# Design, Implementation, and Early Experimentation of a Music Tangible User Interface for Elderly People Rehabilitation

Helene Korsten[0000−0001−9870−3414], Adriano Baratè[0000−0001−8435−8373], and Luca A. Ludovico[0000−0002−8251−2231]

Laboratory of Music Informatics
Department of Computer Science
University of Milan
via G. Celoria 18, Milan, Italy
helene.korsten@studenti.unimi.it, adriano.barate@unimi.it, luca.ludovico@unimi.it
https://www.lim.di.unimi.it

**Abstract.** This article proposes an innovative approach for cognitive and motor rehabilitation of elderly individuals that combines tangible user interfaces, digital technologies, and musical expression. After reviewing the current literature on age-related impairments and the use of tangible user interfaces in rehabilitation, we introduce a specific MIDI controller called *Kibo* that employs geometric fiducials called tangibles. Thanks to Bluetooth connectivity and the adoption of the Web MIDI API, this device communicates with a specially-designed web framework that includes three games to facilitate the development or recovery of cognitive and motor abilities. The feedback obtained in an early experimentation phase from domain experts and a focus group underlined some strengths and weaknesses, thus driving the first revision of the interface and the gameplay. This work will describe the design and implementation of the early prototype and will shed light on the future evolution of the web platform. From the tests conducted so far, this solution based on a musical controller equipped with tangibles exhibits the potential to enhance the effectiveness and enjoyment of rehabilitation programs for elderly individuals.

**Keywords:** Music · Tangible User Interface · Web · Elderly Rehabilitation.

## 1 Introduction

The present study focuses on the rehabilitation needs of elderly individuals who may experience cognitive or motor impairments or reduced social interactions. To this end, we conducted an analysis of common age-related changes in cognitive and motor abilities and developed a prototype that could be applied to music therapy rehabilitation sessions. As stated in a document by the American

Music Therapy Association, music therapy "is the clinical and evidence-based use of music interventions to accomplish individualized goals within a therapeutic relationship by a credentialed professional who has completed an approved music therapy program" [2].

The prototype's interventions can target various healthcare and educational objectives, such as promoting wellness, managing stress, alleviating pain, expressing feelings, enhancing memory, improving communication, and promoting physical rehabilitation.

Our web-based prototype incorporates a tangible user interface called *Kibo*, which facilitates intuitive interaction with musical parameters, taking advantage of haptic interaction skills with the environment. Three browser games have been designed to train rhythm, spatial, and recognition skills. The web platform was shown at the prototype stage to two user categories: i) professional caregivers and rehabilitation experts, and ii) a focus group of elderly users. We collected their opinion in order to drive a new iteration of the design phase with the final goal of improving usability and effectiveness. In this paper, after describing the hardware and software ecosystem that we have designed and implemented, we will investigate the potential of our prototype solution to enhance rehabilitation outcomes for elderly individuals and contribute to their overall well-being.

The rest of the paper is organized as follows: Section 2 provides the state of the art about common age impairments; Section 3 defines the concept of tangible user interface and explores its adoption in the fields of rehabilitation and musical expression; Section 4 addresses the main technologies employed in the project; Section 5 describes the characteristics of the web games and the gameplay; Section 6 reports the results of early experimentation; finally, Section 7 draws the conclusions.

This work is an extension of the paper presented at the 6$^{\text{th}}$ International Conference on Computer-Human Interaction Research and Applications (CHIRA 2022) [4].

## 2 State of the Art

This section focuses on a selective review of the scientific literature on age impairments, a subject that is highly pertinent to our objectives. Considering the vastness of the subject, we acknowledge that our coverage cannot be all-inclusive.

Due to changes in life expectancy, the number of elderly people has increased significantly worldwide. According to the World Health Organization (WHO), the share of the population aged 60 years and over will double from 1 billion in 2020 to 2.1 billion in 2050. The number of persons aged 80 years or older is expected to triple between 2020 and 2050, thus reaching 426 million.[1] According to the United Nations, by 2050, 1 in 6 people in the world will be over the age of 65, up from 1 in 11 in 2019.[2]

[1] https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

[2] https://www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2019-Highlights.pdf

The growing demographic of older adults requires changes at the individual and societal levels. Sustainable development goals should include investment in education, health, and well-being for all, including older adults. Society will have to offer more and more products and services that meet the specific needs and desires of the geriatric age group. 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 diseases. Relevant examples embrace degenerative cognitive conditions caused by dementia and Alzheimer's disease and impaired-movement pathologies such as Parkinson's disease.

As stated in [40], while the demographic transition moves into a stage of increased longevity, attention must shift from an *aging society* to a *longevity society*. The former definition focuses on changes in the population's age distribution, the latter aims to leverage the benefits of extended lifespans by transforming the way we approach aging.

Everyone experiences changes as an inevitable part of the natural degeneration associated with aging [28]. 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 spatiotemporal sequences, decline with age [23]. Elderly people also struggle more with multitasking, especially if the tasks are complex [44]. 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 [14]. Because of reduced processing efficiency, the *working memory*, which is the ability to keep information active while processing or using it, declines with age [38]. Similarly, *prospective memory*, which is the ability to remember to do something in the future, also declines with age [32]. 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 [14,22].

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 and reflexes are typically slower than younger persons'. This also includes reaction to stimuli [19]. The loss in the sensitivity of touch in older people reduces the ability to differentiate between shapes and textures by touch [22]. 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 [29].

Even if not an impairment, another phenomenon relevant to our work is **anxiety towards technology**. In a study by Czaja and Sharit dating back to 1998, elder people saw themselves as having less control over computers than younger people [15]. 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 [31]. The elderly may have a harder time using new technology, but it helps with practice [13]. These considerations pushed us to develop a solution based on a computing system but relying on a tangible interface to ease user interaction.

## 3 Tangible User Interfaces

Tangible user interfaces (TUIs) are interaction mechanisms that replace graphical user interfaces (GUIs), more common in computing systems, with real physical objects. The key idea is to give digital information a physical form which serves as both a representation and a control means 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 [26]. *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*" [27].

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.

