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Jaime Miguel Santos Montalvão Carvalho

DISSERTAÇÃO

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Especialização em Sistemas de Informação

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Dissertação orientada pelo Prof. Doutor Luis Manuel Pinto da Rocha Afonso Carriço

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para a minha Mãe.

Resumo

As aplicações de entretenimento móvel têm hoje em dia um papel importante e significativo no mercado de software, abrangendo um grupo variado de utilizadores. Tudo isto se deve ao repentino sucesso de dispositivos de interacção inovadora, como o Wiimote da Nintendo, o Move da Sony e o Kinect da Microsoft. Por sua vez estas técnicas de interacção multimodal têm sido exploradas para jogos móveis. A recente geração de dispositivos móveis vem equipada com uma grande variedade de sensores, para além dos óbvios como ecrã táctil e microfone. Existem ainda outros componentes interessantes como bússola digital, acelerómetros, sensores ópticos. Os dispositivos móveis são também utilizados como máquina fotográfica digital, agenda pessoal, assim como para ver videos e ouvir música, e claro, para jogar jogos. Olhar para os novos grupos de utilizadores e para as novas formas de jogar e incluir nos jogos formas de interacção novas, usando os atributos e potencialidades de novas plataformas e novas tecnologias é pois um assunto pungente e deveras desafiante.

Com este trabalho pretende-se estudar e propor novas dimensões de jogo e interacção com plataformas móveis, sejam smartphones, sejam tablets, que se adequem às mais distintas comunidades de jogadores. Pretende-se sobretudo explorar modalidades alternativas como as baseadas no tacto e vibração, assim como no áudio, combinadas ou não com outras mais tradicionais de foro visual. Almeja-se ainda explorar jogos em grupo, à distância e co-localizados, encontrando e estudando novas formas de expressão em jogos clássicos e jogos inovadores que envolvam pequenos conjuntos de indivíduos. A ubiquidade inerente aos dispositivos móveis faz ainda com que se tenham que encontrar neste jogos de grupo formas de fluxo de jogo que sustentem saídas e entradas rápidas ou menos rápidas sem que ainda assim se perca o interesse e a motivação de jogar.

Este trabalho iniciou-se com uma pesquisa intensiva de trabalho relacionado, sobre a área de jogos móveis e suas multimodalidades, passando consequentemente pela acessibilidade inerente, jogos em grupo e suas formas de comunicação e conexão, e por último dando especial atenção a jogos de puzzle, sendo o tipo de jogo focado neste trabalho. Seguidamente, foi efectuado o levantamento de requisitos e exploradas as opções de jogo e de interacção relativas a jogos de puzzle móveis multimodais.

No âmbito deste estudo foram criados três pequenos jogos sobre um conceito comum: jogos de puzzle. A primeira aplicação contém três modalidades diferentes de jogo: uma visual, apresentando um jogo de puzzle de imagens baseado nos tradicionais; uma segunda auditiva, que recria o conceito de jogo através de música, tornando as peças em pequenas parcelas sonoras da música de tamanhos equivalentes; e a terceira háptica, criando deste modo um puzzle com peças de padrões vibratórios diferentes. A segunda aplicação recriou o mesmo conceito de jogo, puzzle, no modo audio, mas retirando toda a informação visual, apresentando simples formas de interacção. A terceira aplicação apresenta uma abordagem sobre os jogos em grupo, permitindo jogar puzzles visuais e de audio em dois modos distintos: cooperativo, onde os jogadores têm de jogar em equipa de forma a conseguir completar o puzzle; e competitiva, onde os jogadores são forçados a ser mais rápidos que o adversário de modo a poderem vencer. Todas estas aplicações permitem ao utilizador definir o tamanho do puzzle e o nível de dificuldade, assim como escolher as imagens e músicas que pretendem resolver em forma de puzzle.

Foram conduzidos vários testes de utilizador, nomeadamente um para cada aplicação desenvolvida. Sobre a primeira aplicação vinte e quatro participantes jogaram puzzles visuais e auditivos, distribuídos equitativamente pelas modalidades. Deste modo, cada participante resolveu nove puzzles de imagem ou nove puzzles audio distintos. Neste primeiro estudo procurou descobrir-se as estratégias de resolução dos puzzles, procurando principalmente igualdades e diferenças entre os diferentes modos. Para o segundo estudo foi usada a segunda aplicação desenvolvida, e foram abrangidos novamente vinte e quatro utilizadores, doze dos quais sendo cegos. Cada participante resolveu três puzzles audio diferentes. Relativamente a este estudo, foi proposta uma comparação entre os modos estudados anteriormente, especialmente sobre o modo audio, uma vez que foi usado o mesmo procedimento. Para os utilizadores cegos o objectivo foi provar que seria possível criar um jogo divertido, desafiante e sobretudo acessível a partir de um conceito de jogo clássico. Para o último estudo, vinte e quatro participantes, organizados em pares, jogaram puzzles visuais e de audio em modo cooperativo e competitivo. Cada conjunto de participantes resolveu quatro puzzles, um para cada modo de jogo por cada tipo de puzzle, o que significa dois puzzles visuais, um competitivo e outro cooperativo, e dois puzzles audio, sendo também um cooperativo e outro competitivo. O objectivo mais uma vez foi procurar as estratégias de resolução, permitindo também a comparação com outros modos anteriormente estudados.

Todos os jogos foram transformados em dados contendo todas as acções que cada jogador tomou durante a resolução do puzzle. Esses dados foram depois transformados em números específicos de forma a poderem ser analisados e discutidos. Os valores obtidos foram divididos em três grupos principais, as tentativas de colocação de peças, o número de ajudas, e o tempo de conclusão do puzzle. Em relação às tentativas de colocação de peças é possível identificar a ordem correspondente segundo três formas distintas, pela classificação do tipo de peças, pela disposição das peças na fita e pela ordem sequencial do puzzle. Os resultados do estudo mostram que uma mesma estratégia de resolução de puzzles é usada através de todos os modos estudados, os jogadores optam por resolver primeiro as zonas mais relevantes do puzzle, deixando as partes mais abstractas e confundíveis para o final. No entanto, parente novas modalidades de jogo, pequenas percentagens de utilizadores mostraram diferentes estratégias de resolução. Através das opiniões dos utilizadores é também possível afirmar que todas as aplicações desenvolvidas são jogáveis, divertidas e desafiantes. No final foi criado um conjunto de componentes reutilizáveis e um conjunto de parâmetros para a criação de novos jogos.

Numa linha de trabalho futuro foram propostos vários objectivos interessantes que podem promover e reaproveitar o trabalho desenvolvido. Deste modo foi criado um jogo de puzzle baseado na primeira aplicação desenvolvida, mantendo os modos visual e audio, de forma a poder integrar no mercado de aplicações móveis, permitindo deste modo, um estudo em larga escala sobre os mesmos conceitos estudados neste trabalho. Foi também pensada a criação de um servidor centralizado, permitindo conter os resultados de todos os jogadores de forma a criar um ranking geral, podendo deste modo incentivar os jogadores a melhorar o seu desempenho, e ajudar a promover o próprio jogo. Outra alternativa passa por melhorar e aperfeiçoar o modo háptico, de forma a criar mais uma modalidade viável sobre o mesmo conceito de jogo, de forma a poder ser também estudada de forma equivalente. O puzzle para invisuais pode também ser melhorado e aperfeiçoado de forma a criar mais desafios através da inclusão dum modo háptio. E por fim, não menos importante, criar novas dimensões de jogo em grupo, permitindo jogar os modos cooperativo e competitivo em simultâneo, tendo por exemplo duas equipas de dois jogadores cada, a cooperar entre si para completar o puzzle, e de certa forma a competir contra a outra equipa para terminar primeiro e com melhores resultados. O objectivo seria, mais uma vez, estudar as estratégias usadas.

Abstract

Mobile entertainment applications have an important and significant role in the software market, covering a diverse group of users. All this is due to the sudden success of innovative interaction devices such as Nintendo's Wiimote, Sony's Move and Kinect's Microsoft. On the other hand, these multimodal interaction techniques have been explored for mobile games. The latest generation of mobile devices is equipped with a wide variety of sensors, in addition to the obvious such as touch screen and microphone. There are other interesting components such as digital compass, accelerometers and optical sensors. Mobile devices are also used as a digital camera, personal organizer, to watch videos and listen to music, and of course, to play games. Looking for the new users groups and for the new ways to play the games and include new forms of interaction, using the attributes and capabilities of new platforms and new technologies is an issue as poignant and very challenging.

This work aims to study and propose new dimensions of play and interaction with mobile platforms, whether smartphones or tablets, which suit most distinct communities of players. It is intended primarily to explore alternative modalities such as touch-based and vibratory, as well as audio based, combined or not with traditional visual ones. It also aims at exploring group games, spatially distributed and co-located, finding and studying new forms of expression in classic games and innovative games that involve small sets of individuals. The ubiquity inherent to mobile devices leads us to find input and output flows which support rapid or less rapid entry commands, without losing the interest and motivation to play. In addition to the design and implementation of three or four small game applications intended to create a set of reusable components and a set of guidelines for creating new games.

Keywords: multimodal interaction, mobile interaction, mobile devices, games, player community, visually impaired community.

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Chapter 1

Introduction

Playing videogames nowadays is a very common activity, embraced by an increasing number of individuals. This increase and diversification of the target public is due in part not only to a fundamental change in the way of playing, but also in the underlying technology that can be sustained. In fact, in this last context the adoption of online games, the framework games in social networks and its ubiquitous use in mobile devices propelled the emergence of what is known as casual games, simple, interruptible and playable in almost all locations and expanded community players well beyond the traditional group: adolescent and young adult males without disabilities. Looking for new groups of users and for new ways to play these games and including new forms of interaction, using the attributes and capabilities of new platforms and new technologies is therefore a matter quite poignant and challenging.

1.1 Motivation

Mobile entertainment applications reach a wide group of users, and therefore have a very important and significant role in the software market [73]. All this success is due to the inherent innovation on the use of new interaction technologies associated with the latest generation of mobile devices. The newest mobile devices are equipped with a variety of sensors that allows new forms of interaction, such as through gestures, touch or voice, which can be used as input modalities, as for output is possible to use vibration, sound or image, or even try combinations.

The creation of multimodal games for mobile devices triggers an interesting challenge, in order to use most of the functionalities provided by these devices as means of input or output, and to further capture the attention of the user. Existing applications have several gaps as regards the use of multimodalities, since they are carelessly used or even used in excess, causing a lack of information on the user side [93]. An important set of issues are the inclusion and the accessibility. The produced applications are not designed for users with any type of disability, as a result there is long way to go, as in new forms of interaction, in user tests and creating final prototypes that can be used without restrictions. Multimodalities have the potential to overcome some (or all) of this social problems. On the other hand there are multimodalities not yet properly explored in mobile games, leaving open pathways that may be in the future novel forms of interaction, such as location based multiplayer games.

In this line of thinking, it is important to develop new forms of interaction, providing, through multimodalities, new challenges and opportunities to the users. It is possible to include new groups of users, with some kind of disability, due to a non-existence of more focused applications accordingly; they have been excluded from new technologies.

1.2 Objectives

This work aims at studying and proposing new play dimensions and interaction with mobile platforms, whether they are smartphones or tablets, which suit most distinct communities of players. These play dimensions and interactions are simple modifications or new inclusions over the used modalities of a game concept. It is mainly intended to explore alternative interaction modalities such as tactile and vibratory, as well as audio based, combined or not with other more traditional visual modalities. The exploration of an inclusive and accessible game using the mentioned modalities is an important objective. It also aims at exploring group games, remote and co-located, finding and studying new forms of expression in classic and innovative games that involve a small number of individuals. The ubiquity inherent to mobile devices leads us to find input and output flows which support rapid or less rapid entry commands, without losing the interest and motivation to play.

The object of study will be multimodal games on mobile devices. To further focus the type of casual game involved in the process, puzzles have been selected, because they alone represent an interesting challenge and a mental stimulation. Exploring simple puzzles with new modalities offered by mobile devices leads to the creation of something new and innovative.

In the context of puzzle games, our research focused on studying if players use the same type of strategies across different types of multimodal puzzles. In particular we wanted to determine if users tend to prioritize particular puzzle pieces or if they solved the puzzle in the order the pieces are presented to them.

Finally, this research will also produce 3 or 4 small games intended to create a set of reusable components and a set of guidelines for creating new games. Naturally, the developed sets must be validated by appropriate tests in significant numbers (10 to 20 subjects) and preferably during a significant period (2-3 weeks).

1.3 Results and Contributions

To aim at the goal described in the previous section, one must carefully plan and define the main applications to be developed in this work's context. Three main puzzle game applications were developed under a multimodal context, to be described below:

- Multimodal Puzzle Game: a mobile application that allows a user to tackle on visual, audio and haptic puzzle. The visual mode was developed taking inspiration on the traditional paper board jigsaw puzzle games. The audio puzzle game allows a song selection in order to solve it as a puzzle. The haptic mode creates vibratory challenges;
- Simple Audio Puzzle Game: a mobile application that recreates the audio puzzle challenge without visual feedback. This application aims to promote inclusion of people and context situations;
- Multiplayer Puzzle Game: a mobile application that allows two users to play visual and audio puzzle games together as a team or to compete with each other.

These mobile applications enabled the possibility of conducting a series of user trials comprising three experiments. The work developed and the trials' findings resulted in valuable contributions, which showed that:

- It is possible to develop different games with different modalities maintaining the same game concept, being playable, fun and challenging;
- Player's solving strategies are reapplied over different modalities, even when the new modalities are a novelty, but diverse playing approaches are also used to cope with these new modalities' challenges;
- The addition of alternative modalities enabled the creation of enjoyable variants of intrinsically visual games, without the any visual counterpart, that can be used by blind persons;
- Users engaged in cooperative and competitive versions of a classical game finding it playable and challenging, potentially to a new level considering the ubiquity of the platform (mobile devices);
- Solving strategies follow a similar pattern, with interesting performance outcomes.
- Presented important guidelines created for the development of mobile puzzle games using multimodalities.

Since the definition of this project, some of the contributions were validated by the scientific community by presenting and publishing scientific papers on both national and international conferences on information systems, mobile computing, human-computer interaction and videogames.

