A Memory Game for All: Differences and Perception as a Design Strategy

Vanessa R. M. L. Maike
Institute of Computing
University of Campinas
Campinas, Brazil
vanessa.maike@ic.unicamp.br

Julián Esteban Gutiérrez Posada
Systems Engineering and Computing
University of Quindio
Armenia, Colombia
jugutier@uniquindio.edu.co

M. Cecília C. Baranauskas
Institute of Computing
University of Campinas
Campinas, Brazil
cecilia@ic.unicamp.br

***Abstract*—In this paper, we present a literature analysis of accessibility in games based on Natural User Interface (NUI). We also present a case study where we made an adaptation to the traditional memory game and tested it with four visually impaired people. This adaptation was conceived from a Universal Design perspective, and employed NUI. The analysis of both literature and the case study allows us to propose a design strategy for natural interactions for all.**

***Keywords*-Universal Design; Accessibility; Tangible User Interface; TUI; Natural User Interface; NUI; Natural Interaction;**

I. Introduction

From the old arcades that simulated real cars (with chassis, steering wheel and pedals) to gesture-based controls such as the Kinect, the Wii Mote and the Playstation Move, the context of video games has harbored many initiatives that went towards more *natural* interactions. Within this context, the term Natural User Interface (NUI) has been used to refer to devices and technologies that can offer a more direct mapping between the actions in the virtual world and the actions they require the person to perform in the real world [1].

Since the "naturalness" of NUI has been questioned [2], [3], in this paper we attempt to explore it in the context of accessibility in games. In the end, our main goal is to propose a design strategy for games that are both accessible and that provide natural interaction. Our analysis of literature and the design of the game presented in our case study are based on two concepts: differences and perception.

We understand differences from the philosophical stance of Gilles Deleuze [4, p. 28]: "*Difference is this state in which determination takes the form of unilateral distinction*". In other words, differences mean bringing out one aspect of a whole and defining it as distinct from the rest. However, instead of focusing on only one difference, we intend to look at how differences contribute to a better whole. For this reason, we chose Accessibility as the context of our study, since in it we work for the differences, not against them.

Perception, on its turn, we understand in terms of *affordance*, as established by James Gibson [5, p. 127]: "*The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment.*" Threrefore, in terms of Human-Computer Interaction (HCI), perception is more than simple input and output; it is also the relationship between the person and the environment or computer system s/he is interacting with. The closer this relationship, we believe, the more natural the interaction will feel.

The coupling between these two elements, differences and perception, is the basis of what we believe is a design strategy towards accessible NUI. This entails the intricate relationship between the person's perception of the world, the world's response to this perception, and the infinite cycle that is generated from that. To further explore these ideas, this paper is organized as follows: in the next section, we will present the work related to our chosen context, accessibility in games using NUI. Then, in the following section we will present our case study, in which we proposed a NUI adaptation of the traditional memory game. Then, we analyze both our case study and the related work under the scope perception and differences. In the final section, we present our concluding remarks.

II. Related Work

The following subsections show our search strategy for finding the related work, and then our analysis.

A. Search Strategy

To find work addressing accessibility in games, we searched through conference proceedings and journals focused on either NUI, games or accessibility. Hence, for **games**, we looked at the Brazilian Symposium on Computer Games and Digital Entertainment (SBGames), and the Symposium on Computer-Human Interaction in Play (CHI PLAY); for **accessibility**, we went through the journal Universal Access in the Information Society (UAIS), and the Conference on Computers and Accessibility (ASSETS); finally, for NUI, we looked at the Conference on Tangible, Embedded and Embodied Interactions (TEI), and the Conference on Designing Interactive Systems (DIS). From this search, we selected papers from the last ten years, i.e., no older than 2008, and that comprehended NUI, accessibility and games, all at once.

We also performed a second search, looking specifically for "memory game", since this was the subject of our case study. We used this string of search on Springer, ACM Digital Library and Google Scholar. Again, we selected papers from the last ten years, that addressed games and accessibility, but this time they did not necessarily have to include NUIs. Our rationale for this decision was not to limit the types of technology considered in the studies. We believe including those papers in our study allows a deeper analysis on the subject.

We performed a third and final search, looking for "enaction AND game", once we realized none of the papers we had found addressed a concept that is important to us, *enaction*, as proposed by Varela et al. [6]. The search databases were the same as from the second search. The selection criteria, however, was papers no older than 2008, and that included NUI, accessibility and games, all at once. From these three searches we came up with a total of 16 papers. After reading them, we have grouped these papers into **four categories**: *memory game*, *health*, *learning* and *adaptation from visual information*.

B. Memory Game

The first category has four papers. Raisamo et al. [7] created a memory game that both sighted and visually impaired children can play. Players have to find pairs of vibration patterns, provided by a video game controller, which is also used for input. Navigation through the virtual game board has visual and sound aids. The computer screen displays a grid of rectangles, shown in high contrast for children with low vision. Then, different sound pitches represent horizontal and vertical coordinates in the board. The game was tested with seven children with visual impairments. Results indicated good controller usability and that it is possible to use vibration patterns in a memory game. However, forming a mental model of the board was a challenge for some children, so previous training with a tangible representation was necessary.

Delić & Sedlar [8] propose a memory game that is entirely sound-based, including the board and the user input. Hence, there are no tangible artifacts for players to interact with. To navigate between the cards, sounds vary in direction (to represent the horizontal coordinates) and in frequency (to represent the vertical coordinates). The cards hold a word, stored in audio form, and players have to find the pairs of words. A user test was performed with eighteen children, nine visually impaired, and nine sighted. Their results were compared, but authors did not make it clear whether the test conditions were the same for both groups. Sighted children completed the game faster, but with similar number of attempts (card-turning) as visually impaired children.