### 3.1 Tangible User Interfaces in Rehabilitation

Games can be used to increase the motivation of patients affected by cognitive or physical impairments in rehabilitation sessions [1,9,11,41,42]. Motivation is one of the main problems evidenced in traditional therapy sessions, often hampered by the repetitive nature of exercises. Most studies show that effective rehabilitation must be early, intensive, and repetitive [10,37]. 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 [37]. 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

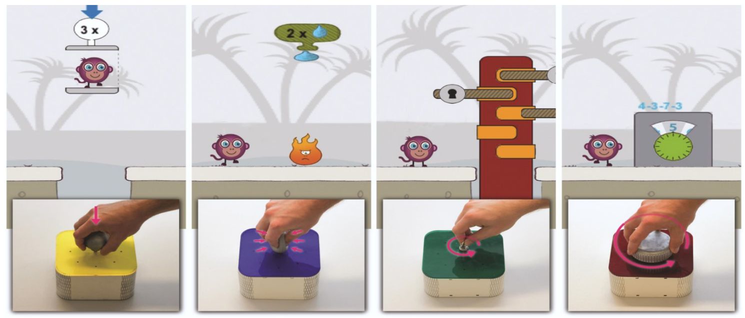


**Fig. 1.** User interface and activities with *Handly*. Images taken from [43].

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 [17]. These games can be not only a way to prevent the feeling of loneliness [16], but they can also enable social interaction [20]. 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 [24]. Pearce reports that studies of digital games with an emphasis on older people are still rare because this need is relatively new [36]. 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 [43]. *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 (see Figure 1). *Handly* combines tangibles specifically designed for repetitive task-oriented motor skill training of typical daily activities with serious gaming, thus offering a comprehensive approach. *Handly* focuses on therapy for various neurological disorders that can cause functional disabilities in the hands.

*Segara* is an integrated hand rehabilitation system for patients with rheumatoid arthritis (RA) very similar to *Handly* [46]. *Segara* consists of tangibles for training six tasks with Interactive functional handgrips and a motivational serious game (see Figure 2). 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 [18]. The artwork consists of several interactive game environments, which enable artistic expres-


**Fig. 2.** User interface and activities with *Segara*. Images taken from [46].

sion, 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 (see Figure 3). 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 cognitively stimulating older people with dementia problems in nursing homes [12]. 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. From these experiences, guidelines for the design of tangible activities for this kind of users were extracted for the design and evaluation of tangible activities that could be useful for other researchers. *NIKIVision*'s game activities are specially designed for the elderly and have different levels of difficulty and audio feedback. The list of activities includes:

- *Clothes Activity* — Based on the daily task of getting dressed, users interact with the tabletop by using different objects with realistic drawings of pieces of clothing and letters. Fine motor skills are addressed when users have to pick up the two-dimensional objects to place them on the tabletop;

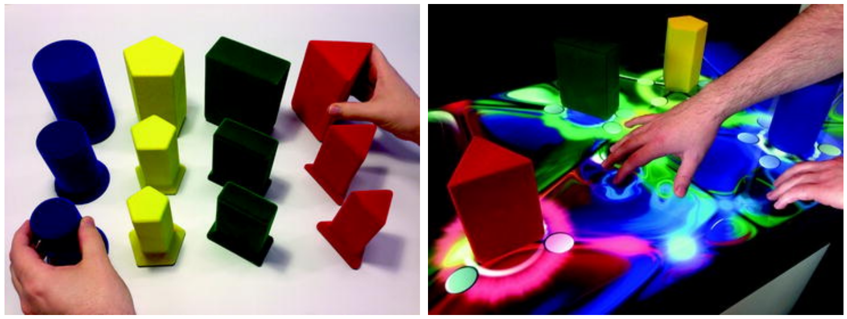

**Fig. 3.** User interface and activities with *Resonance*.

– *Shapes Activity* — Users have to select the indicated geometrical shapes and situate them on the box displayed on the tabletop;
– *Roads Activity* — Focusing on upper-half motor skills, users have to move the object on the tabletop surface by following a virtual road, also avoiding physical obstacles in the most difficult levels. The objects with which the users interact are different handles designed to stimulate different kinds of grabbing actions.

In conclusion, as regards their applicability to rehabilitation, one of the advantages offered by TUIs is the facilitated user experience, since the interaction occurring between the user and the interface itself is a physical rather than a digitally-mediated one. Recognizing (a cognitive task), grabbing, and moving objects (physical tasks) can be parts of the rehabilitation process. Another advantage is usability since the user intuitively understands how to manipulate the interface by knowing the function of the physical object.

### 3.2 Tangible User Interfaces in Music

TUIs have been used considerably in musical performances and music-therapy treatments. A tangible interface, being "real" and "concrete", offers a physical way to interact with music and sound parameters. The design is centered around the concept of tangibility, aiming to bridge the gap between physical and digital music interfaces. The underlying idea is that physical interaction with objects enhances the engagement and expressivity of users; thus, by placing importance on the tactile experience, these interfaces aim to provide more intuitive and natural means of music creation.

All physical objects can be part of a digital user interface [25]. A possibility is that an object moved or put in a specific location originates itself a digital signal to communicate position and/or movement to the surrounding system; another case is that of an external device, e.g. a camera or a pressure sensor, that senses the object.

Music TUIs can play a number of roles: synthesizers to generate sound, sequencers that perform audio samples and mix them together, remote controllers for music and sound parameters, interfaces for music-related games, and so on. Some of these devices have been reviewed or analyzed in detail in dedicated scientific works. To cite but a few references, Paradiso *et al.* reviewed TUIs based on magnetic tags [35], Newton-Dunn *et al.* described a way to control a dynamic polyrhythmic sequencer using physical artifacts [34], and Schiettecatte and Vanderdonckt presented a distributed cube interface based on interaction range for sound design [39]. Due to their availability, LEGO bricks or similar building blocks have often been employed in the control of musical parameters [6,21,33].