The list of published papers from this work's author is as follows:

- Jaime Carvalho, Luís Duarte and Luís Carriço (2012). "Puzzle Games: Player Strategies across Different Interaction Modalities", Fun and Games, Toulouse, France, September 2012.
- Jaime Carvalho, Luís Duarte and Luís Carriço (2012). "An Analysis of Player Strategies and Performance in Audio Puzzles", 11th International Conference on Entertainment Computing, Bremen, Germany, September 2012.
- Jaime Carvalho, Tiago Guerreiro, Luís Duarte and Luís Carriço (2012). "Audio-Based Puzzle Gaming for Blind People", 2nd Mobile Accessibility Workshop at MobileHCI 2012, San Francisco, California, USA, September 2012.
- Jaime Carvalho, Luís Duarte, Diogo Marques and Luís Carriço (2012). "Puzzles: Explorando Designs Multimodais", 4th INForum Informatics Symposium, Portugal, Lisbon, September 2012.

1.4 Methodology and Work Plan

On early project stage was crucial to study the related literature according to multimodalities, mobile devices and casual games, in order to follow a conscious route for the applications development, definition of user studies and contributions for the scientific community. After this phase, follows the applications development and the user studies accordingly to each one. For each user experiment was necessary an analysis of the obtained results. The work plan scheduling is represented on Table 1.

Table 1 – Work Plan Scheduling

ID	Task Name	2011			2012								
		Out	*Nov*	*Dez*	*Jan*	*Fev*	*Mar*	*Abr*	*Mai*	*Jun*	*Jul*	*Ago*	*Set*
1	*Search/investigation related work*	■	■	■	■	■	■	■	■	■	■	■	■
2	*Written preliminary report*		■	■									
3	*Application development*			■	■		■	■		■	■		
4	*User study*					■			■			■	
5	*Results analysis*					■			■			■	
6	*Written final report*											■	■

1.5 Document Structure

This report is organized as follows:

- **Chapter 2: Related Work** – This chapter will describe the synthesis of the whole process of research on multimodal games on mobile devices, addressing each theme accordingly.
- **Chapter 3: The Multi-Puzzle Game** – This chapter will explain the needs and challenges involved on the creating of casual puzzle games with multiple modalities and convert them to system's requirements. Will start with the development process definition, moving on to the architecture and initial design, describing the components and their relationship, explaining the game engine and its function and also presenting user-system interaction. First prototypes will be presented in this section, complemented by diagrams that will enlighten the interaction processes. Ending with the final applications, addressing the main challenges of the implementation phase, as well as each application's final interface. We will start by presenting the first developed puzzle game with three possible modes: visual, audio and haptic. Then we will present the audio puzzle application without any visual feedback. Finally, we will discuss the multiplayer puzzle game which provides a cooperative and competitive mode for two players.
- **Chapter 4: System Evaluation** – This chapter will present the evaluation of all the developed applications. The user trials have in average 12 participants. Three different applications were assessed (divided between two distinct modes: image and audio). In total, over 336 games were analyzed in this research.
- **Chapter 5: Discussion** – This chapter will present a discussion for the evaluation of the previous chapter. Will be addressed individually for each experiment accordingly.
- **Chapter 6: Conclusions and Future Work** – This chapter will be divided in two parts: the conclusions obtained from the conducted tests and the future work that might be developed based on these studies.

Chapter 2

Related Work

This chapter will explain briefly the existing gaming industry considered relevant to our research, focusing on new technologies that enable new ways of interacting with games. These multimodalities are present in the newest videogame consoles, and also in modern mobile devices, allowing for richer casual games from an interaction perspective and thus, potentially reaching a wider audience. Being the main subject associated to multimodal mobile games, the related work that we consider relevant to our investigation has been studied and will be explained in the next subchapters. Having regarded the specific theme chosen for this study, puzzle games, there is a single subchapter to address this topic. The related work found on multimodal games considered relevant to our investigation was studied and analyzed, to be presented on correspondent subchapters. Therefore, this chapter is structured incrementally by topics, from the simple to the most complex; it begins by exemplifying games in general, moving on to mobile games, continuing to multimodal games, and then multiplayer games, and finally puzzles in specific.

2.1 Games

Videogames can be used for various ends, ranging from personal entertainment [18][69], as a catalyst for social interaction [68], as a support tool for teaching and learning process [6] or as an experimental platform for new technologies or design concepts [12]. Furthermore, videogames are so versatile at all levels and have a great variety of genres that makes them useful tools for achieving any objective.

The videogame industry became popular in the mid-70s with arcade games. Since then, the videogames industry's momentum has hardly ever faltered, generating revenues of approximately US$9.5 billion in the US in 2007, $11.7 billion in 2008, and $25.1 billion in 2010 (ESA[1] annual report).

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[1] http://www.theesa.com/

Over the 70s Atari game's Pong [86] and Space Invaders [16] were among the first developed arcade video games and became very popular, followed by the Namco's Pac-Man [40]. In the 80s the arcade video game industry had is golden age, increasing significantly the total number of sales of arcade machines during this period, and consequently the profit [96]. In the early part of the decade, home computing rose with the ZX Spectrum in Europe and NEC PC-88 and MSX on Asia. At the end of the decade the first handheld game console system was release: Nintendo Game Boy [15].

The 90s reveal several advancements related with game technology, such as the adoption of CD-based storage and software distribution, the adoption of GUI-based operating systems, such as the series of Amiga OS, Microsoft Windows and Mac OS. Progresses were verified on 3D graphics technology, on CPU speed and over a miniaturization of hardware; were developed mobile phones, which enabled mobile gaming. The emergence of the internet enabled online cooperative and competitive gaming.

Today, the video game industry is populated with new interactive forms of play such as controllers with built-in accelerometers combined with infrared or color detection (Nintendo Wiimote and PlayStation Move) or even motion sense input devices (Microsoft Kinect). Nevertheless, many casual games have been developed for mobile phones and social networking sites and some became popular and successful.

2.2 Mobile Games

In the entertainment domain, and with the proliferation of various types of mobile devices, and adding the growing popularity of mobile games, design issues become increasingly important [23], due to the complexity of the games and the different types of existing devices. There are certain inherent limitations that should be considered such as the screen size, the size of control buttons, memory storage and the mobile context involved. Even so, the same game will be played on different mobile interfaces.

The usage of specific playability heuristics [17][70] is required in order to evaluate video games, because traditional heuristics lack in comprehension and cannot be directly applied [25]. Several studies were conducted on this matter, offering specifically designed heuristics for evaluating mobile games; an example is a model divided in three modules [46], *game usability*, *mobility* and *game play*. The game usability heuristics cover the game controls and interface that can be subdivided in visual design and presented information, navigation arrangement and general controls, feedback and help. Mobility is defined by how easily is to enter the game and how it behaves in diverse and unexpected environments. Finally game play heuristics are focused on the game performance, goals and players behavior.

Regarding performance in games, there are works relating with other heuristics it trough data emerging from physiological status [20][21]. The authors assess the emotional status of users, correlated with user experience and fun, through sensors and propose interaction patterns, which improve users' performance, engagement and enjoyment. These interaction patterns may be materialized in bonuses, for positive performance impacts, or feedback overload, for negative, and how they change the users' experience, the users' behavior and overall the ultimate playability and challenge [22], or as commonly stated, game flow [14].

Mobile game development is also used as a motivational tool [49] to engage students early in the curriculum. In the aforementioned study some important areas were discussed, namely programming on mobile devices and related limitations such as the small screens, limited CPU and battery power in order to understand their significant impact on game development. Computer graphics, human computer interaction and multimedia are also important topics [88], to make the user experience more interesting. Data structures, algorithms and database management are important issues in order to handle and store the game data [89]. Computer networking and software engineering [13][27] are regarded as advanced subjects. Finally the usage of artificial intelligence [95] is interesting because it reveals challenges for single player games, providing different difficulty levels appropriate to each player capabilities and characteristics.

Gaea [11] is an example of a persuasive location-based multiplayer mobile game to encourage pro-environmental behaviors. This game tries to reflect the real recycling process, proposing people to recycle virtual objects within a geographical area, forcing players to move around and physically go to the coordinates indicated in their mobile phones, and collect the virtual garbage; this needs to be placed into the right virtual recycle bin, so the players should bring it near to the public display that will present the several possible answers. The players are rewarded with points when they choose the correct recycle bin, and are informed about recycling facts regarding that object. After the play area is clean, a quiz starts on the public display with questions about recycling topics; the users are then prompted to use their mobile devices to answer those questions, by selecting one of three possible answers, and earn extra points. This application was evaluated under two equal tests with different groups, first a small-scale event and then a large-scale one. The users were presented with questionnaires in order to classify the application according to several aspects (fun, pleasure, usefulness, among others). The results from these tests were positive, regarding game play and persuasive ability. In conclusion, *Gaea* promotes social interaction between users and members of the audience, and allows disclosure of information to a larger group of people, also can help to shape people's attitudes and behaviors towards a better environmental conscience.

SciMyst [80] is another pervasive mobile game that extends a virtual game world into the real world environment. The main goal is to bring together the technology of the mobile phones with people by making them play and learn about the environment surrounding them. The game is composed by enigmas divided in questions or tasks to be solved during the game; there are three different types of enigmas: *Multiple choice*, *Take a picture*, and *Find a picture*. There are two game modes to choose, *Casual*, where we can explore and enjoy the environment in a free and relaxed manner, and the *Battle* mode consisting of a set of random enigmas and a timer; points are earn by the number of correct enigmas solved in a fixed amount of time. At the end of the game a simple survey most be answered in order to understand what was more important to the player; curiosity, challenge, personal control and fantasy. A research was preformed focused on identifying the elements that are important in a pervasive playful application that can trigger the interest of different individuals towards the reflection and understanding of the knowledge surrounding them. The results suggests that a common environment as a playground encourage social interaction between players; playing at the same time, teaming up with their friends and family to solve the enigmas together. The main elements for finishing the game were curiosity followed by challenge.

Playing mobile games has several implications as in terms of the physical context surrounding the user, as much as in the manner of use and how the information is presented. All of these variables imply several possible scenarios where the application must always be prepared, since the user may be in motion at any time or for some reason want to quickly end the game. In order to evaluate our game application we can use heuristics such as game usability, playability and mobility, enriching them with difficulty, challenge and fun [18][57][87].

2.3 Multimodal Games

Videogames are currently widespread across different platforms [12][68][80]. Furthermore, given the increased computational power [47] and the number of features present in modern mobile devices, developers are recurring to different modalities [64][73][75] to provide players with alternative challenges which would not have been possible before [32]. These mobile devices, especially those having touch screens, are becoming increasingly popular, and are being designed with daily use intention. Audio and haptic feedbacks are predominant features in mobile devices, and recent studies [8][33][51][71][91] indicate that this feedback can be beneficial to users, increasing typing speed and reducing errors.

New modalities for both input and output are becoming more creative and innovative, providing new experiences for users. Researchers have begun assessing opportunities for using speech recognition in mobile games [101]. This study demonstrates several possible interactions through voice for some games for mobile devices, where the user can perform specific actions by issuing speech commands. The future goal is to get the speech recognition for multiplayer online games.

Another form of innovative input shows that the built-in digital compass is not solely used to point north. Ketabdar's study [41] presented a new approach that simulates playing music on mobile device with gestures, allowing interaction with music and audio applications through usage of an external magnet, moving it around the mobile device, using all the physical space possible, thus causing the changing of magnetic field. The change in the magnetic field is sensed by the magnetic compass sensor embedded on the mobile device. Several music applications were developed based on the proposed method for mobile devices. With these bundled applications and the use of a magnet on the fingers it is possible to play guitar with a gripping device in hand and making realistic movements with the other hand that has the magnet. It is also possible to play other instruments such as drums or xylophone, or even try other modes of instrumental interaction especial created to take advantage of this new interaction modality.

Another modality example that has been explored was the camera-based input to capture user movements [9]. In this study a mobile maze game was developed, based on the traditional game where the players have to control a ball through a physical maze by moving it. The game has several levels of complexity and has been tested through the completion time of the labyrinth. The evaluation consists of comparing user input with camera to traditional keypad input.

One game type which still lacks proper support is puzzle games. There are a few examples of puzzle games which go beyond the visual version [18], but they are either too simplistic, or are yet to explore the full potential of modern smartphones to provide players with adequate challenges, specifically with puzzle representations which go beyond the traditional figure jigsaw puzzle. This example will be addressed on puzzle games section.

There are several modalities available and ready to be used in order to create innovative games, also creating new challenges for users. The applications must be built carefully to not overload users with too much confusing information at the same time.

2.3.1 Accessibility

Casual mobile games can be improved with multimodal features, promoting accessibility for impaired people and for contextually debilitating situations. According to Oviatt's study [67], about 95% of users prefer multimodal interaction over a single mode interaction. Furthermore, using a higher number of modalities can enhance the vocabulary of symbols available, leading to an increased accessibility [65].

There are studies based on non-visual interfaces in mobile phones for games [93] that aim at enabling visually-impaired people to play on mobile devices by designing games that fit both sighted and non-sighted audiences. Therefore, games with multimodal feedback are important in order to fully integrate a player without the need for visual feedback. *The Audio Flashlight* [93] is a game of treasure hunt which uses mainly sound, where the game goal is to navigate through a maze until find the objective represented with musical patterns, volume and rhythm variations, involving the player in proper context, but also uses vibration in certain aspects, such as obstacles. The player can interact with the system through simple and intuitive gestures, in the form of moving forward, backward, right and left. The evaluation of the game had positive results where important information has been achieved, such as the fact of not overloading the user with a lot of audio and vibratory information cues at the same time for extended periods, taking the risk of confusing the user. Another important aspect is the critical context required for a game that is dependent on audio modality.

Other existing game examples that allows the creation and re-creation of different beats through different sound pieces [43][29] have an interesting goal of implementing a game design that allows visually impaired and sighted users to play the game in the same way, with the same level of challenge, and share a common gaming experience. *TapBeats* [43] is an accessible and mobile casual game which presented an interesting menu concept designed for touch screen interaction that allows visually impaired and sighted users to select their game options. To explore the menus and the available options, the user can swipe their finger over the screen. As a finger touches a menu item, the phone will speak out the correspondent option and will vibrate. Once the user hears the desired item, a double tap anywhere on the screen will select it. To return to a previous menu, the user can swipe with two fingers anywhere on the screen. This gesture also can pause the game. Finally, if the user wants to know in which menu they are currently on, they can double tap with two fingers.