Kawamoto & Martins [9] present a visuospatial memory game designed specifically for elders. The game consists of four squares, each with a color (yellow, green, red and blue) and a sound associated with it. To win, players must correctly select the squares in the presented sequences, by controlling a hand cursor through the Kinect. The game was tested with ten older adults, and results indicated they found that controlling a cursor with their hand (Kinect) was tiring, frustrating and more difficult than using the mouse.

Winoto & Tang [10] propose two games, both for the visually impaired. The first uses a helmet with five buzzers, each placed on a different location. The player has to repeat a sequence of sounds by turning a smartphone in the directions indicated by the buzzers. Sounds or vibrations indicate if the player was successful. The second game is played on the smartphone, with a piece of cardboard placed on top of the screen. It has a grid of rectangular holes cut through it, representing cards faced down. The player has to find the pairs of cards, by touching the holes to flip the cards. The pairs are always in different columns, a restriction used to reduce the game complexity. Both games were tested with five sighted people, who were either blindfolded or with their eyes closed. Results indicated the first game was easier, despite one of the buzzers (in the back of the head) being difficult to recognize.

In summary, we have four works with five different approaches to memory games (since Winoto & Tang [10] showed two games). Four were exclusive for the visually impaired, so their focus was on translating visual into audio or haptic information. The other proposal, from Kawamoto & Martins [9], focused on elders and therefore attempted to make the interaction simpler by making it gestural. Overall, the papers in the memory game category focused on specific audiences and their needs, in terms of how information is presented and how player input is made.

C. Health

The second category includes six papers. Geurts et al. [11] present four mini games they designed for the rehabilitation of people with limited motor control. To come up with the games, they used participatory design, involving patients and therapists. The games use different technologies, such as the Wii Mote, the Wii Balance Board and a webcam. They were tested with 21 people, and results pointed towards the importance of game calibration to each player's skills and goals.

Di Loreto et al. [12] propose an action game where the player controls a naval ship that needs to shoot its enemies and avoid obstacles. The game was designed with a *Universal Design* [13] philosophy, so it aims to be fun for everyone and, at the same time, a hemiplegic rehabilitation game. To engage players that are not under rehabilitation, the game was designed to maintain a high level of challenge at all times, and it keeps a score rank, to instigate competition. Displayed during a gaming exhibition, the game was played 700 times by players with and without motor disabilities. Results indicate both audiences were entertained, and that some people played the game several times. To be accessible to people with different motor skills, the game supported multiple input devices, such as keyboard/mouse, joystick, Kinect, tablet, and Wii Board.

Hwang et al. [14] wished to test whether the effects of balancing algorithms in exercising games for people with disabilities persist or change over time. To do so, they created two games and tested them with eight children with cerebral palsy. One is a racing game, where the player controls the speed of a lizard by pedaling a custom bicycle. The other is a shooting game where the player has to hit their adversary by aiming and shooting with a video game controller. Results indicated that, in the course of six days playing these games, the balancing algorithms did not alter player behavior. This happened even after they understood how their efforts were compensated to even the chances between players.

Vandermaesen et al. [15] present a game for the rehabilitation of upper limbs, for people with neurological disorders. The controls consist of four wooden boxes, each with a unique grip for training a specific hand task. Inside the boxes, an Arduino and sensors check if the tasks are executed correctly. The player controls a virtual avatar and has to overcome obstacles that are specific for each box. The game was first pilot tested with five healthy individuals, and then with eight people with multiple sclerosis. Results indicated the game was useful for rehabilitation, and that the controls were easy to learn. However, participants suggested more features would promote long-term playing.

Gerling et al. [16] propose a Kinect game that uses full-body motions and is directed to older adults. The theme of the game is gardening, and there are four gestures the player can make, each mapped to an action: growing plants, growing flowers, making flowers bloom, and catching a bird. To grow flowers, for instance, the player lifts or waves one arm, activating rain. The game was tested with twelve adults with ages from 60 to 91 y/o. Results showed that players enjoyed the full-body gestures, and that the chosen theme appealed to them. However, recalling the gestures was a challenge for most players, so authors suggested it might be better to map gestures closer to real world actions.

Sonne & Jensen [17] present a game for helping children with Attention Deficit Hyperactivity Disorder (ADHD) in controlling their stress. The custom game controller looks like a blowfish, and, to succeed, players have to inhale or exhale into the fish at the right pace. The idea is to disguise breathing exercises into the game. To build the controller, the authors used a sensor to detect temperature changes and LEGO. As a preliminary evaluation, they tested the game with sixteen adults. Results showed that the game can successfully make players relax, but first they need to understand the rhythm they are expected to breathe in and out. Otherwise, they can become anxious, or even hyperventilate.

In summary, from the six papers in the **health** category, four focus on rehabilitation for motor skills, one is directed to elders and one is for children with ADHD. Hence, unlike the **memory game** group, these works are more concerned with *how* the user will interact with the game, and not so much with *translating* information from or to visual, audio or haptic formats.