Several working prototypes are also available that did not originate from a scientific publication or resulted in a commercial product. Noticeable examples include the music maker device [3] designed by Lapponi *at al.* as a course project at the University of Oslo, the tangible user interface to control an audio player [4] realized by Brumley at the California College of the Arts, and the abandoned collaborative interface called *Block Jam* by Collect.Apply.

A successful case of commercially available music TUI is the *Reactable* [30], used by renowned artists such as Björk in their live performances. It provides a unique and immersive experience by combining physical objects with real-time digital audio processing and visual feedback. The *Reactable* consists of several key components that work in harmony to facilitate music composition and performance. The central element is a backlit translucent tabletop surface, equipped with a grid of light-emitting diodes (LEDs) and an underlying camera-based tracking system. This surface acts as the primary interface for interaction, allowing users to manipulate physical objects, referred to as "tangibles", placed on its surface. Each tangible object represents a distinct musical component or function, such as sound generators, audio effects, filters, or sequencers. These tangibles are typically equipped with fiducial markers, enabling the tracking system to identify and interpret their position, orientation, and other relevant parameters. The system captures the movements and configurations of the tangibles, translating them into real-time audio and visual feedback. Users can interact with the tangibles by rotating, moving, or connecting them to each other. These actions modify the musical characteristics or relationships between the elements represented by the tangibles.

Concerning our proposal, we rely on *Kibo*, another commercially available music TUI whose characteristics will be described in detail in Section 4.1.

In conclusion, music TUIs aim to offer a compelling user experience that blends physicality, visual feedback, and auditory output. A sense of engagement and creativity is expected to be stimulated when interacting with the system, thanks to the tangible and multisensory nature of the interface. The design of the experience should encourage exploration, experimentation, and improvisation, enabling learners, experienced musicians, and performers to discover new sonic possibilities and express their artistic ideas more intuitively.

[3] https://youtu.be/sKojCxcpgnk
[4] https://youtu.be/ZQdIxQ_EOLI

## 4 Employed Technologies

In this section, we will address the key technologies employed in the project: a music TUI called *Kibo* (Section 4.1), the way it is connected to a web application (Section 4.2), and the web languages and formats used to implement the browser games described later (Section 4.3).

### 4.1 *Kibo*

*Kibo* [5] is a wooden board produced by Kodaly that presents eight distinct, easy-to-recognize tangibles. These geometric shapes can be inserted into and removed from the corresponding slots, thus triggering events encoded in the form of MIDI messages, specifically Note On and Note Off. The device is also sensitive to pressure variations on single tangibles; individual dynamic responses are communicated via Channel Pressure messages. Additionally, the device is equipped with a knob that can be clicked and rotated and with a gyroscope, triggering Control Change messages.

*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 tool. Windows and Android operating systems are also supported via third-party drivers. As mentioned before, 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 like those documented in [7]. Being a MIDI controller, *Kibo* can also be integrated into any MIDI setup without the intervention of the app as a mediator, and this is the approach we follow in our proposal.

The control over music parameters is mainly based on the 8 tangibles shown in Figure 4. Each object has a different shape fitting in a single slot and presents symmetry properties so that it can be arbitrarily rotated and flipped before being inserted. Thanks to their magnetic core, tangibles can be stacked one on top of the other and interact through magnetic fields. The body of *Kibo* contains a multi-point pressure sensor able to detect the insertion and removal of tangibles. The characteristics of the sensor make the instrument extremely sensitive and, simultaneously, very resistant. For further details, please refer to [3].

Even if our proposal bypasses the native *Kibo*'s app and re-implements its functions, it is interesting to analyze the three operating modes originally conceived by *Kibo*'s manufacturer, since they inspired our initiative:

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*, namely the pressure variations over tangibles after note attacks;

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

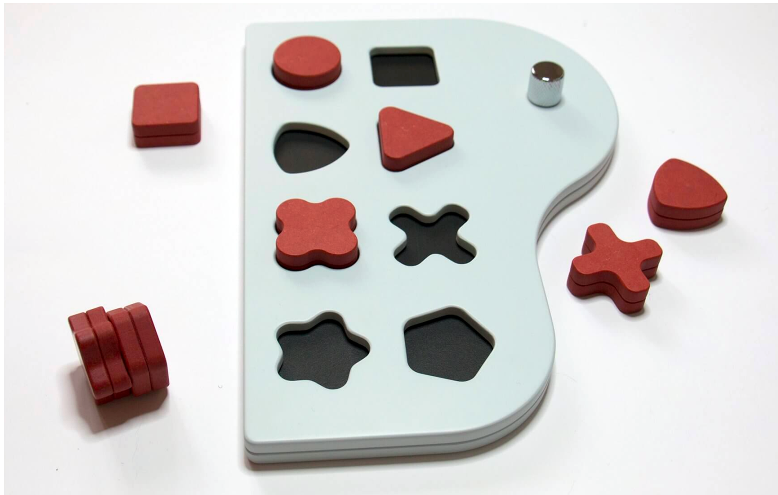

**Fig. 4.** *Kibo*'s wooden body and tangibles. Image taken from https://www.kodaly.app/

2. *Beat Mode* — In this scenario, each tangible is mapped onto a single percussive instrument. 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 a tangible is inserted, the corresponding track is activated; when it is removed, the track is muted, but it goes on running silently, so as to preserve global synchronization.

Focusing on rehabilitative and therapeutic scenarios, the reconfigurability of *Kibo*coupled with the adoption of a standard communication protocol enables heterogeneous scenarios. Multiple *Kibo* units forming 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 *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 5, explores this possibility.

Even if originally conceived as a general-purpose tangible-based MIDI controller, when used in a suitable scenario *Kibo* can also be considered an *assistive* technology falling in the category of communication boards [45]. Under this perspective, it has a *therapeutic* function since it encourages upper-limb movements and challenges cognitive skills. Moreover, it is *compensatory* from both a motor point of view, being able to translate even small movements into sound, and a cognitive point of view, enabling intuitive musical expression by lowering the barriers of a traditional instrument.

