Web Games* can be easily generalized and adapted to other scenarios. For example, the platform can be profitably used to develop music parameters and geometric concepts awareness in young students, even in preschool age, thanks to TUI-based playful activities. Moreover, *Kibo Web Games* can help recover cognitive and motor abilities not only in elderly people but also in younger users; some experiences in this sense are reported in (Baratè et al., 2021).

6 CONCLUSIONS

In this project, we investigated the suitability of the *Kibo* to compensate for age impairments. The device proved to be a good solution from a technical and a physical point of view due to user-friendliness and robustness. Unfortunately, it is not an affordable product. Thanks to the *Kibo*'s 8-voice polyphony, multiple participants have the opportunity to access the interface simultaneously. Collaboration could be advantageous for seriously disabled individuals needing assistance from caregivers. However, the described games are not designed to explore this scenario in full.

The possibility to choose parameters and set difficulty levels allows users to progress at their own pace without confronting insurmountable obstacles. A therapist or a caregiver can suitably configure game sessions based on the players' attitudes and abilities. Moreover, no game penalties were implemented with the distinct purpose of not discouraging elderly users who are often not technology savvy and likely to be afraid of making mistakes or getting stuck.

The inspiration for future work mainly comes from the observations and remarks by experts reported in Section 5. Short-term future improvements include the creation of a different game field for each specific game, keeping the interface's look as simple as possible to avoid any distractions during the gameplay, and the implementation of two different windows (one for the user/patient who can only play the game and one for the specialist who can set the game parameters). In addition, tracking parameters like pressure variations could test and improve tactile and fine motor skills in action. After on-the-field experimentation, gaming speed will probably need to be adjusted to accommodate slower apprehension in aged people. Finally, an aspect to further explore is the use of proper musical feedback to be applied in music therapy.

Our expectation is that *Kibo Web Games* are able to stimulate declining cognitive abilities and reignite strained motor skills in elderly people in order to keep them active and fully integrated into society through a set of engaging activities.

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