More recently, but outside from a mobile context, other focus has been in promoting physical activity through games for individuals with visual impairments: *Vi-Tennis* [60] and *Vi-Bowling* [61] use only tactile and audio modalities on Wiimote to promote engagement on the game. The studies show that it is possible to create games intended to promote physical activity on visual impairment individuals and that their results were improved over time with practice and experience. Another area of interest is music and rhythm, because they are particularly suitable for blind people, perfectly capable of perceiving audio signals. As an example, there is a game that allows blind people to play Guitar Hero: The *Blind-Hero* [99], Yuan et al. uses a haptic glove that provides the user with the needed feedback to know when to press a button, which button in particular and how long to hold, using a simple set of unique vibration pattern that starts a quarter of a second sooner than on the game, and vibrates on the correspondent finger and lasts the length of each note. By using this glove while holding the guitar it is possible for a blind person to play Guitar-Hero. These game examples can be converted in mobile games since the most recent smartphones have the necessary capabilities.

Other study [24] presents a design discussion on the main issues of graphical and sound-based interfaces for partially sighted and blind children. In visual games two main concerns were highlighted: the importance of object shapes, so they can be more easily distinguished, and the used colors, which must be carefully chosen in order to highlight objects and prevent confusions. For sound-based games the main concern relied on the fact that sounds do not have the same information that an image possesses. The sounds must be carefully selected and placed on the game, being careful to not overload the user with too much sound information. Other enhanced aspects are the sound positioning, to simulate height and depth, and the use of sound effects in especial situations or icons.

Other accessibility problem in a mobile context, beyond promote solutions for impaired people, is contextual debilitating situations. Every once in awhile all people are situationally impaired [81]. Some examples are sun blindness over the phone screen, interacting while wearing gloves in a cold weather or driving, among others. These scenarios as well as in the case of individual disabilities give space for different interaction modalities. These are likely to be able to cope with a wider range of abilities and scenarios thus promoting inclusion [30][37][78][79][98] by using determined single and multi finger gestures such as flicking, rotating, and pinching [97], combining with speech or audio feedback describing items or options. These works presented studies on blind accessibility for touch screens but they can easily serve sighted people in eyes-free situations as well [38].

2.4 Multiplayer Games

Currently, many digital games are multiplayer or offer this functionality, and are often considered more interesting and challenging than just single player games, because there is an active interaction between the players causing a higher interest, and therefore increases the time spent in the game [47]. When evaluating the playability or even designing multiplayer games, we need to consider player to player interaction. Some studies [47] present some important guidelines and concepts to take in consideration when evaluating or designing multiplayer games: the main concerns are the visibility and communication with other players and the network latency.

Real Tournament [59] is an augmented reality multiplayer mobile game, combining real world and virtual reality components. The game uses each player physical location, orientation and player status, to become key factors in the game play. In order to obtain this context, the player's mobile device was augmented with an array of sensors, including a GPS device and an electronic compass, also uses a Mobile IPv6 enabled wireless network to share game state in real-time between players. This work was developed in 2003 and, at that time, mobile devices lacked on these features, leading to the necessity of augmenting them with special sensors. The aim of the game was to work with your team mates in order to capture as many virtual monsters as possible during a game session. Playing this game requires a wireless network infrastructure, Mobile IPv6-enabled on client devices, access routers, gateway router and authentication server.

It is possible to play *Gaea* [11] on teams' mode, where users must choose one of the three available teams, one for each type of waste: paper, plastic/metal and glass. Becoming a group cooperating towards a common goal, and a competitive social activity, where the individual points are summed to obtain the final score of each team, winning the one who has more points.

Collaborative Puzzle Game [3] is an example of a puzzle game over an interactive table designed to promote collaboration in children with autism spectrum disorders. This example will be addressed on the puzzle game section.

2.4.1 Communication

In Multiplayer games one of the main concerns is the communication. Regarding game play and objectives there are several communication options to consider. The game features can influence the selection for the best and most suitable communication option available. Overcome this barrier the synchronization must be addressed in order to provide a correct visibility. Finally, the network latency must be taken in consideration in order to prevent undesired situations.

Some studies defend the usage of a module to reduce the inconsistent views in multiplayer mobile games [42] created by communication delays across the network, which are even more crucial when playing via a 3G network. The authors propose a solution called synchronization medium, a separate module which is responsible for communication as well as consistency maintenance. The advantage is the possibility to be reused many times by different applications, with a specific synchronization algorithm. This also improves programmers and developers concentration, because separating the synchronization concern from the game logic, and putting it in a communication component, leaves behind the synchronization issues of the game.

Fun in Numbers [1] is a proposed framework for developing pervasive applications for entertainment and educational purposes, using ad hoc mobile wireless sensor network as a connection solution to multiplayer games. This framework allows faster prototyping of applications that require input from multiple sensors, by offering a set of programming templates and services, such as topology discovery, localization and synchronization. Several games were developed and implemented under this framework, supporting location aware services, demonstrating real time player interaction and delay tolerant networking, some have context aware services, and others requires input related to the players' motion and relative distance.

Other study presents a form to use Bluetooth for mobile multiplayer games, when the goal is player's proximity [50]. They used MUPE, an Open Source application platform for creating mobile multiplayer context aware applications. Bluetooth is used to detect other players nearby and as a communication channel. They design and implemented Sandman game, where every player has the power to put others to sleep and is played by two teams. The objective of a team is to put all the players in the opposing team to sleep. In this game two strategies where find; one is to avoid other players and wait till most of them have fallen to asleep; other would be that a player actively tries to find a big concentration of other team players and then puts all of them to sleep. The authors also reveal that age of the players is a big factor, causing different forms of play.

Mobile multiplayer games are innovative and simultaneously challenging since they promote the interaction between players, allowing cooperative or competitive game modes. The choice of the communication between devices must be carefully chosen, regarding to the intended type of interaction.

2.5 Puzzle Games

Puzzle is the term used to define games consisting of a problem or enigma that aims to test the player's ability to solve it, providing pleasant moments while playing and giving satisfaction to achieve the desired resolution. The most basic puzzles are aimed at handling and/or union of parts in a logical manner in order to find the solution; these are often created as a form of entertainment, but also can result from mathematical or logistical problems, making its successful resolution of a significant contribution to mathematical research. From this definition we automatically think in traditional cardboard puzzles, where several pieces with different shapes come together to form an image, but this definition is more comprehensive, embracing different types of puzzles.

Many believe that the *n-puzzle* was invented by Sam Lloyd around 1870 [55], when in fact, Noyes Palmer Chapman is credited with his invention, as shown in Slocum and Sonneveld [84], which documents the history of this puzzle. This puzzle made its first appearance in the scientific literature in 1879 [35]. The 8-puzzle was then discussed in Doran and Michie [19]. The game is played on a grid $m \times m$ (which can also be played on a grid $m \times n$); within the grid are n square tiles, such that $m^2 - 1 = n$, each of which has a unique number between 1 and n; thus, one of the squares on the grid is always empty, which is called "white", and depending on their position, "white" has two, three or four adjacent tiles; a movement of one of these tiles placed in the position of the "white" and relocates the blank space to the previous position of the tile moved; similarly one can also assume that the motion belongs to the "white" space. At the beginning of the game, the tiles are placed in a random configuration, and the objective is to rearrange the squares in ascending order from the upper left corner, just as we read and write. Korf [44] gives an excellent overview of the problem *n-puzzle*, with particular reference to the 8, 15 and 24-puzzle. Over time this puzzle in particular was getting increasingly popular since it began to use images for the tiles, instead of numbers.

Sudoku is a numerical puzzle, played on a grid $n^2 \times n^2$ which is divided into equal segments $n \times n$. To start the game some squares are filled with a number between 1 and n^2, the aim being to fill the entire game grid with numbers so that each column, row and segment contains the numbers 1 to n^2 without repetitions [63]. *Cross Sum*, also known as *Kakuro* is also a numerical puzzle consisting of a table $m \times n$, with black and white squares; white squares form rows and columns with two or more adjacent squares; each row and column is indicated with a number on a black square, representing the respective sum; the aim is to place a digit between 1 and 9 in each of the white squares to yield the correspondent indicated sum, but is not possible to repeat any number of each sum [90].

There are many examples of puzzles created on tables with rows and columns, *Light Up* is a good example played on a grid $m \times n$ composed of black and white squares; the action of clicking on a white square put a lamp on it; the black squares have a number of 0 to 4, representing the number of lamps to be placed directly next to this square, vertically or horizontally; a lamp illuminates the row and column corresponding to its placement in the four directions, until reaching the limit of the playing area or until a black square; the aim is to illuminate all the white squares, without two lamps light up with each other [66]. *Clickomania* is also played on a table with c columns and l lines; the table is initially populated with squares of k different colors; groups are formed with squares of the same color, when its edges are in contact; a movement deletes a group containing at least 2 squares; the squares are continuously pulled down until they touch the bottom of the table or on another square, and the gaps created by deleting a group are filled with the squares that are on top; when the squares of a column are all erased, the squares on the left and right side join together to fill the space; the game starts with the table completely filled, meaning, there are square in all positions; the objective is to remove all the squares [5].

There are puzzles that were originally created in a physical form and only later introduced into the digital world, such as *Mastermind* is a game to be conventionally played by two players, where a person establishes a problem and another tries to find the solution, however can be easily transformed into a single player game, where the computer creates the problem and provides the necessary and relevant information; after being created the secret set of 4 colors, among the possible 8, the player has a limited number of attempts to deduce the correct color sequence [36][4]. Other example is *Rubik's Cube* that was invented in 1974 by Erno Rubik; the original puzzle is composed by cube divided in $3 \times 3 \times 3$, where the nine squares of each face share the same color; when the hub is correctly oriented, all the squares of the same face containing the same color, and all faces of the cube have their own color; each plane $3 \times 3 \times 1$ of the hub can rotate independently of the rest of the cube; initially, the cube has 6 faces of their own color, but with just a few movements is possible to distort this configuration in order to mix all the colors; the challenge is to manipulate the hub to restore its original shape [44][45].

There are also popular examples of digital nature, such as *Rush Hour*, created by Nob Yoshigahara, and it is played on a 6×6 grid, where exists a number of cars with different sizes, and one of them being what we have to maneuver out of the grid, through the only exit; the cars take a size in between 2 to 3 squares and only can move back and forward, but not sideways; the objective is to move the cars in such a way that our car (usually red) can be directed to the exit [26][82]. *Minesweeper* is a popular computer game that usually comes with the Microsoft operating system; it is played on a grid of $m \times n$ squares, where the content is initially hidden, where X mines were randomly distributed; clicking on a square reveals its content, can be a mine, or can be a number between 1 and 8, which corresponds to the number of adjacent mines in any direction; if a square does not contain a mine or is near a mine, then displays a blank square, as well as other adjacent white squares, until they are disclosed square with numbers; the game ends when in defeat, when a mine is revealed, or ends in victory, when all squares are revealed that do not contain mines; therefore the goal is to reveal all the safe squares, and let hidden all mine squares [10][74]. Other example is *Tetris*, a popular computer game played on a grid of $m \times n$, where pieces that are created through a combination of 4 solid squares, go falling from the top of the grid until they touch the bottom or other solid; while the pieces are falling, it is possible to move them to the right or left, or to rotate them; when are created a line consisting of solid pieces, it is erased from the grid, and all that is above falls down a line; lose the game happens when the pile of pieces reaches the top; rising level also increases the speed of descent pieces; the name of the game, *Tetris*, means eliminating simultaneously 4 consecutive lines [83][100]. This game has a different purpose from all other previously presented; there is not a state of final solution, but to achieve the best possible score as well as higher levels.

In the education domain, to be able to reach all students through different learning styles, it is important to incorporate multiple teaching techniques. One such technique is the use of puzzles and games to reinforce learning objectives [31], and this is particular important for students to develop learning skills which allow them to easily create abstractions of concepts or algorithms, obtain benefits through strategic thinking, develop creativity and problem solving skills, and also provides motivational value, creating interest for problem solving [54]. In particular, puzzle games have yielded positive results in such learning process. There are various examples of the usage of puzzle games in distinct areas. There are various examples of the usage of puzzle games in distinct areas, such as Mitchell [58] that has advocated the use of puzzles and games to introduce computing courses, many specific examples on this subject can be found in the work of Ginat [28] and Hill [31]. Huang [34] described their experiences in using games in various teaching situations. Ross [76] shared his experience using three popular puzzles junior level in Java courses. Levitin [52][54] discovered puzzles that illustrate all the major algorithms design techniques of a new taxonomy.

Collaborative example: In another study the design and evaluation of the *Collaborative Puzzle Game* [3] was presented as an interactive table designed to promote collaboration in children with autism spectrum disorders. This application was developed based on the original cardboard puzzles, but is designed to be played by two players simultaneously, on a big horizontal screen to allow a modality of interaction similar to other recreational activities that occur on tables. The task, as in the traditional game, is to assembly an image from a variable number of pieces, which are digital on-screen objects that can be moved by direct contact and drag. A set of special rules were created to promote collaboration, forcing users to take actions together on the digital pieces, while avoiding or nullifying the effect of individual actions. The graphical elements of the interface consists of a variable number of rectangular puzzle pieces, that at the beginning of the game are spread on the surface at random positions, a target image is displayed at the top of the screen, showing how the puzzle looks like when completed properly, and finally a solution area, positioned near the users and centered horizontally, where the pieces must be dragged and dropped to complete the puzzle. The solution area is comprised by a rectangle with a dark edge and is divided into an equal number of visible cells, corresponding to the positions in which the pieces can be placed. The movements that the players can perform are simple and clear: each piece can be dragged to a new position, either in solution area or away from it; whenever a piece is dropped into the solution area is anchored to the cell closest to the release zone; it is possible to take a piece from the solution area using the same technique. Several animations have been implemented to make the game more exciting and fun, and sounds were used to indicate actions and provide positive and negative feedback, were based on studies of their effectiveness for collaborative interfaces [62][85], and its appropriateness for the population study was verified during the pilot tests. Two studies were conducted to test whether forced collaboration has the potential to serve as a paradigm of interaction that would promote collaborative skills. The first study involved 70 children with normal development, and the second study involved 16 children with autism spectrum disorders. The results show that the special rules created had a positive effect on the collaboration, although it appears to be associated with a complex interaction. For children with autism to interact with the forced collaboration is associated with increased movements reflecting negotiation and coordination of shared activities, which may reflect the real difficulty in social interaction common in these children.