### 4.2 Network Technologies

In our proposal, *Kibo* has to be directly connected to the computing system that hosts the browser via Bluetooth. Bluetooth is an open standard for radio-based communications in the 2.4 GHz Industrial, Scientific and Medical (ISM) band. It targets low-power, low-cost, low-range, and moderate-rate applications. A more specialized protocol, called MIDI over Bluetooth (or, simply, Bluetooth MIDI), has been conceived to exchange MIDI messages over Bluetooth connections [8].

*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. BLE hardware is ubiquitous on modern devices and native driver support is available under most desktop and mobile operating systems. Once a BLE MIDI device is paired, it will transparently operate with MIDI-compatible applications on most mobile and desktop platforms with no additions.

Given its significant advantages in terms of compatibility, wireless capability, and low power consumption, BLE MIDI is an ideal choice for controllers. A potential problem in real-time scenarios could be latency, but in MIDI applications it is comparable with WiFi and, while bandwidth appears to be worse, is near to the original MIDI specifications.

### 4.3 Web Languages and Formats

The platform we are proposing has been implemented in the form of web pages. To this goal, we adopted W3C [6] standard languages and formats. As a result, the proposed activities can be experienced using any HTML5-compliant browser. In particular, the project was realized using HTML to structure the pages, CSS for animations and style, and JavaScript to handle and verify actions and events. With respect to HTML and CSS, whose role is descriptive, JavaScript is a programming language that can be used to modify or animate web content in response to users' actions.

A special technology adopted to bring MIDI into the web is the Web MIDI API. The main goal of such a programming interface is to allow the connection and interaction between a browser app and an external MIDI system, either physical or virtual. About 10 years from the release of the first public document, the Web MIDI API is still at the stage of a working draft and, as such, it is not fully supported by the totality of HTML5-compliant browsers. At the moment of writing, among the major browsers, only *Apple Safari* is not supporting this technology; conversely, *Google Chrome*, *Mozilla Firefox*, *Microsoft Edge*, *Opera*, and, more generally, all the browsers deriving from the open-source *Chromium*

[6] World Wide Web Consortium, https://www.w3.org/

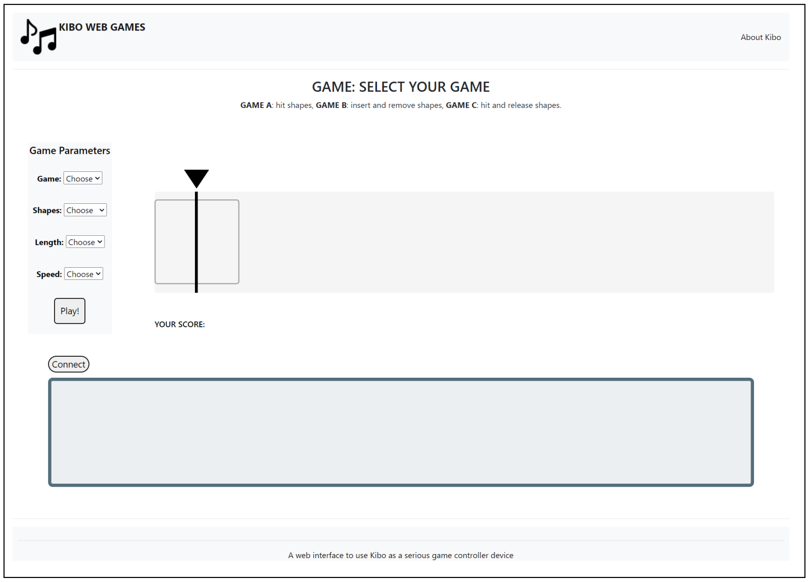


**Fig. 5.** The interface for *Kibo Web Games* common to the three rhythm games.

project do support the Web MIDI API. Further details on this subject have been recently discussed by Baratè and Ludovico in a dedicated scientific paper [5].

Since all technologies in use are client-side, the platform can also be enjoyed locally on the user's client, with no need to connect to a server. Nevertheless, we have publicly released the platform over the web to distribute it freely and keep it up-to-date in the case of a new release.

## 5 Kibo Web Games

The goal of linking music therapy, rehabilitation exercises, and technology through *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 games are intended to foster the association between physical elements (geometric tangibles) and the concepts they represent (e.g., notes, tracks, and hit buttons).

The platform is available at https://kibogames.lim.di.unimi.it/ and its original web interface is shown in Figure 5. *Kibo Web Games* need a *Kibo* device to be connected via BLE.

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:

– The **game** to play, which 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;
- The **number of shapes** (1 to 8) that can randomly be involved during the game experience;
- The total **length** of the game sequence, i.e. the number of actions a user should carry out in a game session;
- The **speed** of 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 the user's actions is when they hit the black vertical line. Another relevant part of the interface shown in Figure 5 is the *MIDI message console*, namely the lower rectangle that displays Note On, Note Off, Control Change, Program Change, and Polyphonic Key Pressure messages received from *Kibo* after attaching it through the *Connect* button. Finally, the *Play* button starts the selected game with the parameters set by the user.

Concerning the gameplay, *Kibo Web Games* focus on the interactions occurring between the player and *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 with the aim to help restore or keep active cognitive functions. *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 a 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 *Kibo* physical body when it reaches the vertical line in the delimiter box (Figure 6). Specifically, the first game asks the user to timely push the tangibles, the second game expects the user to insert or remove shapes from their slots, and the third game asks the user to press and/or release multiple shapes. Games will be better explained in the following. The scores, levels of difficulty, and feedback for the players depend on their time precision in performing the actions required.

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

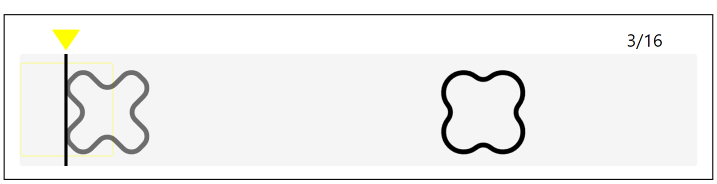


**Fig. 6.** When the left shape hits the vertical line, it starts to disappear.

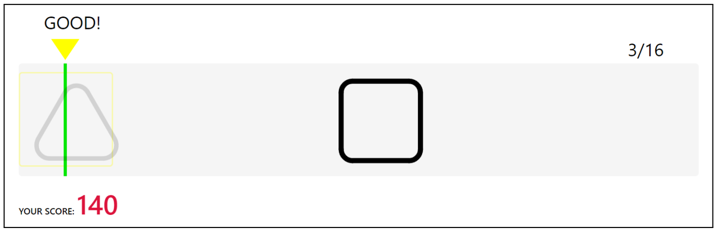


**Fig. 7.** A good hit for the triangle tangible. The vertical line turns green and the score is incremented. In the meanwhile, a new square-shaped tangible is approaching.