D. Learning

This category has three papers. Sánchez, Sáenz & Ripoll [18] present a game of spatial exploration, where the input tool is a wooden carpet with twelve haptic cells on it, simulating a clock. The idea is that blind and low-vision children interact with the game using their bodies, and the main goal is to teach them spatial orientation. To achieve this, they use the hour system and the wooden carpet to orient themselves and navigate in the game. Their objective is to find an object in a virtual environment full of rooms, and a sound cue tells them when they are close to the object. Twenty children with visual impairments tested the game, and results indicated the carpet was easy to use and a helpful tool for learning spatial orientation.

Milne et al. [19] designed a suite of smartphone games that promote Braille literacy for children. As form of input, the games take touch or gestures, and the feedback to the user is through sound or vibration. The Braille is shown in the smartphone screen in an oversized scale, as it is usually done when teaching with non-digital materials, like egg cartons and tennis balls. This means the games are for teaching the Braille encoding, but not to develop the tactile sensitivity. The authors designed the four games following a set of principles: to be accessible, to be educational, to accommodate different skill levels and, finally, to be available for mainstream devices. They tested the games with eight blind children. Results showed children were able to learn some Braille concepts with the game, and that, for the most part, they were able to play autonomously. However, the games did not engage players for a long time, and many children reported they played collaboratively with their sighted siblings, despite the game being designed for the visually impaired.

Vanden Abeele & Schutter [20] present a mini game meant to be played by seniors and youngsters, together. Authors use the terms *enactive knowledge* (proposed by Jerome Bruner [21]) and *enactive interaction* to refer to physical action that requires previous knowledge. As seen in the work of Gerling et al. [16], from the **health** category, it is important for gestures to be mapped close to real world actions. Vanden Abeele & Schutter [20] also use the term *digital affordance*, referring to how the virtual world of the game must indicate to the player which actions are possible or expected. Hence, the game proposed by the authors has players using the Wii Mote to perform actions such as rotating screws or cleaning a dirty surface by rubbing it. They designed the game thinking of "equality in ease of use", i.e., the game is meant to be challenging and fun for all ages. A user evaluation with seven seniors and eight youngsters resulted in most participants quickly understanding how to play, and in similar performances between the two age groups.

In summary, from the three papers in the **learning** category, two have specific goals of teaching certain skills to visually impaired children. The other one focuses on how to use previous knowledge to improve interaction. Hence, two use technology for learning purposes, and one uses learning in favor of technology design.

E. Adaptation from Visual Information

The fourth and final category contains three papers. Yuan & Folmer [22] translated visual information into haptic stimuli, to make a famous rhythm game accessible to the visually impaired. Players must use a special glove that contains small motors in each finger. This way, vibrations indicate which buttons in the plastic guitar controller players need to press at the correct time. Authors conducted a usability study with three blind and nine blindfolded sighted people. Results indicated the glove was successful in translating visual information into haptic stimuli, but with limitations, such as restricting players to an easier game difficulty.

Allman et al. [23] also present an adaptation of an existing musical game, but instead of a plastic guitar, players use a drum kit controller. The visual cues of the game are translated into audio and vibration, the latter occurring in different parts of the player's body through straps with small motors. There are five straps, which are attached to biceps, wrists and one of the ankles. The haptic feedback tells players when and what to do, e.g., hit the drum's pedal when there is a vibration on the ankle. Meanwhile, the audio serves to vocalize text (such as instructions or scores) and provides feedback whether the player performed an action successfully or not. The study involved four people with visual impairments in both design and evaluation phases. Players reported the game was fun and easy to learn, but some suggested using their hands instead of drumsticks, to get a better sense of where the drums were.

Morelli, Foley & Folmer [24] propose an adaptation of a virtual bowling game, using the Wii Mote, that has a built-in accelerometer and vibration capability. The game requires the player to hold the controller upwards and then mimic the tossing motion of the real world bowling. The controller vibrates more intensely as the user points it towards the direction of the throw, to guide the visually impaired. Other visual information are given by sound, such as score and how many pins were hit . Six blind adults tested the game and found it fun and easy to play. They suggested adding a multiplayer option and more sounds, such as a cheering crowd, or spatial audio to indicate where the ball hit.

Overall, the **adaptation from visual information** group presented three game adaptations with translation from visual to haptic and sound information. In two of these works, the translation was only possible by restricting the game difficulty. Allman et al. [23] did not have to make this concession, but their translation had another limitation, also present in the work of Yuan & Folmer [22]: players cannot anticipate future moves, since the haptic feedback can only tell them of the immediate required action. All three papers present approaches that go towards assistive technologies, and do not encourage bringing together different types of players.

III. Case Study

Thinking of the research opportunities we found in Section II, we conducted a case study with visually impaired individuals and a memory game we created.

A. Game Design

The main artifact of our case study is an accessible adaptation of the memory game. In the traditional version, a deck of cards is laid out face down in rows and columns, forming a grid. There are pairs of identical cards, and the goal is to find all the matching pairs by flipping the cards, two at a time. When the player flips two cards, if they are a pair, they are both removed from the board. Otherwise, they are turned face down again. Usually, pairs are represented through images, making it inaccessible to the visually impaired.

In our adaptation, the intention was to maintain the core of the game, and make it accessible to as many people as possible. The physical artifact consists of a board where the cards are laid out, as illustrated in Fig. 1. It is made of Ethylene-Vinyl Acetate (EVA), and has dimensions of 40cm by 50cm. The board has pockets to hold the cards, allowing a visually impaired player to feel the board with her hands without scrambling the cards. Each pocket has a bump on its top, to mark its location. The pockets form a 5x5 grid, mapped by coordinates: columns are letters from A to E, and rows are numbered from 1 to 5. Hence, there are twelve pairs of cards, and the remaining one is a trap, i.e., it does not match with any other card.