Multimodal example: *Audio Puzzler* [18] is a casual puzzle that uses audio excerpts as puzzle pieces, containing actual speech, taken from short videos. Players must first transcribe what they hear and then join the audio clips to complete the puzzle. This game was designed to be fun and enjoyable to play, while producing significant textual transcripts of the audio speech used. This method of reformulating the task in the form of a game, in order to get the job done while people play is known as “Human Computation” and has been successfully applied in areas such as labeling images [92] and music [94]. This game was created in Flash to be played online; here, players aim at assembling parts as quickly and accurately as possible. The interface allows through a double click on each piece to access a text box allowing to write the words that are heard, and access to audio control buttons for each piece. After the text inserted pieces can be dragged onto another, connecting them, getting text highlighted in green or red depending on the matching words. Each audio puzzle is divided into three levels of increasing difficulty, together with a countdown clock that starts on three minutes. The scoring system in Audio Puzzler is designed to promote rapid resolution of the puzzle and make the game more challenging, providing a sense of time pressure. The system was evaluated through a user study on the amusement achieved by aspects of the game and its usability, but was also analyzed the accuracy of the transcripts generated while playing the game. The authors reached to the conclusion that the use of games-based approaches to the creation of transcripts is effective, challenging and fun for users. The players found the puzzle aspect engaging, but parameters and duration of the challenge need to be adjusted. Although the choice of content affects the meaningful and entertaining experience of the game, there is an enormous variety in each individual player choice, but with enough content to Audio Puzzler could appeal to a wide range of people over the internet.

All these examples are elucidative of the importance of games in general, and in particular puzzle games, for a diversity of domains, improving aspects of people's lives. The *Audio Puzzler* [18] may serve as an example of a multimodal puzzle game, regarding audio speeches in order to arrange and transcribe them. Our aim is to create a similar concept game for mobile devices, allowing users to play with songs or any other sounds and providing a reusable structure to tackle any other modality, such as haptics. Complementing these goals, it may be possible to develop an accessible puzzle game for visually-impaired people. *Collaborative Puzzle Game* [3] has an interesting adaptation approach of the traditional figure jigsaw puzzle.

2.6 Summary

The videogame industry is very important and is on constant evolution. Mobile games are a small part of this gaming world, but are growing and reaching different groups of people. Mobile devices are equipped with several important features providing the needed tools for developing applications, including games. These features enable the possibility of including multimodalities in our game applications, such as vibration, sound, touch and gestures, among others. The use of multimodalities can promote accessibility not only for people but also on special context situations that can be debilitating. Over a multiplayer game context, mobile devices can offer several wireless connection options, from low-range to high range, but the correct choice relies on each game interactive objective between players – if the game objective is to promote physical interaction, a low-range connection must be selected. In terms of puzzle games, almost every example has a square matrix for a solving area (the game board) and a mathematical relation – the user must use mathematical knowledge in order to solve an enigma. Puzzle games examples in multimodal formats were hardly found, most of them are do not take advantage of mobile devices features.

Chapter 3

The Multi-Puzzle Game

The system development and implementation was based on the research analysis previously presented and also taking in consideration the casual games guidelines. Casual games should be easy to play, with simple rules and interfaces [48] as well as discrete and easily interrupted. Casual video games are fun and enormously popular, and proved to change player's physical state consistent with increasing mood and decreasing stress [77].

With the aim of exploring multimodal concepts using the same classic game, some issues must be taken in consideration. First of all, the transformation of a physical classic game on a functional mobile video game is not trivial. The mobile aspect has some limitations, such as the screen size, processing power, and causing situational impairments. For the multimodal exploration in a classic game it is necessary to switch and/or insert specific characteristics, maintaining the game concept, using different modalities. These questions and the chosen options will be explained in this chapter.

3.1 Development Process

A cyclic process had to be selected for the development of this project. Spiral and Waterfall Process Models [7] were considered as possible choices for the development process, but the fact that they produce new prototypes each iteration led to a search for a model that reuses or adapts the developed prototypes from earlier iterations. The Evolutionary Prototyping Model was chosen as the development process [56], because of its important features allowing the development of several required applications and the fact that users became an important and involving part of the process. Project characteristics also combine with this model: in principle the system should not achieve a high level of complexity; the game requirements should not be changed; and user involvement will deliver evaluation tests and valuable feedback. This model is characterized for building robust and functional prototypes in the early system development process, by constantly adapting them to users' needs. The process diagram can be seen on Figure 1.

The process is usually applied to human-computer interface systems. As new functional requirements are always appearing, only well known functionalities are implemented and then refined according to tests' analysis and feedback from users. With this process a functional version of the system is quickly implemented. As system functionalities are refined, new versions are properly tested in order to check the requirements. In the end, the final product is comprised of several prototypes, which are fully integrated for the final release.

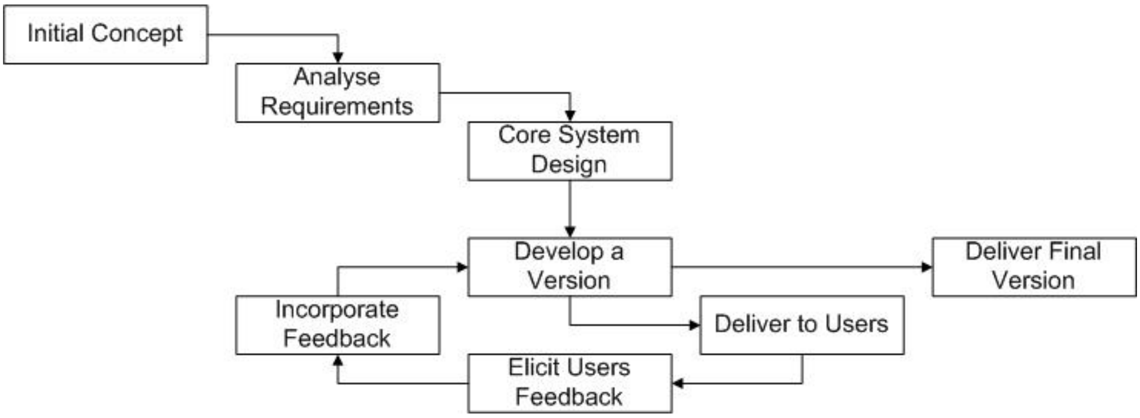

Figure 1 – Evolutionary Prototyping Model (adapted from [56])

This project process starts with the concept of a classic puzzle idea, in order to explore multimodal concepts. Several application prototypes versions were developed, taking into account the different modalities. The entire project was developed using Eclipse[2] under Java Android[3] programming language, and is intended to be used on Android platforms, such as smartphones and tablets.

3.2 Requirements Analysis

The first step of requirement analysis stage is the definition of the system actors. Only one actor was identified for the puzzle game application:

- **Player:** the person who sets the game properties and solves the puzzle while playing the game.

To create a playable application equivalent to traditional puzzle games, all features must be maintained and somehow recreated:

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[2] http://www.eclipse.org/

[3] http://www.android.com/

- The user must have access to the final solution of the game, in order to know what to assemble.
- The user must have access to all of the puzzle pieces.
- The user must have access as well to the content of each piece.
- He/she should be able to place the pieces on the solving area.
- The user should be able to solve the puzzle in any order.
- Allowing the user to choose the size of the puzzle is also an important attribute to consider.
- The game should be fun, playable and challenging.

Our goal is to focus on mobile devices and explore inherent multimodalities. We presented some important requirements for mobile devices and necessary modalities:

- Using the suitable forms of interaction available regarding the capabilities and limitations of mobile devices (such as size).
- Explore mobile context situations.
- Explore multimodalities, such as audio, haptic and also available censors and actuators.
- Exploring group gaming modalities, such as collaboration and competition.

When doing large puzzles at home, usually we scatter all the pieces over the table, or even on the floor. On mobile devices, despite their screen sizes, they will never be larger as our tables at home (not even mention the floor size). Solving puzzles on mobile devices becomes a problem due to the available screen space. The maximum size value possible for a puzzle most be defined according to the screen size of each smartphone.

The use cases are used to capture system’s functional requirements. A use case covers one or more scenarios, showing the system-user interaction to accomplish a determined goal. Use cases tend to avoid technical details concerning the system implementation, preferring synthetic definitions of the process.

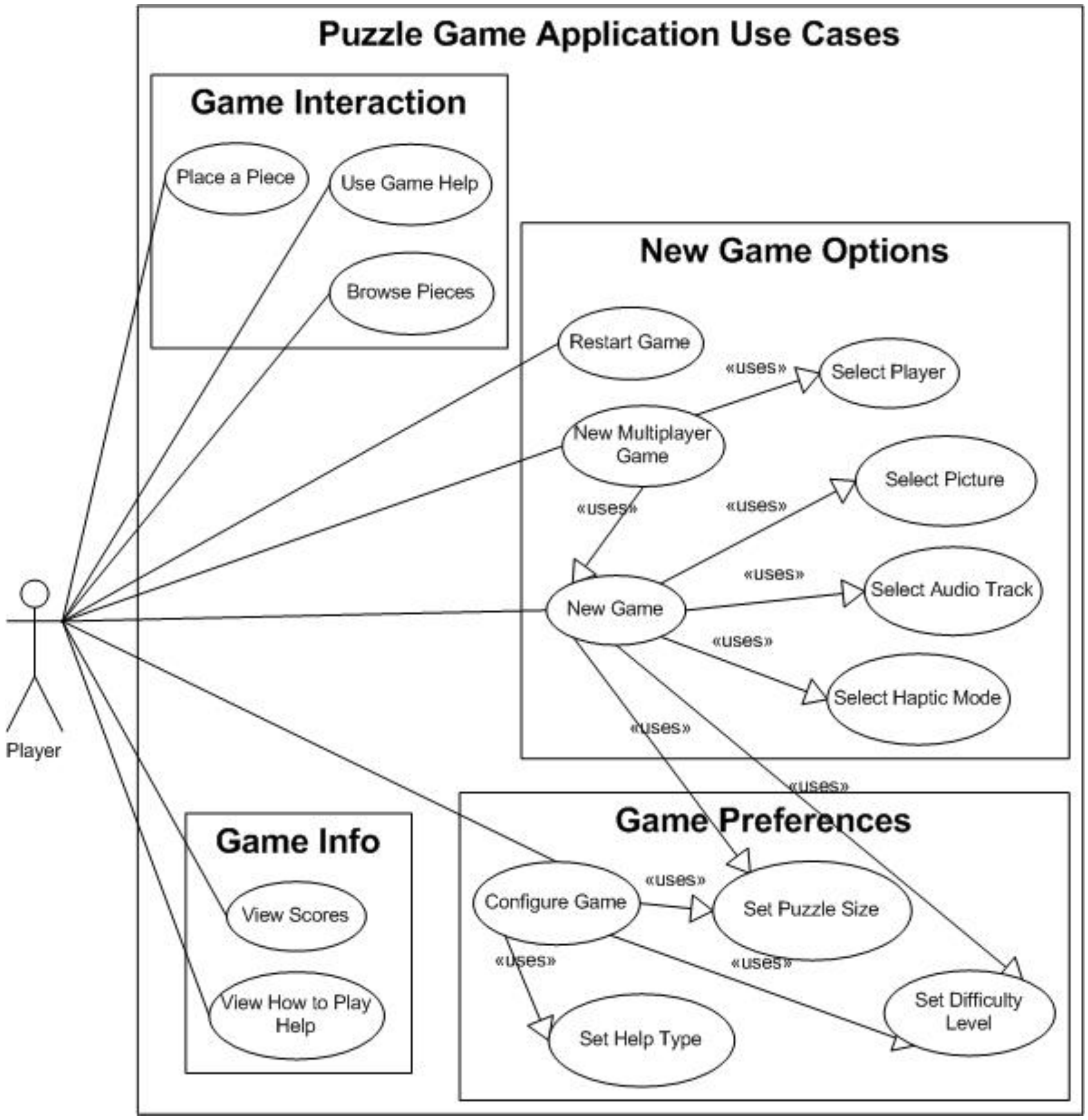

Figure 2 – Use Cases

We will present the use cases of the puzzle game application in a single diagram display on Figure 2, as well as brief presentation of each identified use cases in the following section:

- **Place a Piece:** in this use case, the goal is to allow the user to place a piece on the game board, in order to complete the puzzle. At the end of this action the user will be informed of the correct or incorrect state of the piece regarding the chosen position.
- **Use Game Help:** in order to complete the puzzle, the user must know the puzzle goal. This use case represents the action that enables the game help.
- **Browse Pieces:** allows the user to navigate through all the pieces and access their contents.

- **New Game:** this important action allows the user to create a new puzzle game. The user can select one of the different play modes and configure them as well.
- **Select Picture:** allowing the user to select a preloaded visual game or to select an image or a picture from their own smartphone library and use them in order to play as a puzzle game.
- **Select Audio Track:** allowing the user to select a preloaded audio game or to select a song from their own smartphone library and use them in order to play as a puzzle game.
- **Select Haptic Mode:** allowing the user to select a randomly haptic game in one of the three available modes, single vibration, multi vibration and Morse code, in order to play as a puzzle game.
- **Restart Game:** upon the selection of this feature at any moment the user became able to restart the current game.
- **New Multiplayer Game:** this action allows the user to play a multiplayer puzzle game with another player. The user can choose the game mode between cooperative and competitive.
- **Select Player:** allowing the user to select a player to tackle in a multiplayer puzzle game.
- **Configure Game:** this important use case allows the user to configure the game options, such as size, difficulty and help type, in order to provide new and unique challenges.
- **Set Help Type:** this use case allows the user to change his help type from global to individual and vise-versa, at any moment on the game.
- **Set Difficulty Level:** the goal of this use case is to create harder or easer puzzles to solve. The user can define the difficulty level most appropriate for their skills.
- **Set Puzzle Size:** in order to provide some control over the game set up for each user is possible to select the puzzle size. The bigger the puzzle more difficult it is. The maximum puzzle size is calculated by the size of the screen.
- **View Scores:** the user can view the top five scores of each puzzle type as well as the total score achieved until that moment.
- **View How to Play Help:** in order to learn how to play and always present on this option from the menu, is a simple explanatory text for the game knowhow.

3.3 Architecture

In this chapter a representation of the game system flow engine will be presented, as well as the system overview and the multiplayer connection interaction. Activity diagrams will be presented to define the process and information flow of the system and how the components relate with each other. Some prototypes are presented as well.

All the game play is based on one main activity that relies on one surface view. The surface view is responsible for the game flow engine and for the rendering of the game objects. The game flow engine represents the game response to the user interaction, in order to create a fluid and reliable interaction between the user and the interface.