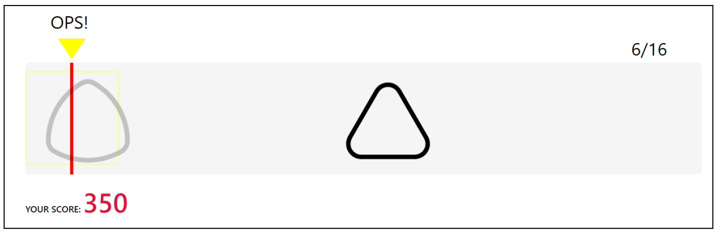


**Fig. 8.** Wrong shape recognition caused, e.g., by clicking a circle instead of a rounded triangle. The vertical line turns red and the score is not incremented. In the meanwhile, a new triangle-shaped tangible is approaching.

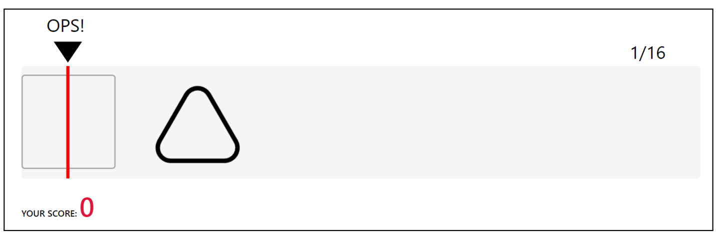


**Fig. 9.** Wrong timing in pressing the triangle-shaped tangible. The vertical line turns red and the score is not incremented.

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 tiny time interval around the exact timing. Good hits (see Figure 7) 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. Score penalties for wrong shape recognition (Figure 8) or missed hits (Figure 9) have not been implemented to avoid frustration in players, but this feature could be easily integrated.

Please note that *Kibo Web Games*'s interface allows users to play with *Kibo* as a simple musical controller, regardless a game session is active or not. In this scenario, only sound feedback and console messages are available. From a technical point of view, this allows the user to check the device connection, but, above all, this “sandbox mode” can help gain confidence with the controller.

As a final remark, please note that the three game modes do not require a music-education background nor make explicit use of music concepts.

### 5.1 Game A – Tap the Shapes

*Game A* is based on *Kibo*’s *Beat Mode* (see Section 4.1. 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. In order to play this game, all tangibles must stay in their slots. Difficulty varies according to the speed, number of shapes involved, game length, and score precision.

The rhythm game expects the user to press the expected tangible in the right timing range, namely when the arrow and delimiter box turn yellow (see Figure 6). The therapeutic and rehabilitative goals of this game include the ability to recognize shapes and timely activate commands.

### 5.2 Game B – Insert and Remove Shapes

*Game B* recalls *Kibo*’s *Song Mode* (see Section 4.1). Tangibles are associated with independent synchronized tracks within a multi-track environment realized with Pro Tools [7] 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 unmuted when the corresponding tangible is inserted into the device’s wooden base. Conversely, removing the shape mutes the track. All tangibles must be removed and placed in front of the player or at a reachable distance before starting the game. The aim of *Game B* is to score points by timely inserting and extracting *Kibo*’s tangibles once the randomly generated shapes touch the hit-line or perfectly fit the delimiter box, i.e. before the animation ends and the shape disappears. The random algorithm assures that, in the case of right performance, at the end of the session no shapes are left inside *Kibo*’s body.

This game mode solicits the development or recovery of cognitive abilities, including memory (shapes have to be quickly recognized, found in the space around *Kibo*, and inserted into the right slot) and creative reasoning (e.g., finding the most suitable layout for the pieces extracted from *Kibo*’s body).

### 5.3 Game C – Hold and Release Shapes

*Game C* recalls *Kibo*’s *Musical Instrument Mode* and takes benefits from the detection of polyphonic aftertouch. 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

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

tap the corresponding tangible but also to keep it pressed until the same shape appears again. Consequently, multiple tangibles could be in a pressed state simultaneously.

This game mode is 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.

## 6 Early Experimentation

The design and implementation phases of *Kibo Web Games* mainly occurred between 2021 and 2022. Due to the restrictions imposed by the COVID-19 pandemic and the impact of the virus on the elderly and fragile population, at an early stage of development, it was not possible to test the web platform in a real scenario. To have feedback on our work, we had to rely on two user groups: i) experts in the fields of music therapy, physiotherapy, and cognitive rehabilitation, and ii) a focus group made of elderly people selected among family members, friends, and acquaintances.

Concerning the former group, a prototype was presented to researchers 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. Nevertheless, its interface was considered too complex for users with impairments, above all cognitive ones. The first suggestion was to implement a back-office area so as to move the parameter configuration and the MIDI console away from the gameplay interface. In fact, side controls and console messages are not meaningful during the game; conversely, they can be a source of distraction for users. Similarly, in the experts' opinion, other aspects of the interface had to be improved. For example, the presence of colors should be limited as much as possible, using them just to differentiate some actions (e.g., "insert a tangible" or "remove a tangible"). The numeric score, too, could be too difficult to understand; rather, the level of user performance should be returned through a more direct and intuitive representation, such as a progress bar, the number of stars, or similar means.