The artifact also includes an Android app that requires a smartphone with Near Field Communication (NFC) capability, because our cards are actually Radio-Frequency IDentification (RFID) cards that need to be scanned by the smartphone. Hence, when the player brings the device close to a card, it is equivalent to "flipping" that card. Furthermore, the act of scanning a card triggers the following:

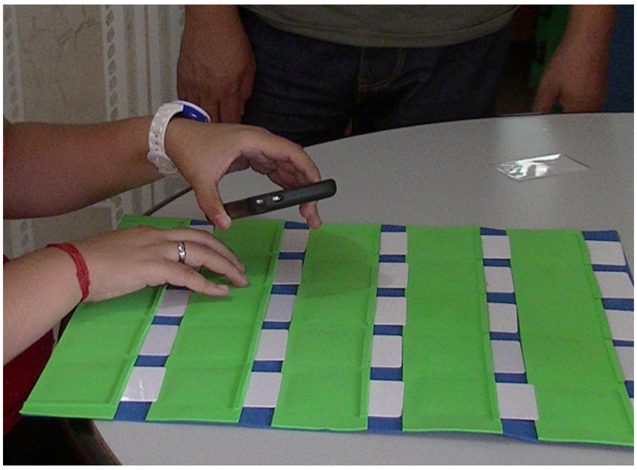

Figure 1. Close-up of the game board while a person is playing our memory game.

1) By synthesized voice, the app informs the coordinates of where the card is located (e.g. E-2).
2) The app displays on the screen the image associated with the card, and plays the sound related to that image. The images and sounds can be of animals (e.g. lion), objects (e.g. church bell), or places (e.g. a city or state).
3) By synthesized voice, the app tells the player if this is the first or the second card she has flipped while trying to form a pair, or if it is a trap.
   a) If it is the *first card*, the player is instructed to flip another card.
   b) If it is the *second card*, the app checks if it forms a pair with the first one. If they do **not**, the player is instructed to scan another two cards. If they **do**, the app asks the player to remove the two cards from the board.
   c) If it is a *trap*, a funny sound plays and the player is informed she fell into the trap. If the trap comes after a first flip of a pair, that flip is reset.

There were no images associated with the physical cards, i.e. they were blank on both sides. This was a design decision made to bring the problem of scrambling the cards to the software, instead of obligating players to physically move the cards around the EVA board. It also brings flexibility to the game, since it allows us to change the images and sounds just in the software. Finally, it is a step towards a "design for all". Having the images directly on the cards brings an advantage to players who can see over those who cannot. They would be less dependent on the coordinates to remember the card locations, whereas the visually impaired, in principle, rely mostly on the coordinates to associate with sounds. Having the images only on the smartphone screen is a smaller advantage, since the image will not be so strongly associated with the location on the board.

B. Participants and Method

We tested our adaptation of the memory game with a group of four visually impaired individuals, three blind and one with low vision.

They are all part of a non-profit institution called "Pró-Visão", located in the city of Campinas. The organization brings together people from the local community with the goal of social inclusion of the visually impaired. The institution tends to people of all ages, and helps them gain autonomy in everyday activities, such as reading Braille, using the white cane, and signing documents. The activities are conducted by a multidisciplinary team that includes educators, psychologists and social assistants. From the start, our partnership with the institution had the agenda of helping the participants learn new skills by putting them in touch with novel technologies. In return, we got their feedback and constructed new forms of interaction along with them. All of this was done with the consent of the institution and under the regulations of an ethics committee. We presented participants with a consent term, read it to them (aloud or with a screen reader) and all who agreed, signed. It was made clear to them they were not obligated to participate.

Three of the participants from this case study had already been on other activities organized by us, where we brought them different devices, including a smartwatch, smartphones, and Kinect and Leap Motion artefacts. The activity of this case study was the last in a series of six, organized in the course of a year. All activities followed the same format, which we called "workshop". First, there was an ice-breaker, where we introduced ourselves and welcomed new participants. Then, we explained the activity of the day: what were the goals, the technology used and the applications to their routines. In this stage, we could ask them questions about such applications, i.e., how they usually deal with the situation without technology. Next, we had them experiencing the technology, usually one-by-one. Then, each participant answered an individual evaluation through the Self-Assessment Manikin (SAM) [25]. It allowed them to give a spontaneous feedback on how they felt while using the technology. Finally, we had a *debriefing* session, i.e., a group discussion about the whole workshop to get both individual and collective qualitative feedback.

C. Results

The results can be divided into four moments. First, the initial discussion about their previous gaming experience. Second, observations from while they played the game. Third, the results from the SAM evaluation. Finally, there is the feedback from the debriefing.

1) Previous Gaming Experience: Participant #1 lost his sight after adulthood, so he said he used to play video games and cards, but has not played anything since. He believes he could play again using a magnifier – since he is not completely blind – but he has not tried.

Participant #2 said she does not play games very often, but when she does, she likes quiz games, on the smartphone. She also told us she has played an adapted memory game at school, but she did not like it. There were different textures and materials to identify the pairs, but she reported it was poorly made.

Participant #3 said she does not care much for games, but has played hangman, word search, and a memory game, all on the computer.