The user inputs are also collected by the surface view. On the other hand, the main activity is responsible for other outputs, such as audio and vibration, and for the game menu and dialogs. This framework diagram is showed on Figure 3.

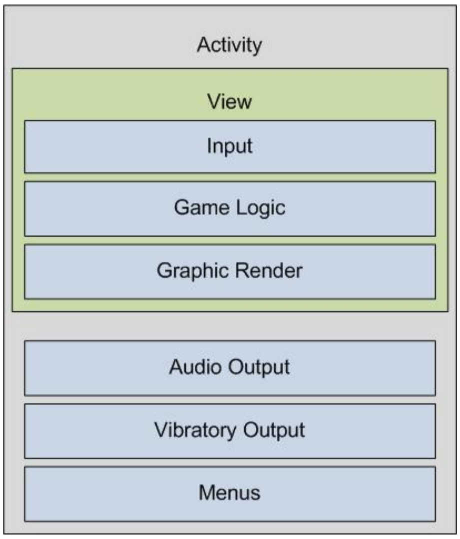

Figure 3 – Game Application Framework Architecture

The game flow engine consists of a basic interaction between the user and the system. This flow engine relies on the user input over the smartphone in order to obtain some finger coordinates. After a pair of numbers entered the system, representing the *X* and *Y* coordinates, they are analyzed by the game logic, which transform the initial user interaction on graphics, audio and vibrations that represent the system output. The system flow engine is represented on Figure 4.

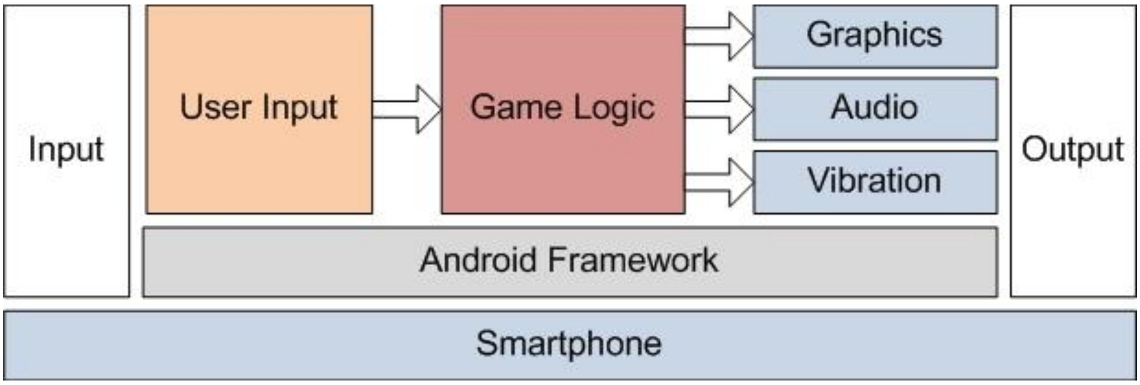

Figure 4 – Game Flow Engine

For the multiplayer flow engine a small difference was added. The game logic acts in the exact same way explained before when a user input occur on the system, but also will produce an output over a fixed time period. In order to represent the opponent's actions on the user smartphone, the game logic demands status updates every second. The system flow engine of the multiplayer game can be observed on Figure 5.

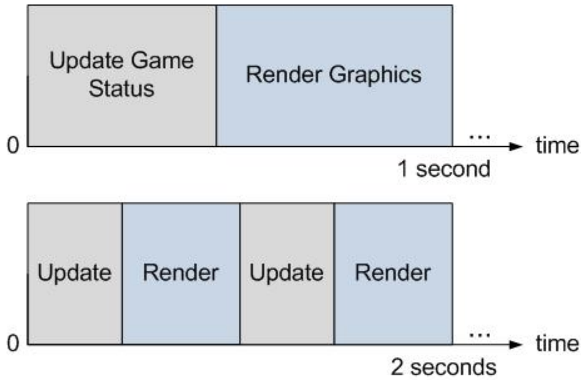

Figure 5 – Game Flow Engine Over Time

For the multiplayer game a nearby user interaction was selected in order to maintain some comparison between the physical card board jigsaw puzzle games – the users will play the puzzle game near to each other. When playing this game type with family and friends is necessary to be next to each other in order to reach the final solution. It was decided to keep this feature in order to keep the players close together so they could interact with each other not merely by their smartphone. To achieve this objective a medium short range connection network was selected – Bluetooth.

3.4 Initial Design

The following activity diagram on Figure 6 displays the player possible actions during a game. When a player launches the game application his/her preferences and last game played are loaded and presented automatically as a new game; if it is the player's first time running the application, a new game with preset values is presented instead. The application saves the player's preferences regarding the help type, puzzle size, difficulty level and the last game played as well. Once the game application starts up and a puzzle game is loaded the player has to choose one of the four possible options: use help, change help type, browse pieces or place a piece.

On changing the help type option the system will save these changes under the user preferences, and a feedback message stating a successful action is presented to the user. Upon using the game help the system will prepare the correspondent help, after checking the help type currently selected (global or individual), and based on the finger input coordinates. If global help is selected the displayed help is the entire solution, otherwise only the help for the touched location is displayed to the user.

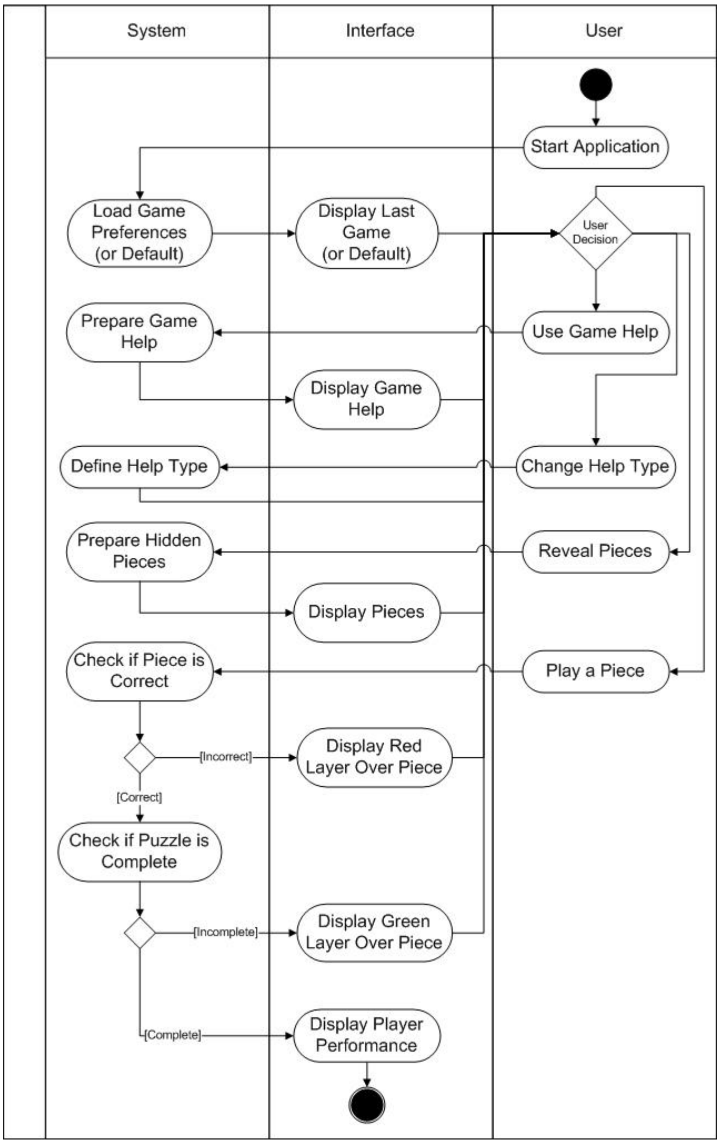

Figure 6 – Game Interaction Activity Diagram

To browse pieces, as previously stated, the player must swipe left or right over the pieces area, the system will verify the existence of more pieces on the chosen side, and prepare than to be presented to the user on game application interface. One of the key action during the course of a puzzle game is to pick a puzzle piece and place it in the solving area: if the piece is incorrectly placed a red transparent layer is displayed over it; if the piece is correctly positioned the system will check if the puzzle is complete: if is not, the piece will gain a green transparent layer to inform the player; if the puzzle is complete the game ends displaying the score screen.

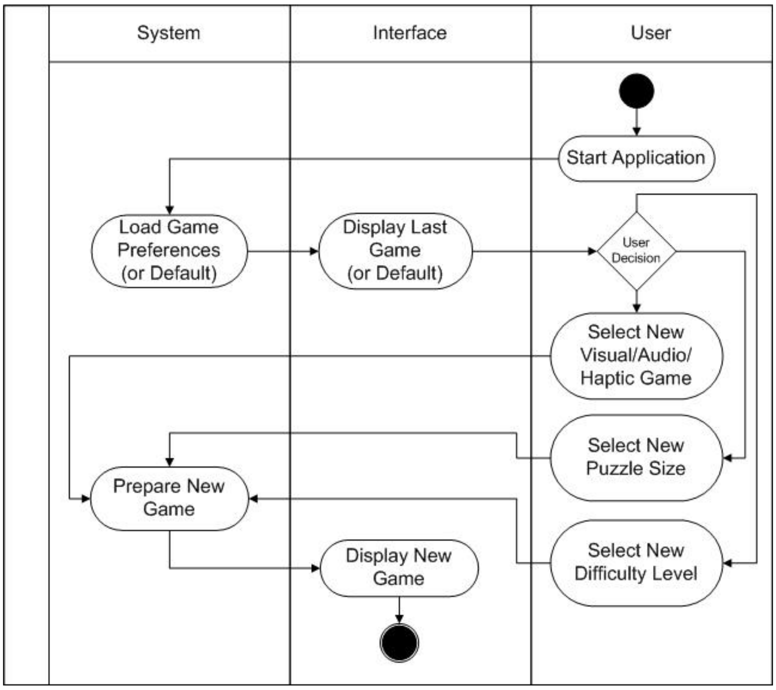

Figure 7 – New Game Options Activity Diagram

Several options are available for a player to be able to define new and different games. After the game application starts and provide the last played game or the default game, the player can select a new visual game (default images or browsing the pictures library), or a new audio game (default songs or browsing the music library), or a new haptic game (single, multi or Morse code options). Upon one of these selections the system will prepare the new game in order to the application interface can display it. Other ways to play new different games is by selecting or changing the puzzle size and the difficulty level. These actions cause the system to prepare a new game with the new selected feature, the application interface will display the new game to the user. The activity diagram regarding the new game options is represented on Figure 7.

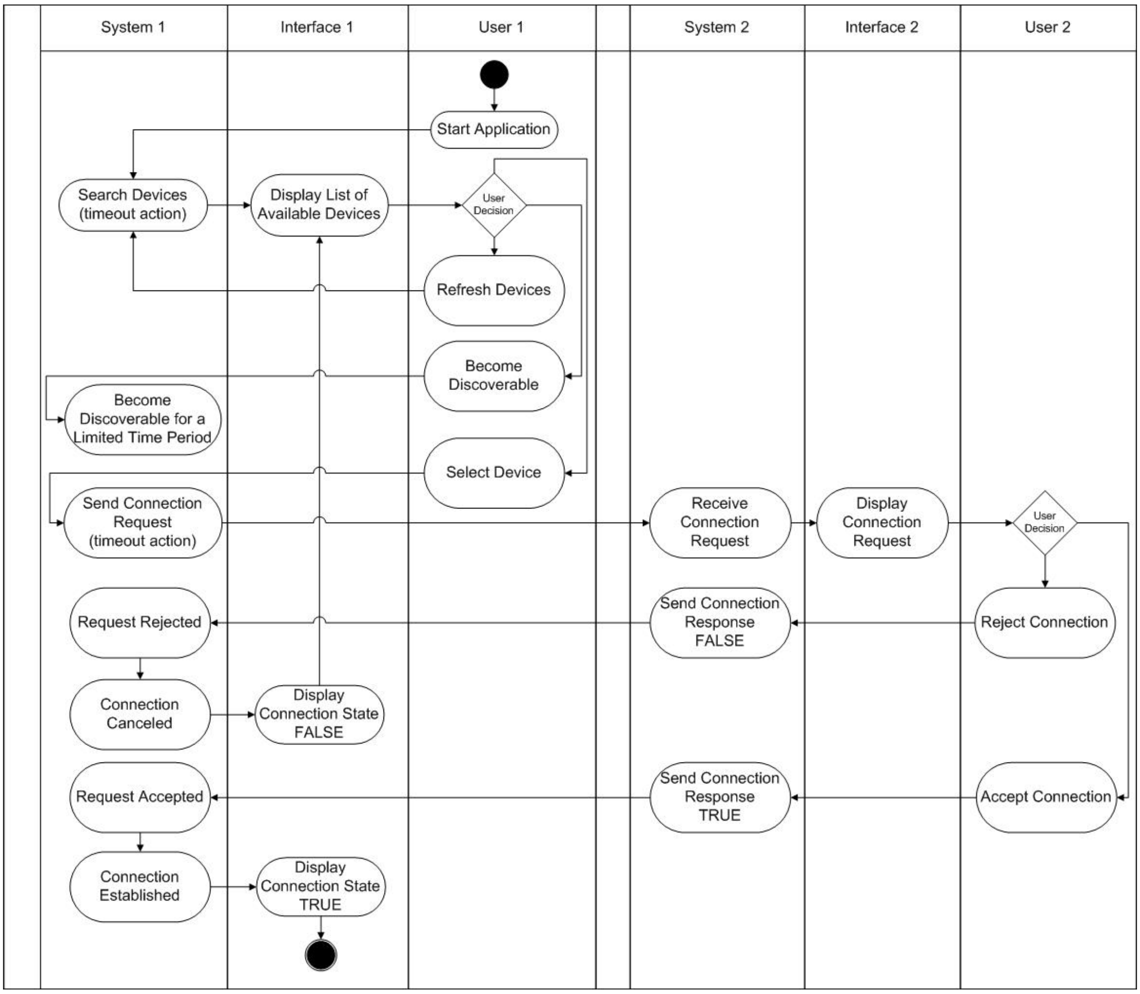

Figure 8 – Bluetooth Connection

The simple task flow overview for the Bluetooth connection is explained on Figure 8. First of all, both players should start the puzzle game application on their smartphones, if the Bluetooth is off the application will ask if the user wants to turn it on, only under a positive answer the user cloud play the game, otherwise the application will terminate. Upon the positive answer the Bluetooth will automatically start up. If the Bluetooth is already on when the application starts, this will continue without any problem.