As regards *Game B* and *Game C*, the experts' concerns focused on the graphical representation of the game field that, being currently the same as *Game A*, could sound a bit confusing for impaired users. The key difference between the former games and the latter one is that *Game A* does not present the concept of status (the symbols proposed to the user have to be clicked), whereas *Game B* and *Game C* involve persistent actions (tangibles must stay in place or must be pressed for a given time). Consequently, a differentiated layout could help, e.g. 8 scrolling areas corresponding to the 8 tangibles. Figure 10 shows the possible revisions of the current interface for *Game A* and *Game B*. Moreover, experts agreed that the last two games are more challenging and, for this reason, they suggested a step-by-step offline process before playing the web version. In the

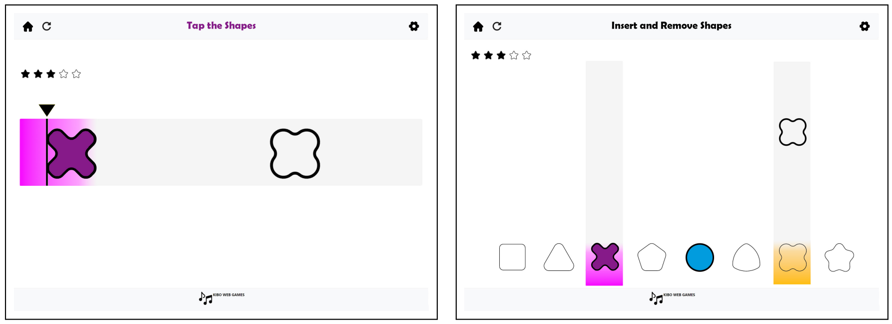


**Fig. 10.** Revised interface for *Game A* and *Game B*.

case of *Game B*, such a process could be first locating shapes with no time constraint, then physically moving shapes into their slots, and so on.

From the dialogue with experts, it emerged that the approach of *Kibo Web Games* could be easily generalized and adapted to other scenarios. For example, the platform could be profitably used to develop music-parameter awareness or transmit geometric concepts to young students, even at preschool age, thanks to the intuitiveness and playfulness typical of a tangible interface. Moreover, *Kibo Web Games* could help recover cognitive and motor abilities also in younger users [7].

Concerning the focus group, in general terms the *Kibo Web Games* platform was appreciated and the experience was perceived by most users as an enjoyable, yet challenging form of entertainment. The interface and the gameplay proposed to the experimental group were the original ones.

Some difficulties experienced in game sessions were particularly illuminating. For instance, some shapes have been often confused, such as in the case of the triangle and the rounded triangle, and in the case of the four-leaf clover, the five-pointed star, and the rounded cross. The occurrence of these tangibles caused a significantly higher miss rate in all games, which suggests that: i) in early game sessions, only one tangible in the set of confusingly similar shapes could be used, and ii) users must gradually get acquainted with distinguishing between them, possibly accompanied by therapists. An issue experienced by one of the participants, absolutely unexpected for us, was due to what we considered a strength of *Kibo*: the user prepared to press the next button by gently placing her finger on the tangible, but the extreme sensitivity of the pressure sensor detected such a gesture as an event and triggered a new note at the wrong timing.

*Game A* was perceived as intuitive and most users were able to play with little or no explanation at all. Conversely, *Game B*, whose starting scenario is having all shapes out of the board, had to be prepared and carefully explained. In general terms, users learned how to play only after a number of game sessions, and even the slowest game speed was perceived as challenging. It was interesting to observe the different strategies employed when tangibles had to be removed; in particular, a user left tangibles almost in place by moving them out from their slots and placing them on the wooden board, which is a very clever strategy indeed. *Game C*, when set to use all 8 shapes randomly, was considered extremely demanding from a physical and cognitive point of view. As a result of the focus group, the gameplay for this scenario must be rethought in order to avoid challenging combinations that would undermine even the performances of non-impaired users.

To obtain subjective feedback, ad hoc questions were mediated by the interviewer and transformed into 5-point Likert scales. All participants in the focus group partially (4 points) or strongly (5 points) agreed with the idea to play *Kibo Web Games* again. They found *Game A* and *Game B* simple from a physical (1 to 2 points in the Likert scale) and a cognitive (1 to 2 points in the Likert scale) point of view. However, it must be noted that the focus group was composed of elderly people with no certified physical or cognitive impairments. In this sense, only clinical experimentation under expert supervision can return significant results.

## 7 Conclusions and Future Work

In this project, we investigated the suitability of music TUIs in general, and a specific device called *Kibo* in particular, to compensate for age impairments. To this goal, we designed, implemented, and tested an early release of a web platform proposing three games based on the same concept, namely the timely interaction with tangibles. The games aimed at developing or reactivating different cognitive functions, physical abilities, and soft skills. Examples include the recognition of shapes, press/insert/remove actions, and the choice of a best-fitting strategy to solve a problem, respectively.

Due to *Kibo*'s 8-voice polyphony, multiple participants have the opportunity to operate the same interface simultaneously. Consequently, a game session can be played in a collaborative way. This could be advantageous for seriously disabled individuals needing assistance from caregivers. However, it is worth noting that the current release of the web platform is not designed to fully benefit from this opportunity.

The possibility to choose parameters and set levels allows users to proceed in small steps and progress at their own pace. Therapists, caregivers, or users themselves can suitably configure game sessions based on the players' attitudes and abilities. Moreover, no game penalties were implemented with the purpose of not discouraging elderly users who are often not technology savvy and likely to be afraid of making mistakes or getting stuck.

The adoption of a standard communication protocol between the controller and the web platform virtually supports a number of generalizations for the proposed approach. For instance, the web platform could be operated through any MIDI-compatible device connected via BLE and sending the same set of MIDI commands (Note On and Note Off on given channels, Control Change with specific CC numbers, etc.). Anyway, it is worth remarking that only tangible-based controllers offer the benefits described in this paper. Moreover, the graphical interface of *Kibo Web Games* was tailored to the physical layout of *Kibo*, proposing the same number and type of shapes. This does not prevent the adoption of a DIY approach to create a low-cost device capable of emulating the interaction of *Kibo*, e.g. by using an Arduino board, pressure sensors, and a 3D-printed case.