Participant #4 told us he is an athlete, and enjoys physical activities such as skateboarding, spinning tops, and playing sports. He also likes playing with an adapted version of the Rubik's Cube and dominoes, which he can use the common version if it is possible to feel the numbers on the pieces. He also plays chess and checkers, but on the computer. To do so, he uses coordinates for locating pieces and making plays, similarly to what we did in our memory game. He said, however, that if he were to play the physical version, he thinks his opponent would have to read him the whole board, making the game slower.

2) Playing the Memory Game: Participant #1 adopted the strategy of exploring the third and fourth rows linearly, and then doing the same for the second row. After exploring the area of these rows, he moved on to the fifth row, and then to the first, finding as many pairs as possible. In total, he took 29 minutes to find all pairs. He had some trouble with the RFID reader; sometimes it took him a while to bring the device to the right distance from the card, a problem he had in previous workshops. At other times, he would maintain the reader over a card, and its content kept being repeated. In addition, after there were few cards left, it was difficult for him to find where they were, as he kept feeling the board, trying to find them. Another difficulty he had was in removing the cards from the board after finding a pair, since he could not always remember where they both were. During the game, on occasion, Participants #2 and #4 gave him tips, and it was interesting to note how, even though they were not manipulating the RFID reader, they were still able to remember some of the cards' positions, just from listening to the coordinates.

Participant #2 adopted the strategy of random exploration, i.e., she did not follow a specific pattern to choose which cards to flip. She took 27 minutes to complete the game, and had a lot of difficulty remembering positions of cards she had already flipped. In addition, she was very anxious and kept talking about other topics while playing, making her distracted. Other participants gave her tips from time to time, and she listened to them.

Participant #3 linearly explored the fourth row, then the fifth (bottom), and then she went back to the third, then the second and, lastly, the first. While exploring, when she found a card she thought she knew where the pair was, she marked it to search specifically for its pair. At first, she did so by placing a finger over the chosen card, while she used her other hand to hold the smartphone and scan cards. Later, she began to take the card from its pocket and set it aside. After finding the trap a few times, she also removed it from the board. In the end, she got the second best time in the group: 16 minutes.

Table I
RESULTS FROM THE SELF-ASSESSMENT MANIKIN.

Participants	#1	#2	#3	#4
Valence	1	3	5	1
Arousal	1	3	5	1
Dominance	1	3	1	1

The best time, however, was from Participant #4. His strategy was to first scan the four corners of the board. Then, he made a cross by going through the middle row and then the middle column. He easily remembered the positions of the cards, so it only took him 11 minutes to find all pairs.

3) Self-Assessment Manikin: Individually and right after playing the game, each participant answered the SAM, an evaluation tool for measuring the feelings of Valence, Arousal and Dominance evoked by a stimulus [25]. In our case study, such stimulus is the memory game in its entirety: the play, the rules, the concrete objects that compose the game (e.g. board, card, smartphone) and the information system that is behind all of it.

We chose SAM because it is the evaluation tool we already used in previous workshops within this institution. In this case study, the goal is not to find correlations, but rather to get the participants' spontaneous reaction to the experience, before the discussion with the whole group.

Each parameter of the SAM has five options, which range from most positive (1) to most negative (5) feelings. Results from all participants, separated by parameter, are shown in Table I. We can see that Participants #1 and #4 gave the best scores on all parameters, meaning they felt happy, excited, and in control while playing the game. Participant #2 gave neutral scores to all parameters, so she did not feel either too positive nor too negative about playing the game. She was really nervous during the game, so it could explain why she did not report more positive feelings. In turn, Participant #3 felt totally in control, scoring maximum dominance, but was neither excited nor satisfied with the experience. This is probably because she does not like games, and even before playing she said she was not feeling motivated.

4) Debriefing: During the debriefing session, participants reported not having difficulties with the game. Participant #2 said that she was afraid to drop the smartphone (because it is expensive), and that it was kind of heavy to hold for a long time. Participant #1 thought it was easier to memorize sounds (e.g. the roar of a lion) than spoken words (e.g. the name of a city). They all concurred the number of cards was good. Participants #3 and #4 reported they relied more on spatial location than on the coordinates to memorize where the cards were. Participants suggested playing against a partner could be fun. Another suggestion was to use Braille or at least different textures to mark the location of the cards, instead of just the bumps on the pockets.

One researcher asked participants about the length of the feedback, since every time after flipping two cards, the synthesized voice would say "this is not a pair, keep looking". When asked if this was too long, they said it was good, although some of them thought it would be fine if it was shorter, e.g., "this is not a pair", or just a buzzer. Finally, the social worker who was present during the activity said the game is good not only for the visually impaired, but also for people with intellectual impairments. She said the sound calls attention and can stimulate them a lot.

IV. Discussion

To be able to reflect upon our case study and our literature research, we start by summarizing the information from the four categories we established in Section II. Therefore, Table II shows how each literature group treated perception within their games, and how they dealt with differences, i.e., what was their target audience and how they worked for it.

A. *Differences*

Looking at Table II, we can see that, in terms of differences, most related works chose one disability or health problem to focus on, and designed their game around that. One of the exceptions is Raisamo et al. [7], that despite having focused on visual impairments, showed a concern for allowing sighted children to also play the game. To do so, they complement the visual information with other senses (haptic and audio), instead of substituting it. Another exception is Di Loreto et al. [12], who focused on hemiplegic rehabilitation but explicitly with a Universal Design [13] philosophy. This led them to a multimodal approach, i.e., their game was compatible with an array of different controllers so that people with many types of motor disabilities could play. They also made sure the game was interesting for people without disabilities, so they kept it challenging and interesting, instead of focusing only on the rehabilitation aspect. Lastly, Vanden Abeele & Schutter [20] work towards "equality in ease of use", so that their game can be equally fun and challenging for both elders and youngsters. To achieve this, they used the concept of "enactive interaction", i.e., employing the player's previous experience with real-life physical actions. This meant the game had visual virtual elements that elicited or afforded to the player the expected actions. The work of Gerling et al. [16] highlights the importance of using such previous knowledge, since the gestures they designed did not have a direct correlation with real-world actions.