Once the Bluetooth is on, the users have same options to choose from: 1) if the desired device is under the available devices list, the user should simple select this device; if not 2) the user must became discoverable for a short period of time; then 3) the user must search for devices (timeout action); if the desired device appear under other available devices list, 4) the user should select this device. When a device is added for the first time, 5) the initiator selects the device to add, a massage is send to the responder requesting whether to accept the connection; if 6) the responder provides a positive answer, the device accepts the connection and both became paired; else if 7) the responder deny the request, the connection will be canceled.

3.5 First Prototypes

For the low-fidelity paper-based prototype was recreated something similar to the original jigsaw puzzle card-board game. Presented on Figure 9 is the paper interface mockup example, with the pieces randomly rounded cut, in order to fit each other perfectly. The pieces are randomly distributed around the puzzle solving area. A small square with the objective picture is presented over the solving area. On touch, this small square becomes enlarged to provide the player with the image to solve.

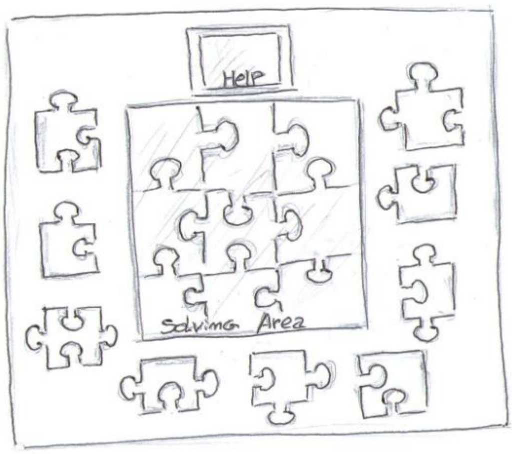

Figure 9 – Paper Prototype

Puzzle pieces can be combined through two different ways, first and foremost from their individual images and then through their distinct shapes. In order to ensure that the resolution of the puzzle is based only on one of these forms of resolution, we have simply to remove one of them. Thereby simplifying the way of the user identifies and groups the pieces in their correct positions. A less conventional but still popular way to solve puzzles is to put all the pieces face down and just use their different shapes to join them. Another simple way is to create all the pieces with the same shape (e.g. square), and this way the user will be forced to distinguish the pieces based only on their individual images. This provides us a certainty of the user selection over determinate pieces.

The first functional prototype only allowed playing a default picture puzzle with nine fixed pieces, which were presented randomly scattered next to the solving area. The pieces and the puzzle are squared shaped. The choice of making square pieces was based on the fact of forcing the user to distinguish the pieces only by their individual images, provide us a certainty of the user selection over determinate pieces. The available options were always visible near the bottom of the board, on one side the option to restart the game, and on the other the help to solve it. This interface can be seen on Figure 10. On this prototype is possible to assemble the design options over users' possible actions, such as touch for selecting a piece and drag and drop to place them – this action was selected for piece placement, in order to be a more realistic movement and keep the reference of the traditional game. Double tap was also selected as a specific selection or action, in order to be certain of user action (single tap became confused with other actions). These selected interaction modes are according to heuristics of game play and smartphone interaction.

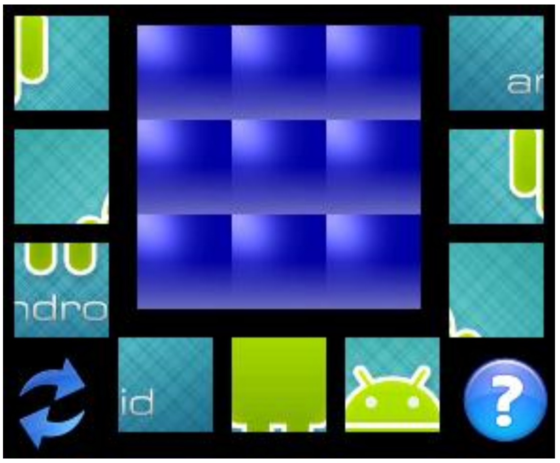

Figure 10 – First Functional Prototype

Puzzles may appear in several different sizes. Usually larger puzzles will have more and smaller pieces, thus being directly related to the difficulty of solving it. In order to allow different puzzle sizes over different platform screen sizes, the pieces should be rearranged on other form, rather than be scattered around the puzzle solving area. When a bigger puzzle size is selected the remaining space around the solving area is not enough to contain all the pieces. Figure 11 shows the prototype solution for this problem, a strip of pieces below the solving area, the player can shift left and right in order to navigate through the pieces.

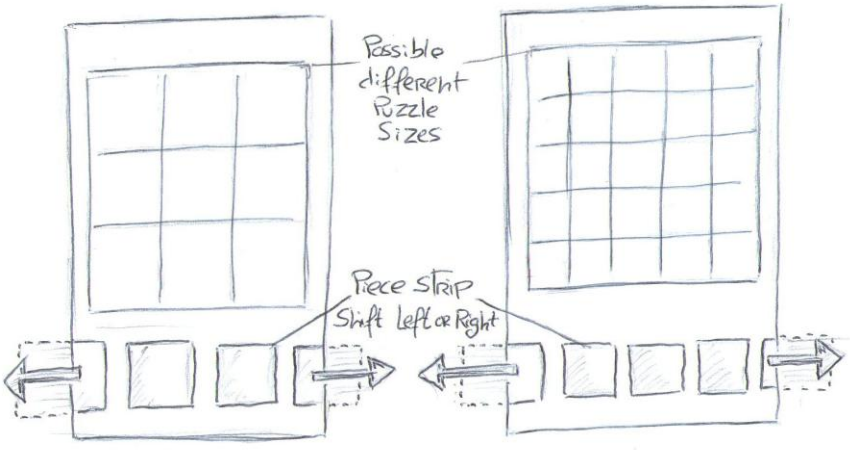

Figure 11 – Piece strip prototype for different puzzle sizes

Figure 12 displays a mockup of the available actions for the audio puzzle game without visual feedback. We considered only elementary actions to play the game: shift left or right to change the current piece; double tap on the bottom of the screen to hear the current piece; and double tap on the top of the screen to hear the entire song. A problem remains to be addressed – placing a piece: a solution could be the addition of a special gesture or a characteristic movement with the mobile device.

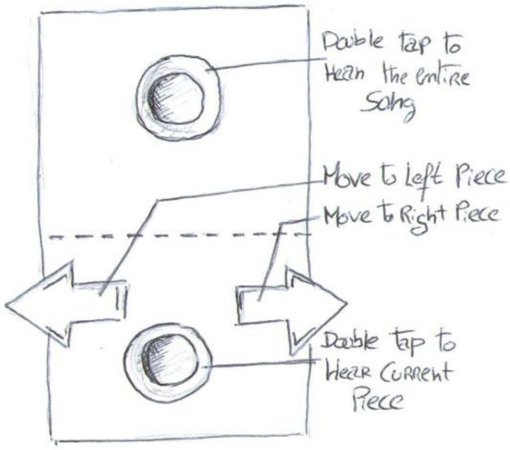

Figure 12 – Actions representation for the puzzle game prototype without visual feedback

Different multiplayer prototypes can be viewed on Figure 13 and Figure 14. Two different modes were developed: cooperative and competitive. In cooperative mode (Figure 13) the idea was to allow the player to cooperate as a team in order to solve the puzzle; both players will have half of puzzle pieces and upon a correct placement the other player will have access to that piece content.

In competitive mode (Figure 14) players should compete for the highest number of correct placements in a puzzle game. When a player places a piece over the correct position, the other player will lose the possibility to place that same piece. Instead, a red cross will appear over the solving area in that piece position.

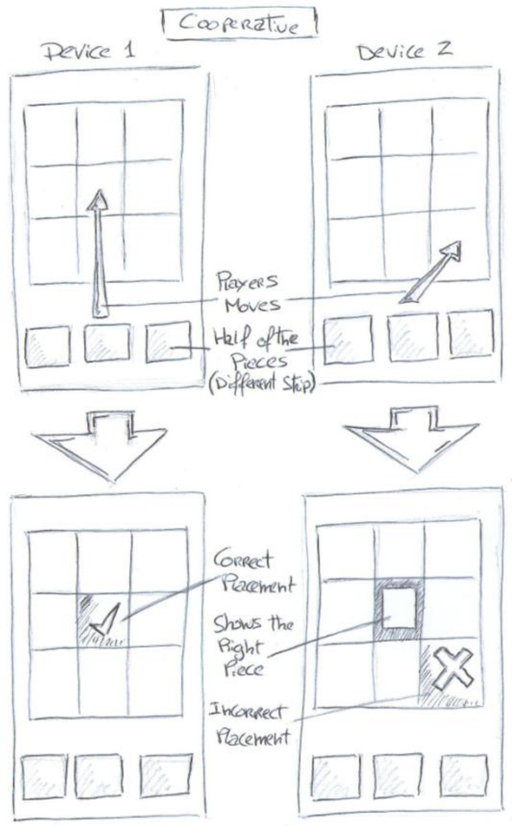

Figure 13 – Cooperative multiplayer prototype

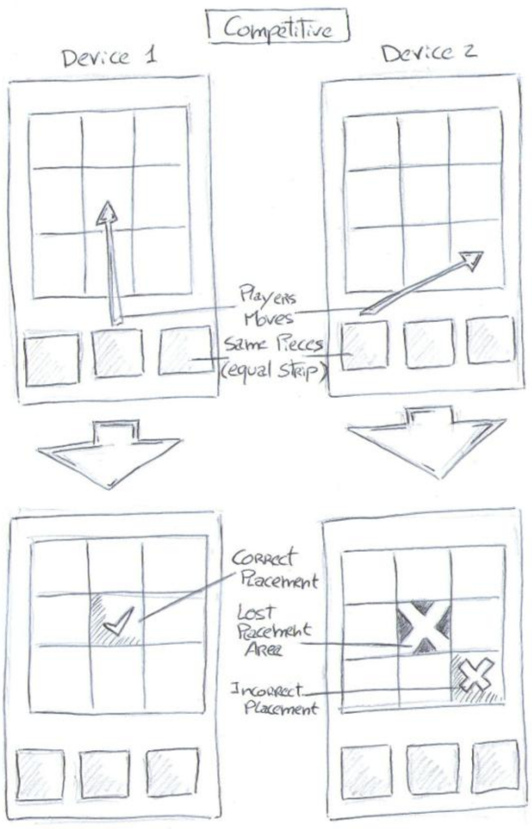

Figure 14 – Competitive multiplayer prototype

3.6 Final Applications

Given the lack of multimodal versions of puzzle games for mobile devices, we envisioned and developed a Multimodal Puzzle Game which allows players to tackle visual, audio and haptic puzzles. The game was developed for Android platforms and allows for the full customization of the puzzle challenge, ranging from number of pieces, to help types as well as allowing the selection of any picture or song present in the user's personal library to be a puzzle.

After this first puzzle application has been tested, three more were developed a version for the Google Play Store[4], comprehending the visual and audio modes, with a shop intended to buy items and features of the game, delivering objectives for a continuous playable game over time; a version withdrawing all the visual feedback, a simple audio version; the last developed version has the multiplayer puzzle game, which have to different modes, cooperative and competitive.

3.6.1 Multimodal Puzzle Game

The Multimodal Puzzle Game as its name implies is an application developed for Android platforms which allows users to solve puzzles across different modalities. While puzzle solving games are moderately popular, the available solutions are still rooted to solving visual jigsaw puzzles, the original concept of the physical counterpart of this game. As such, we envisioned a multimodal puzzle game which allows players to not only tackle on picture puzzles, but also on musical ones, in which the main goal is to place segments of a musical piece in the correct order, and on haptic ones as well, where the objective is to identify the vibratory patterns.

The multimodal puzzle game possesses a small selection of features which need to be addressed in detail to fully comprehend the contents of the game, namely the available game modes, configurable options and the game's interface.

Game Modes

The application comprises three game modes: a visual one, an audio and a haptic mode. The visual mode takes inspiration from traditional physical puzzles in which individuals are required to reconstruct a picture by putting pieces in the appropriate positions. The audio mode has not been so thoroughly explored in both research and videogame industry. In this case it provides a challenge to reconstruct a fragmented song by putting each individual segment in the correct order. Finally, in the haptic mode

[4] https://play.google.com/store/

players have to feel vibratory patterns and place them in the correct order. We will now address each game mode in more detail.

In visual mode, all pieces and puzzle images are square shaped. This means puzzles will have n^2 number of pieces, where n is a value configured by the player corresponding to the number of pieces per line. The game provides two approaches towards the visual mode:

- Players can take the challenge of one of three pre-loaded images which come with the game. These images were created specifically for the Multimodal Puzzle, serving as a default challenge for players. The default images can be observed in Figure 15.
- The second approach stems from a feature included in the game which allows users to browse images stored in the device. The implication is that players can select any image they desire to solve as a puzzle, effectively broadening the horizon of possible new challenges for the players. If the player picks a non-square shape image, the game stretches or cuts the image accordingly to fit the playing area.

Figure 15 – Visual Mode Default Pictures

The audio mode is the most important addition to the puzzle game. The goal of this game mode is for players to correctly order a musical piece which was divided in a configurable number of segments (n^2, similarly to the visual puzzle). Each segment is approximately one second long. Like in the case of the visual mode, players have two different approaches to play the music puzzle:

- Players can tackle one of three default songs, specifically created for the game. The song contains a repeating calm beat (Figure 16) which is interrupted by the initial excerpt (first 6 seconds) of Beethoven's 5^{th} Symphony (Figure 17). The three songs are variations of each other, differing between them in the instant in which the 5^{th}'s excerpt is introduced (in the first variation it is introduced at 2 seconds, in the second variation at 6 seconds and in the third variation at the 9th second).