The inspiration for future work mainly comes from the observations and remarks by experts and early users reported in Section 6. Short-term improvements for the web platform include:

– the creation of a different game field for each specific game, keeping the interface's aspect as clean and simple as possible to avoid distractions during the gameplay;
– the implementation of a dedicated page to set game parameters;
– methodologies to record game performances and track specific parameter values (e.g. pressure variations) as a support tool for rehabilitation experts.

Further developments are expected to be inspired by thorough experimentation in clinical environments, thus extending the number of participants as it regards both patients and rehabilitation experts.

Our expectation is that *Kibo Web Games* will constitute an effective and engaging way to stimulate declining cognitive abilities and reignite strained motor skills in elderly people.

## Acknowledgements

The authors are grateful to *Kodaly S.r.l.*, the manufacturer of *Kibo*, for the support. The authors also wish to thank the experts of *Fondazione Don Carlo Gnocchi, Milan* for their help in the early evaluation of the prototype and all elderly people participating in the focus groups.

## References

1. Adlakha, S., Chhabra, D., Shukla, P.: Effectiveness of gamification for the rehabilitation of neurodegenerative disorders. Chaos, Solitons & Fractals **140**, 110192 (2020)
2. American Music Therapy Association: About music therapy & AMTA. https://www.musictherapy.org/about/ (2022), last accessed: May 27, 2021
3. Amico, M.D., Ludovico, L.A.: Kibo: A MIDI controller with a tangible user interface for music education. In: Int. Conf. on Computer Supported Education. pp. 613–619. SCITEPRESS (2020)
4. Baratè, A., Korsten, H., Ludovico, L.A.: A music tangible user interface for the cognitive and motor rehabilitation of elderly people. In: Constantine, L., Holzinger, A., Silva, H.P., Vanderdonckt, J. (eds.) Proceedings of the 6th International Conference on Computer-Human Interaction Research and Applications (CHIRA 2022). pp. 121–128. SCITEPRESS - Science and Technology Publications, Lda. (2022). https://doi.org/10.5220/0011395900003323

5. Baratè, A., Ludovico, L.A.: Web MIDI API: State of the art and future perspectives. Journal of the Audio Engineering Society **70**(11), 918–925 (2022). https://doi.org/10.17743/jaes.2022.0028
6. Baratè, A., Ludovico, L.A., Malchiodi, D.: Fostering computational thinking in primary school through a LEGO®-based music notation. Procedia Computer Science. Knowledge-Based and Intelligent Information & Engineering Systems: Proceedings of the 21st International Conference, KES 2017, 6-8 September 2017, Marseille, France **112**, 1334–1344 (2017). https://doi.org/10.1016/j.procs.2017.08.018
7. Baratè, A., Ludovico, L.A., Oriolo, E.: An ensemble of tangible user interfaces to foster music awareness and interaction in vulnerable learners. In: Proc. 5th Int. Conf. on Computer-Human Interaction Research and Applications. pp. 48–57. SCITEPRESS (2021)
8. Bartolomeu, P., Fonseca, J., Duarte, P., Rodrigues, P., Girao, L.: Midi over bluetooth. In: 2005 IEEE Conference on Emerging Technologies and Factory Automation. vol. 1, pp. 8 pp.–102 (2005). https://doi.org/10.1109/ETFA.2005.1612507
9. Berton, A., Longo, U.G., Candela, V., Fioravanti, S., Giannone, L., Arcangeli, V., Alciati, V., Berton, C., Facchinetti, G., Marchetti, A., et al.: Virtual reality, augmented reality, gamification, and telerehabilitation: psychological impact on orthopedic patients' rehabilitation. Journal of clinical medicine **9**(8), 2567 (2020)
10. Burke, J., McNeill, M., Charles, D., Morrow, P., Crosbie, J., McDonough, S.: Augmented reality games for upper-limb stroke rehabilitation. In: 2010 Second International Conference on Games and Virtual Worlds for Serious Applications. pp. 75–78 (2010). https://doi.org/10.1109/VS-GAMES.2010.21
11. de Castro-Cros, M., Sebastian-Romagosa, M., Rodríguez-Serrano, J., Opisso, E., Ochoa, M., Ortner, R., Guger, C., Tost, D.: Effects of gamification in bci functional rehabilitation. Frontiers in neuroscience **14**, 882 (2020)
12. Cerezo, E., Bonillo, C., Baldassarri, S.: Therapeutic activities for elderly people based on tangible interaction. In: ICT4AWE. pp. 281–290 (2020)
13. Chu, R.J.c.: How family support and internet self-efficacy influence the effects of e-learning among higher aged adults–analyses of gender and age differences. Computers & Education **55**(1), 255–264 (2010)
14. Czaja, S.J., Lee, C.C.: The impact of aging on access to technology. Universal access in the information society **5**(4), 341–349 (2007)
15. Czaja, S.J., Sharit, J.: Age differences in attitudes toward computers. The Journals of Gerontology Series B: Psychological Sciences and Social Sciences **53**(5), P329–P340 (1998)
16. De Carvalho, R.N.S., Ishitani, L., Nogueira Sales De Carvalho, R., et al.: Motivational factors for mobile serious games for elderly users. Proceedings of XI SB games pp. 2–4 (2012)
17. Dörner, R., Göbel, S., Effelsberg, W., Wiemeyer, J.: Serious games. Springer (2016)
18. Duckworth, J., Mumford, N., Caeyenberghs, K., Eldridge, R., Mayson, S., Thomas, P.R., Shum, D., Williams, G., Wilson, P.H.: Resonance: an interactive tabletop artwork for co-located group rehabilitation and play. In: Int. Conf. on Universal Access in Human-Computer Interaction. pp. 420–431. Springer (2015)
19. Farage, M.A., Miller, K.W., Ajayi, F., Hutchins, D.: Design principles to accommodate older adults. Global journal of health science **4**(2), 2 (2012)
20. Fonseca, X., Slingerland, G., Lukosch, S., Brazier, F.: Designing for meaningful social interaction in digital serious games. Entertainment Computing **36**, 100385 (2021)