From these three exceptions, we can take an important lesson about dealing with differences in the design of games with natural interaction: there are ways to include as many people as possible. Multimodality of inputs is one alternative, and redundancy of information for several senses (vision, hearing and touch) is another. However, these are mostly solutions for physical disabilities, since they focus on the medium, and not on the information itself. To deal with cognitive difficulties, such as those that might be caused by aging, there is no clear pattern of solution. In particular, two works designed games specifically for older adults. Kawamoto & Martins [9] trusted the technology (Kinect) would be enough to make the interaction more natural for elders. Gerling et al. [16] relied on the same device, but went a bit further by worrying about the gesture design and the theme of the game, making sure it was attractive for the audience. Following a different direction, Vanden Abeele & Schutter [20] designed a game specifically for youngsters and seniors to play together. To achieve this, they based the game actions on real-world activities. In a similar fashion, Sonne & Jensen [17] has the player inhaling or exhaling into a fake tangible version of a pufferfish, to make a virtual fish inflate or deflate. This, in turn, is supposed to help children with ADHD learn breathing exercises.

Hence, the related work we found that deals with cognitive issues does so by mapping game actions close to real-world actions. This points us towards a connection between such mapping and natural interaction, as it had already been argued by Skalski et al. [1]. However, what the authors did not point out [1] – and these works indicate to us – is that inclusion is part of this equation. From the related work we analyzed, those that revolved their design around a specific technology or target audience made little room for including more players. In contrast, works that tried to bring differences together were more successful in making technology an ally instead of a barrier. In the end, we believe this is what constitutes a natural interaction: enabled by technology, for as many people as possible.

In this sense, in our case study presented in Section III, we proposed a memory game that intended to suit players with distinct preferences, backgrounds and game strategies. The four visually impaired people who played the game were able to complete the game, and all felt in control while doing it – even the one who was not entirely motivated by the activity. Furthermore, in the design of our memory game we did not focus on disabilities, i.e., our adaptation was not meant to be exclusive for the visually impaired, for instance. However, we had to consider disabilities players might have, to achieve a design as inclusive as possible.

In this sense, we could push our game design towards a more natural interaction. The most evident issue is that holding the RFID reader (i.e. the smartphone) seemed to cause discomfort and fatigue. In addition, for Participant #1 it was difficult to bring the device to right distance. Hence,

Table II
HOW EACH GROUP WORKED WITH PLAYERS' PERCEPTION AND DIFFERENCES.

GROUP	PERCEPTION	DIFFERENCES
MEMORY GAME	Players have to identify patterns of sound, image or vibration. Input is through buttons, touch, gesture or sound. Rarely there is redundancy between them.	Focus on a specific characteristic: visual impairment or old age. Design strategy is to provide help just for the chosen issues.
HEALTH	Feedback mostly visual. Emphasis on physical rehabilitation, so input is either by gesture, touch or custom control (breath – by Sonne & Jensen [17], bicycle – by Hwang et al. [14] or grips – by Vandermaesen et al. [15]).	Focus on rehabilitation of specific health issues. Aside from Di Loreto et al. [12], there is no concern to include healthy players.
LEARNING	Game has visual representation, even those for the visually impaired. Feedback is either sound, vibration or visual. Input is through gesture or touch. Little concern for redundancy.	Focus on a specific characteristic: visual impairment or old age. Design strategy is to provide learning based on the chosen issues.
ADAPTATION FROM VISUAL INFO	Visual representation substituted by vibration or sound. Input is through buttons or gestures.	Focus on visual impairments. Design strategy is to provide assistive technology through sensory substitution.

we could either use a lighter reader, or eliminate it altogether. In this case, we could have pressable buttons behind the cards. This solution would also make the board more self-contained, and the game more inclusive for players with motor impairments – as long as the buttons do not require much strength to be pushed. However, maintaining the game accessible to people with hearing disabilities, there would have to be some sort of screen on the board, displaying the contents of the card that was flipped, the same way the smartphone does.

B. Perception

In terms of **perception**, we conclude from Table II that the **health** and the **learning** groups usually took some form of exercise – physical or intellectual – from the real world and tried to translate it into a game. In turn, both the **memory game** and the **adaptation from visual information** groups usually focused on translating information from one sense (vision, touch and hearing) into others. In most cases, this went more in the direction of sensory substitution than on providing redundancy. These alignments are probably a reflection of similar intentions between the works from these groups. While the **health** and the **learning** groups aim to turn into fun something that is usually perceived as boring, the **memory game** and the **adaptation from visual information** groups adapt existing games to reach specific audiences.

In our case study, since we made an adaptation to an already existing and well-known game, we tried to preserve as much as possible its original features. We managed to maintain the idea of placing the cards in a grid, while at the same time making it possible for people to run their hands through the cards without taking them out of order – an important feature for the visually impaired. The major change we made, in the name of *differences*, was to create a metaphor for flipping the cards. This was necessary to take the focus away from the visual information, since the idea of the flip is to reveal the image contained on the hidden side of the card. Hence, in our adaptation, players access the cards' contents using an RFID reader.