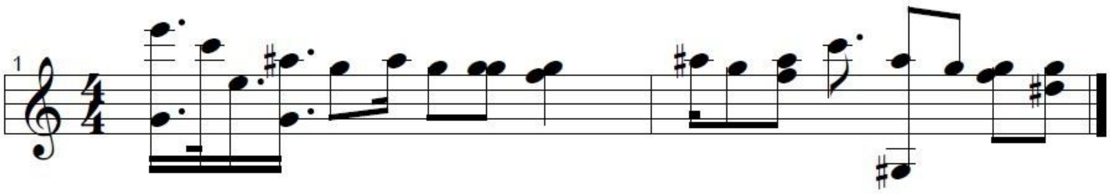

Figure 16 – Beat excerpt created for the default audio song

- Alternatively, players can select any song they have stored in their smartphone and load it to the game in order to complete it as a puzzle. The game is responsible for segmenting the song in n^2 pieces and then shuffles them for the players. If the player picks a song which is not long enough for the number of pieces established for the puzzle, the game prompts the player if he/she desires to change the puzzle length to one appropriate to the song length, or if he/she desires to pick a new song. If the song is longer than the available puzzle length (the typical scenario) the initial part of the song is selected to feature in the puzzle.

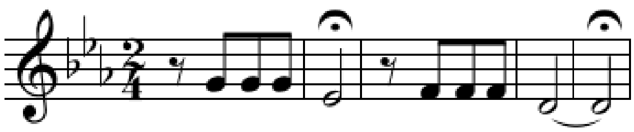

Figure 17 – Beethoven's 5th Symphony initial segment

In haptic mode, players have to feel vibratory patterns and place them in the correct order. The puzzle pieces are divided in a configurable number of segments (n^2, similarly to the previous modes). There are three different ways to play the haptic puzzle:

- The first and more simplistic one is where the pieces have a single vibration with different sizes, and the puzzle is arranged in ascending order from smallest to largest vibration. The objective is to distinguish each vibration length from all the pieces and make the match to the correct location.
- The second variant for playing this mode is similar but instead of a simple vibration, each piece now has a set of vibrations, all different from one another. The goal is of this mode is the same as the previous mode.
- In the last variant vibratory patterns are the representation of letters and numbers in Morse code. The goal is to identify the Morse code haptic patterns on the pieces and again on the location solving zone in order to solve the puzzle.

Help Type

During the course of the game, players have two help types at their disposal: individual and global. In individual mode, players are able to tap one particular square in the unsolved puzzle area to reveal the piece that fits in that place:

- In the visual puzzle, the individual help displays the image piece belonging to the tapped location.
- In the case of the music puzzle, the individual help plays the musical segment corresponding to that piece in the puzzle.
- For the haptic puzzle, the individual help creates a vibration correspondent to that particular piece of the puzzle.

In global mode, upon tapping the unsolved puzzle area, the whole solution is revealed. This means that:

- In the visual mode, the puzzle figure is shown to the player.
- When playing the music puzzle, the whole music is reproduced for the player.
- In the haptic puzzle, all the vibrations are recreated in a row. This help mode is only available for the first hapic game mode, due to the total size that a puzzle can reach.

The help type can be adjusted in the options menu prior to beginning a new puzzle or during playtime according to the player's preferences and play style.

Rules

A score based system is used to rank each puzzle solving attempt. Players are awarded 3 points when they place a puzzle piece in the correct position (for the first time per piece only). Positioning a puzzle piece incorrectly deducts one point from the current score. The intent of this system is to force players to think about their actions prior to executing them, avoiding unnecessary penalties for using, for instance, trial and error strategies.

Ranks are kept separately for each puzzle type and puzzle size. Games with the same score in the same category (puzzle size and type) are ranked according to the time taken to complete the puzzle.

Interface

The game's interface can be observed in Figure 18 for the visual mode, audio mode and haptic mode. For the first two haptic modes variations the interface layout is exactly the same to the audio mode. The interface layout for the last haptic variant (Morse code mode) is similar in every way to the audio mode, exception made for the pieces which are no longer android figurines; instead they are the letters and numbers corresponding to the vibrant patterns as shown in Figure 18 (left). The main region in the center is the unsolved puzzle area. Here we can see the segmented puzzle and all pieces which still remain to be discovered and the ones which are already placed. Correctly placed pieces keep their original colors, while incorrectly placed ones receive a subtle red transparent layer on top to signal their special status. A correctly placed piece displays a green transparent layer on top of them for short time period and then assumes its original image fragment (in the case of the visual mode).

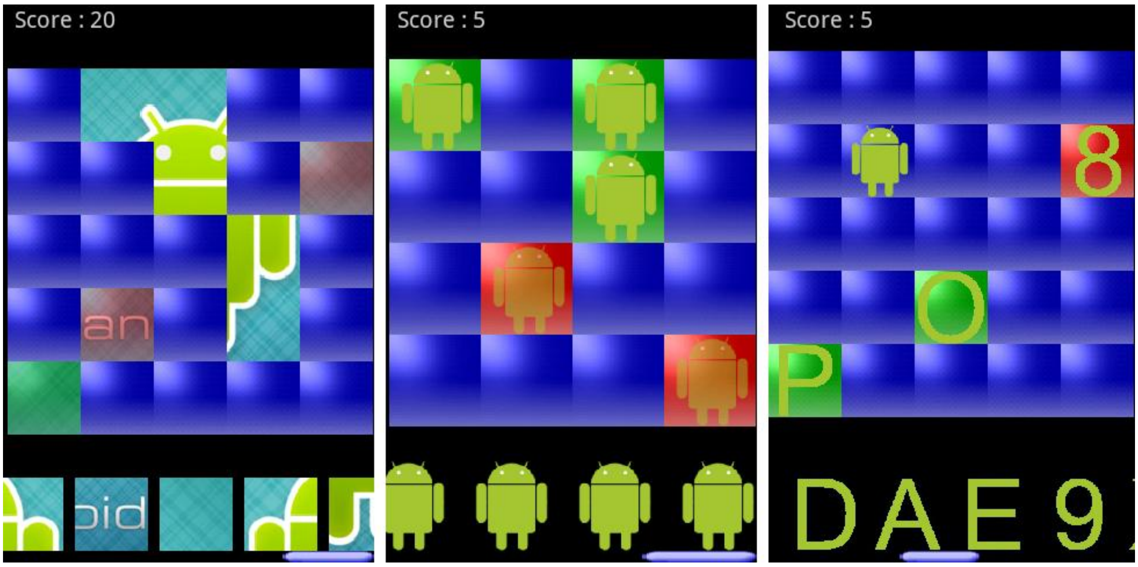

Figure 18 – Interface layout modes: visual (left), audio (center) and haptic (right)

The lower section of the interface comprises a strip which contains the puzzle pieces. The order of the pieces in this strip is randomly generated prior to each game. In the case of the visual mode, the pieces showcase the image fragment they represent. In the audio mode, each piece has the same visual representation. To access its content, players need to tap once to play the audio segment. To place a puzzle piece in the unsolved area, players tap and drag the piece to the desired position and then let it go to execute the positioning action. During a game, and particularly in large puzzles, players may move a significant number of pieces from the strip to the unsolved puzzle area, causing it to be overcrowded and hindering the comprehension of which pieces are in place and which are not. We implemented a shortcut to make all incorrect pieces return to their original positions in the strip. By double tapping the strip area, the players are able to force all incorrectly played pieces to return to the strip in their original order.

The Multimodal Puzzle Game also comprises a Configuration menu which allows users to set their preferences, such as default help type, default puzzle size or default image and music library paths. The smartphone’s menu button opens a quick menu with several shortcuts, namely *New Game*, *How to Play*, *Preferences*, quick access to *Restart* and *Exit* (Figure 19). Scores and player preferences are stored in both the Android application and on a XML file for backup.

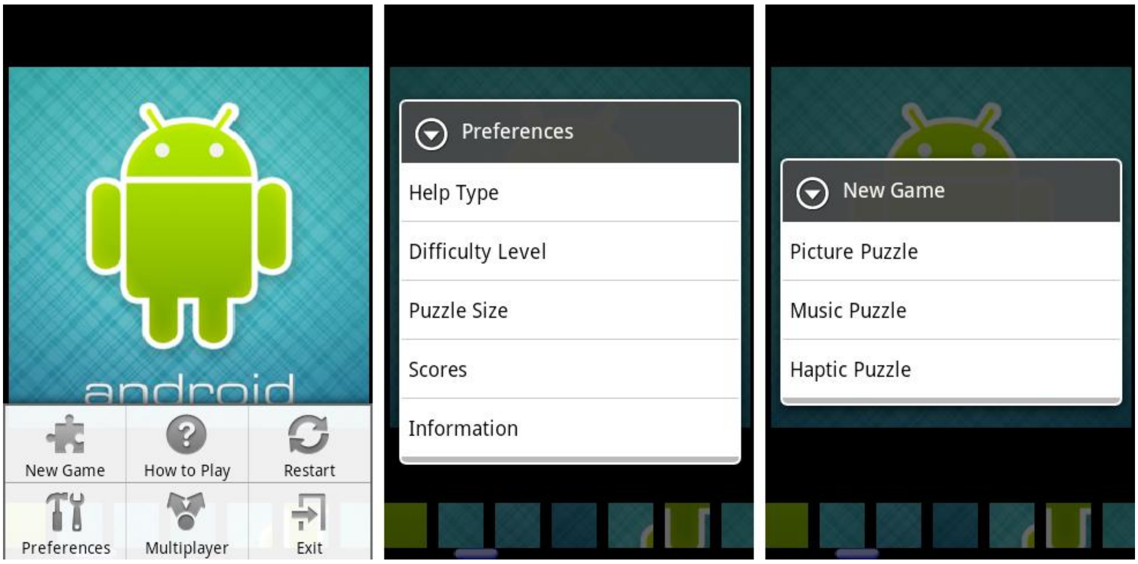

Figure 19 – Application menus: main menu (left), preferences (center) and new game (right)

3.6.2 Multimodal Puzzle Game – Market Version

This version is very similar to the one presented before, but with some important changes in order to become more suitable to the characteristics of the available market casual games. On this version only the visual and audio modes are available. A new formula for generating the score was developed, as well as a game shop for acquiring game features in exchange for game points. This version sends the game XML logs via email when the application starts and again when is closed if a reliable internet connection is in range and the player has agreed to share that data.

Game Modes

There are available two different modes, the visual and audio mode. They are exactly the same as in the multimodal puzzle game presented before; puzzles will have n^2 number of pieces, where n is a value configured by the player corresponding to the number of pieces per line. The game has an initial forced trial consisting of 4 games (2 visual and 2 audio ones), in order to explain the game's basic functions and to integrate the players with the different game modes available. After this trial the game provides two approaches to each mode:

- Players can play the default games with the default images and songs. These first games will give the player points to acquire some new features.

- After purchasing the available correspondent features, the players can play visual puzzle games with images stored in their own device, and play audio puzzle games with songs from their own music library.

The game help types are also the same: global and individual. They are always available and work in the same way explained before.

Rules

A different score based system was developed in order to congratulate the player with points equal to the obtained score after completing a puzzle. This score based system provides better scores to more difficult puzzles and worst scores with random played games. A correct placed piece will gain a green transparence and an incorrect attempt will obtain a red transparence. The score properties are briefly explained below:

- Players are awarded 10 based points when they place a puzzle piece in the correct position (for the first time per piece only).
- For bigger sized puzzles and on higher difficulty levels a corrected placed piece will give more points. The square root of a puzzle size minus one (+1 for hard mode) will multiply with the piece base value.
- For each time global or individual help are used more points will be deducted. For global help 20 points will be deducted at the second time used, them 20 * *number of uses* will be subtracted. For the individual help 25 * *number of uses* for each unresolved zone will be reduced.
- For each incorrect placement attempt of a piece the points will decrease. A incorrect attempt based value is equal to 10 points, for each piece will be reduced 10 * *number of uses*.

Interface

The market's version interface during game play is the same as the previous version, for visual mode (Figure 18 – left) and for audio mode (Figure 18 – center). The main difference is the layout of the menus and available options. In this version the menu will show a new option named *Shop* where the player can purchase game features by exchanging the points earned while solving puzzle games. The *Shop* menu can be seen in Figure 20 (left). The *Preferences* menu (Figure 20 – center) option will have unavailable items that have not yet been purchased in *Shop*. The *New Game* options (Figure 20 – right) available are the default games, the other options (*Select Image* and *Select Music*) must be as well purchased on the *Shop*.

Figure 20 – Market application menus: shop menu (left), preferences (center) and new game (right)

3.6.3 Simple Audio Puzzle Game

The main change in this audio puzzle game is the removal of all visual feedback. The game playability was transformed into a simple combination of finger movements (e.g. swipe to move pieces and taps to require help) and audio/haptic feedback. The screen, although with no visual feedback, is equally divided in three zones. The target strip is placed in the top area. The middle area contains the currently selected piece, while the bottom area is a container for the complete song being played. By double tapping the middle area, the user can listen to the current piece. By swipe the finger to the right or left, the next piece is selected, working like a strip of unplaced pieces (song segments). By swipe the finger up, the user tries to place the piece in the target strip. Different feedback sounds and vibration patterns are associated with success and failure in placing a piece. No manipulation of the target area is possible, making piece placement a sequential process, thus following the natural order of the song being played (the first piece to be placed must be the first segment of the song). Exception is made for double tapping the target area (top) which plays the completed part of the puzzle. All the possible actions that can be taken on this game mode are represented on Figure 21 (left).

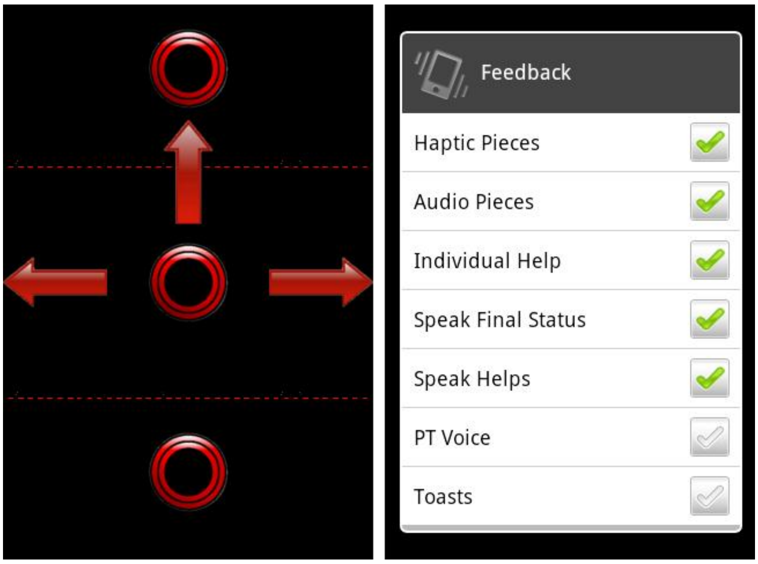

Figure 21 – Simple audio mode: representation of actions (left) and feedback menu (right)

This game application offers the same configurations as previous versions, but extends the feedback options by allowing the user to choose which to enable/disable (Figure 21 – right):

- Upon placing pieces there are two feedback available options, haptic and audio. The user may have both or only one of them activated.
- It is possible to change the speak feedback options regarding the player final status and the number of pieces in help selection.
- The default voice is English, but it is possible to change it to Portuguese (a Portuguese text to speech software on the smartphone is required)
- Simple action messages can be activated for some visual feedback.
- An individual help option is available. It will activate another movement, swipe down, in order to listen the song from the completed part till the end, instead of listen the song from the beginning.