21. Gohlke, K., Hlatky, M., de Jong, B.: Physical construction toys for rapid sketching of tangible user interfaces. In: Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction. p. 643–648. TEI '15, Association for Computing Machinery, New York, NY, USA (2015). https://doi.org/10.1145/2677199.2687900, https://doi.org/10.1145/2677199.2687900
22. Huppert, E., Cowell, J.M., Cheng, Y., Contreras-Ibáñez, C., Gomez-Sicard, N., Gonzalez-Gadea, M.L., Huepe, D., Ibanez, A., Lee, K., Mahasneh, R., et al.: The development of children's preferences for equality and equity across 13 individualistic and collectivist cultures. Developmental science **22**(2), e12729 (2019)
23. Iachini, T., Borghi, A.M., Senese, V.P.: Categorization and sensorimotor interaction with objects. Brain and Cognition **67**(1), 31–43 (2008)
24. Ijsselsteijn, W., Nap, H.H., de Kort, Y., Poels, K.: Digital game design for elderly users. In: Proceedings of the 2007 Conference on Future Play. p. 17–22. Future Play '07, Association for Computing Machinery, New York, NY, USA (2007). https://doi.org/10.1145/1328202.1328206, https://doi.org/10.1145/1328202.1328206
25. Ishii, H.: Tangible bits: Beyond pixels. In: Proc. 2nd Int. Conf. on Tangible and Embedded Interaction. p. xv–xxv. TEI '08, Association for Computing Machinery (2008). https://doi.org/10.1145/1347390.1347392, https://doi.org/10.1145/1347390.1347392
26. Ishii, H.: The tangible user interface and its evolution. Commun. ACM **51**(6), 32–36 (jun 2008). https://doi.org/10.1145/1349026.1349034, https://doi.org/10.1145/1349026.1349034
27. Ishii, H., Ullmer, B.: Tangible bits: towards seamless interfaces between people, bits and atoms. In: Proceedings of the ACM SIGCHI Conference on Human factors in computing systems. pp. 234–241 (1997)
28. Iversen, T.R.: Exploring tangible interaction: Alternative interfaces for assisting elderly users. Master's thesis, Department of Informatics, University of Oslo (2015)
29. Jankovic, J.: Parkinson's disease: clinical features and diagnosis. Journal of neurology, neurosurgery & psychiatry **79**(4), 368–376 (2008)
30. Jordà, S., Geiger, G., Alonso, M., Kaltenbrunner, M.: The reacTable: exploring the synergy between live music performance and tabletop tangible interfaces. In: Proc. 1st Int. Conf. on Tangible and Embedded Interaction. pp. 139–146 (2007)
31. Laguna, K., Babcock, R.L.: Computer anxiety in young and older adults: Implications for human-computer interactions in older populations. Computers in human behavior **13**(3), 317–326 (1997)
32. Maylor, E.A.: Prospective memory in normal ageing and dementia. Neurocase **1**(3), 285–289 (1995)
33. Miotti, B., Bassani, L., Cauteruccio, E., Morandi, M.: Musicblocks: An innovative tool for learning the foundations of music. In: Proceedings of CSME 2022. pp. 475–484 (2022). https://doi.org/10.5220/0011152100003182
34. Newton-Dunn, H., Nakano, H., Gibson, J.: Block jam: A tangible interface for interactive music. Journal of New Music Research **32**(4), 383–393 (2003)
35. Paradiso, J.A., Hsiao, K.y., Benbasat, A.: Tangible music interfaces using passive magnetic tags. In: Proceedings of the 2001 Conference on New Interfaces for Musical Expression. p. 1–4. NIME '01, National University of Singapore, SGP (2001)
36. Pearce, C.: The truth about baby boomer gamers: A study of over-forty computer game players. Games and Culture **3**(2), 142–174 (2008). https://doi.org/10.1177/1555412008314132, https://doi.org/10.1177/1555412008314132

37. Rego, P.A., Moreira, P.M., Reis, L.P.: Architecture for serious games in health rehabilitation. In: New Perspectives in Information Systems and Technologies. vol. 2, pp. 307–317. Springer, Cham (2014)
38. Salthouse, T.A.: Mediation of adult age differences in cognition by reductions in working memory and speed of processing. Psychological Science **2**(3), 179–183 (1991)
39. Schiettecatte, B., Vanderdonckt, J.: Audiocubes: A distributed cube tangible interface based on interaction range for sound design. In: Proc. 2nd Int. Conf. on Tangible and Embedded Interaction. p. 3–10. TEI '08, Association for Computing Machinery, New York, NY, USA (2008). https://doi.org/10.1145/1347390.1347394, https://doi.org/10.1145/1347390.1347394
40. Scott, A.J.: The longevity society. The Lancet Healthy Longevity **2**(12), e820–e827 (2021)
41. Steiner, B., Elgert, L., Saalfeld, B., Wolf, K.H., et al.: Gamification in rehabilitation of patients with musculoskeletal diseases of the shoulder: scoping review. JMIR serious games **8**(3), e19914 (2020)
42. Tuah, N.M., Ahmedy, F., Gani, A., Yong, L.N.: A survey on gamification for health rehabilitation care: Applications, opportunities, and open challenges. Information **12**(2), 91 (2021)
43. Vandermaesen, M., De Weyer, T., Feys, P., Luyten, K., Coninx, K.: Integrating serious games and tangible objects for functional handgrip training: A user study of handly in persons with multiple sclerosis. In: Proc. of the 2016 ACM Conf. on Designing Interactive Systems. pp. 924–935 (2016)
44. Wecker, N.S., Kramer, J.H., Hallam, B.J., Delis, D.C.: Mental flexibility: age effects on switching. Neuropsychology **19**(3), 345 (2005)
45. World Health Organization, United Nations Children's Fund: Global report on assistive technology. World Health Organization (2022), https://apps.who.int/iris/rest/bitstreams/1424204/retrieve
46. Zhao, X., Deng, Z., Jin, M., Li, X., Zhang, W., Jin, M., Ying, F., Wang, Q., Wang, G.: Segara: Integrating serious games and handgrip for hand rehabilitation in rheumatoid arthritis patients. In: The 9th Int. Symp. of Chinese CHI. pp. 101–104 (2021)