This device became the medium between the player and the cards, i.e., players did not touch the cards to "flip" them. One advantage of this metaphor was that most of the participants from the case study were already familiar with RFID, so it was not something completely new to them. The only one new to the technology was Participant #4, who had the fastest time, and who gave maximum score for the SAM parameter of dominance, so the device was not a problem to him. In opposition, Participant #1 had already used the device before, and this time had the same past problems of placing the reader at the right distance. Still, he reported maximum feeling of dominance.

Hence, the RFID reader has, to the participants of our case study, an *affordance* of revealing sound information, since that is how they had used it before. However, if we were to eliminate the reader, the affordance would go to the cards, bringing our adaptation closer to the original game. If we place pressable buttons behind the cards to trigger the information, we would still be using a metaphor, but maybe one that reaches people who have never used an RFID reader, and people who cannot hold the device to play. In addition, players would have both hands free. This is important, in particular, for the visually impaired, because they would be able to explore the board faster. However, it could actually benefit all players who would wish, for instance, to mark a specific card's location with one of their hands.

Having both hands free would also address the problem of remembering where are the two matching cards the player needs to remove from the board. In the traditional memory game, after finding a pair, the two cards are removed from the board, either by the player or by the computer (in the virtual version). In our case study, we maintained this idea, but for most of the time it was difficult for participants to remember the location of both cards. Usually, they knew where the last card they scanned was, but not its pair. This constituted a further memory exercise, especially if they found the pair by luck. That is why Participant #3 would either mark a card with her free hand, or take it away from the board. Therefore, if players had both hands free to play, they could, for instance, press one card, keep their hand over that card, and press another card with their other hand, hence keeping track of both "flipped" cards.

C. *Difference and Perception as a Design Strategy*

From the previous discussion, we can say that, from the related work, the **health** and the **learning** groups started from the *differences* and went to deal with *perception*, while the **memory game** and the **adaptation from visual information** groups went from *perception* constraints to dealing with *differences*.

We argue that this relationship can be cyclic. For instance, a game from the **health** group that is mostly rehabilitation for patients (*differences*), is not interesting for people who do not need those exercises. However, if the design also went back the other way around, i.e., considering how this game could be interesting, for instance, for the visually impaired, adaptations would be necessary (*perception*). These adaptations would probably involve providing more forms of input and translating visual information to other senses. This completes a cycle, going from a *differences* to a *perception* point-of-view. Now we argue that this cycle could go on, e.g., from the adaptation arises an issue of teaching the visually impaired a skill necessary to play the game (*differences*). This is important to our goal of natural interaction because it points to a design strategy that depends on both *differences* and *perception*; in fact, it lies in-between them.

For this reason, in our case study, from the very beginning, our design went back and forth. We started with a Universal Design perspective, and chose an existing popular game to apply it. Our rationale behind every design decision for the memory game adaptation was based on how it could accommodate more differences, and what these differences would require in terms of perception. As we presented in Section III, there is still room for improvement for making the game more accessible. Therefore, we propose that the strategy for designing a game that provides both *accessibility* and *natural interaction* should strive to find a balance between accommodating differences between users, and providing multiple channels for the perception of information. Furthermore, such balance is dynamic, i.e., it requires constant transition between the two elements, differences and perception. As we saw from our related work analysis, staying in one extreme leads to a solution that is either too exclusive for one audience, or uninteresting for other people.

V. Conclusion

In this paper we found and analyzed papers that addressed accessibility in games using NUI. Such analysis suggested a focus on disabilities, and sensory substitution as a common strategy to deal with them. From this, we presented our case study, involving visually impaired people and our adaptation of the memory game. Our case study allowed us to put to test a design strategy, where the idea is not to focus on specific differences, as the literature we found did with disabilities. Instead, differences have to be incorporated into the design, as many of them as possible. Therefore, we argue that the design of natural interaction should provide the common ground for differences. But how to do that?

The answer lies in the element of perception, the relationship between person and environment, which is unique to each person. In our case study, we saw how our memory game had distinct affordances for each player. Some devised strategies and tried to beat the game fast, while others just wanted to finish it. Hence, the game was inclusive, not just because it allowed visually impaired people to play it autonomously, but also because it became a common ground for different people.

This two-way relationship brings us to a design strategy, which is actually the coupling between the elements of differences and perception. In our case study, we designed a game that was meant to be played by as many people as possible, and to do so, instead of sensory substitution, we strived for sensory redundancy. We succeeded in terms of translating specific visual information to other senses, but we overlooked the fact that, forcing players to have only one free hand, could hide underlying tactile information. For visually impaired players in particular, this became an issue that did not harm the gameplay, but it did push our design a bit away from the naturalness we were hoping for. Therefore, we saw that to design natural interaction is not just about technology, and it is not just about the person using the technology. It is about what lies in-between, that only exists when the differences and the perception intertwine.

Acknowledgment

This work is supported by FAPESP through grants #2015/16528-0 and #2015/24300-9, by CAPES through grant #01-P-04554/2013 and by CNPq through grants #160911/2015-0 and #306272/2017-2.

References

[1] P. Skalski, R. Tamborini, A. Shelton, M. Buncher, and P. Lindmark, "Mapping the road to fun: Natural video game controllers, presence, and game enjoyment," *New Media & Society*, vol. 13, no. 2, pp. 224–242, 2011.

[2] D. A. Norman, "Natural user interfaces are not natural," *Interactions*, vol. 17, no. 3, pp. 6–10, 2010.

[3] K. O'Hara, R. Harper, H. Mentis, A. Sellen, and A. Taylor, "On the naturalness of touchless: Putting the "interaction" back into nui," *ACM Transactions on Computer-Human Interaction (TOCHI)*, vol. 20, no. 1, p. 5, 2013.

[4] G. Deleuze and P. Patton, *Difference and Repetition*, ser. Continuum Impacts Series. Bloomsbury Academic, 2004.

[5] J. J. Gibson, *The ecological approach to visual perception: classic edition*. Psychology Press, 2014.

[6] F. J. Varela, E. Thompson, and E. Rosch, *The embodied mind: Cognitive science and human experience*. MIT press, 2017.

[7] R. Raisamo, S. Patomäki, M. Hasu, and V. Pasto, "Design and evaluation of a tactile memory game for visually impaired children," *Interacting with Computers*, vol. 19, no. 2, pp. 196–205, Mar. 2007.

[8] V. Delić and N. V. Sedlar, "Stereo presentation and binaural localization in a memory game for the visually impaired," in *Development of Multimodal Interfaces: Active Listening and Synchrony*. Springer, 2010, pp. 354–363.

[9] A. L. S. Kawamoto and V. F. Martins, "A visuospatial memory game for the elderly using gestural interface," in *International Conference on Universal Access in Human-Computer Interaction*. Springer, 2017, pp. 430–443.

[10] P. Winoto and T. Y. Tang, "Sensory substitution to enable the visually impaired to play an affordable wearable mobile game," in *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*, ser. UbiComp/ISWC'15 Adjunct. New York, NY, USA: ACM, 2015, pp. 193–196.

[11] L. Geurts, V. Vanden Abeele, J. Husson, F. Windey, M. Van Overveldt, J.-H. Annema, and S. Desmet, "Digital games for physical therapy: Fulfilling the need for calibration and adaptation," in *Proceedings of the Fifth International Conference on Tangible, Embedded, and Embodied Interaction*, ser. TEI '11. New York, NY, USA: ACM, 2011, pp. 117–124.

[12] I. Di Loreto, B. Lange, A. Seilles, S. Andary, and W. Dyce, "Game design for all: The example of hammer and planks," in *International Conference on Serious Games Development and Applications*. Springer, 2013, pp. 70–75.

[13] R. Mace, G. Hardie, J. Place, N. C. S. U. C. for Accessible Housing, and N. C. S. U. C. for Universal Design, *Accessible Environments: Toward Universal Design*. Center for Accessible Housing, North Carolina State University, 1990.

[14] S. Hwang, A. L. J. Schneider, D. Clarke, A. Macintosh, L. Switzer, D. Fehlings, and T. N. Graham, "How game balancing affects play: Player adaptation in an exergame for children with cerebral palsy," in *Proceedings of the 2017 Conference on Designing Interactive Systems*, ser. DIS '17. New York, NY, USA: ACM, 2017, pp. 699–710.

[15] M. Vandermaesen, T. De Weyer, P. Feys, K. Luyten, and K. Coninx, "Integrating serious games and tangible objects for functional handgrip training: A user study of handly in persons with multiple sclerosis," in *Proceedings of the 2016 ACM Conference on Designing Interactive Systems*, ser. DIS '16. New York, NY, USA: ACM, 2016, pp. 924–935.

[16] K. Gerling, I. Livingston, L. Nacke, and R. Mandryk, "Full-body motion-based game interaction for older adults," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '12. New York, NY, USA: ACM, 2012, pp. 1873–1882.

[17] T. Sonne and M. M. Jensen, "Chillfish: A respiration game for children with adhd," in *Proceedings of the TEI '16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction*, ser. TEI '16. New York, NY, USA: ACM, 2016, pp. 271–278.

[18] J. Sánchez, M. Sáenz, and M. Ripoll, "Usability of a multimodal videogame to improve navigation skills for blind children," in *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. ASSETS '09. New York, NY, USA: ACM, 2009, pp. 35–42.

[19] L. R. Milne, C. L. Bennett, R. E. Ladner, and S. Azenkot, "Brailleplay: Educational smartphone games for blind children," in *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility*, ser. ASSETS '14. New York, NY, USA: ACM, 2014, pp. 137–144.

[20] V. Vanden Abeele and B. Schutter, "Designing intergenerational play via enactive interaction, competition and acceleration," *Personal Ubiquitous Comput.*, vol. 14, no. 5, pp. 425–433, Jul. 2010.

[21] J. S. Bruner, R. R. Olver, P. M. Greenfield *et al.*, *Studies in cognitive growth*. Wiley, 1966.

[22] B. Yuan and E. Folmer, "Blind hero: Enabling guitar hero for the visually impaired," in *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. Assets '08. New York, NY, USA: ACM, 2008, pp. 169–176.

[23] T. Allman, R. K. Dhillon, M. A. Landau, and S. H. Kurniawan, "Rock vibe: Rock band®computer games for people with no or limited vision," in *Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. ASSETS'09. New York, NY, USA: ACM, 2009, pp. 51–58.

[24] T. Morelli, J. Foley, and E. Folmer, "Vi-bowling: a ttactile spatial exergame for individuals with visual impairments," in *Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility*. ACM, 2010, pp. 179–186.

[25] M. M. Bradley and P. J. Lang, "Measuring emotion: the self-assessment manikin and the semantic differential," *Journal of behavior therapy and experimental psychiatry*, vol. 25, no. 1, pp. 49–59, 1994.