The puzzle can have any n pieces as long as n^2 does not exceed the maximum length size of the selected music. The pieces are randomly distributed on the middle strip. A speech synthesizer (Pico TTS) was used to read to the user the total number of pieces to be solved, the number of pieces completed so far and the final player statistics. A simple score system was also developed based on the number of correct attempts (adding three points) and incorrect attempts (subtracting one point). This scoring system is meant only to motivate the players allowing better results and performances.

3.6.4 Multiplayer Puzzle Game

A multiplayer puzzle version allows two players to connect and play with each other by using a Bluetooth short-range network.

Game Modes

The multiplayer puzzle game includes visual and audio versions in two distinct game modes: cooperative and competitive. Players should first turn on the Bluetooth to allow the necessary interaction. The connection options are visible on Figure 22 (left). One of the players makes a game request to the other player. Upon this game request, the player who received has the opportunity to choose the type of game (cooperative or competitive) as well as all the features involved, such as the puzzle size, the difficulty and the game type (visual or audio); this interaction can be seen on Figure 22 (center and right). Both players will have 3 seconds to prepare for the game start (Figure 23 – left).

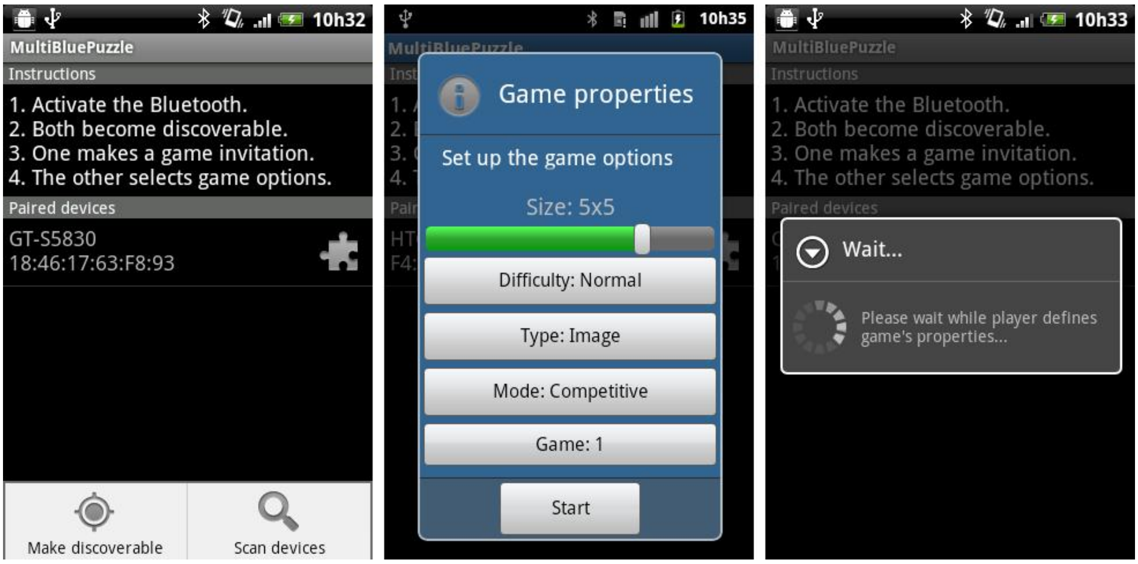

Figure 22 – Multiplayer application: connection options (left), game properties (center) and wait dialog message (right)

The game play on the multiplayer audio and visual modes is very similar to the same modes explained before, with some necessary changes due to the new modality. The help types are exactly the same as before (global and individual) as well as the rules applied (+3 points for a correct placed piece, -1 for incorrect attempt).

For the cooperative mode (visual and audio) players will have half of the puzzle pieces, forcing players to cooperate to actually solve the puzzle. As each player has different puzzle pieces, consequently they will have different strips. Upon a correct piece placement the other player also will be able to access that piece's content. The objective is to solve the puzzle as a team, with the least amount of placement attempts as possible.

For the competitive mode (visual and audio) all the pieces will be randomly distributed in the same order in both players' devices. Upon a correct piece placement the other player will lose the opportunity of place that same piece. The objective is place more correct pieces than the opponent, but with the score rules more correct placements not necessarily mean guaranteed victory; if a player makes to many placement attempts the score will decrease.

Interface

In cooperative visual mode pieces placed by the other player will appear with a small semi-transparent orange board, only to mark them out (Figure 23 – center and right). In order to have a greater challenge which forces the involvement of the players it is necessary that both cooperate to achieve a common goal – to this end the hard mode was created. While the core mechanics are unchanged, pieces can now be rotated. To force cooperation, a player may only place a piece in his/her strip area – his/her team mate will then be responsible for rotating the piece to its correct position. Double tapping over a piece will rotate them 90º clockwise. This way the players are forced to cooperate to achieve the completed puzzle.

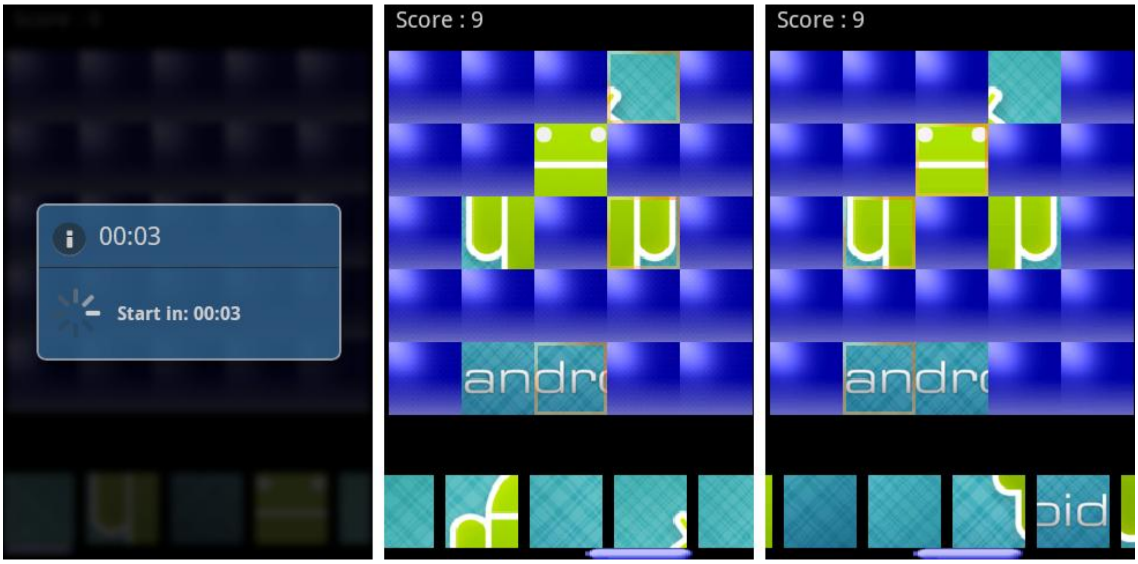

Figure 23 – Anticipate game start (left); visual cooperative device 1 (center) and device 2 (right)

In audio cooperative mode when a piece is placed by a player, on the screen of the other player will appear an orange piece in the same position, only to mark it out; this interaction is visible on Figure 24 (center and right). Upon this game mode players often choose to select individual help on the early game (Figure 24 – left).

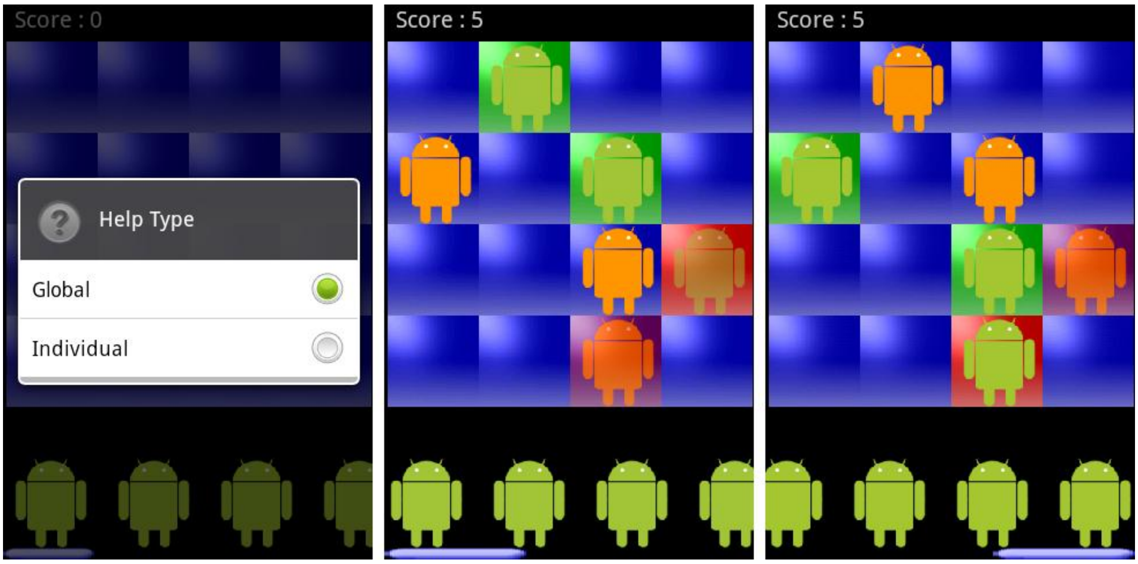

Figure 24 – Help type selection (left); audio cooperative device 1 (center) and device 2 (right)

In both competitive modes (visual and audio), all the pieces will be randomly distributed on the same order in both players devices. When a player places a piece in the correct position, the other player will see a red X on that same place and simultaneously the corresponding piece will disappear, leaving no chance of placing it. Figure 25 represent an example of a competitive visual game, while Figure 26 represents a competitive audio game.

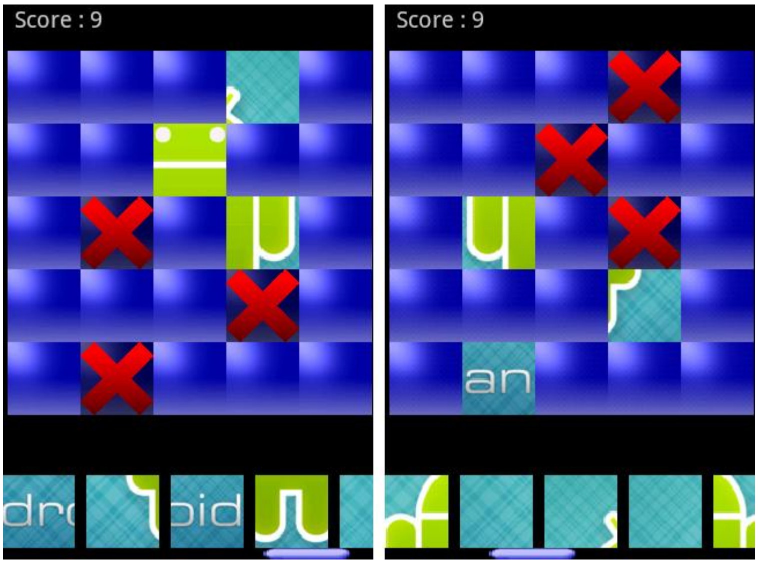

Figure 25 – Visual Competitive device 1 (left) and device 2 (right)

Conflict Resolution

When a piece is placed two messages are sent, a first containing the action performed by the player, indicating the piece played, the correspondent position and for the case of hard visual mode of the state of rotation. The second message contains the current state of the board. There are three main messages in order to fulfill the needs of the game: *P* – Put piece; *T* – Take piece; and *R* – Rotate piece. For the conflict resolution two more messages were added: *A* – All positions (state of the entire board); and *C* – Conflict. Immediately after one of the main messages is being sent, a message with the entire board is also sent. The received board is then compared with the local board: if a conflict is detected, it will be resolved according to a token that will change its value as long as conflicts will appear. A conflict occurs when two pieces are placed in the same position at the same time. To a resolution take place a conflict message is sent to the other player and certain aspects are also resolved locally, such as the number of movements and number of pieces correctly placed.

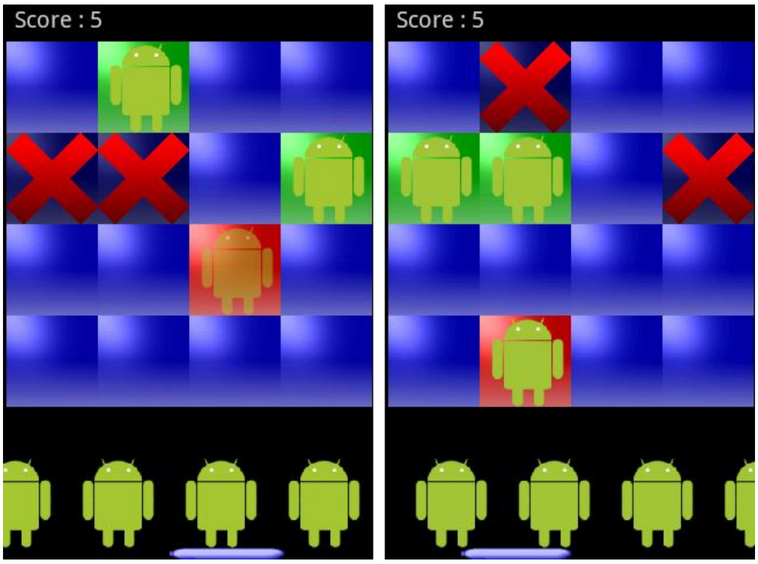

Figure 26 – Audio competitive device 1 (left) and device 2 (right)

3.7 Summary

This chapter starts by defining a cyclic development process. Then we defined the requirements of a puzzle game, starting with the definition of the actors who would be involved in the system. After the requirement analysis we were able to define the use cases related to the puzzle application and all of the important features and functions. The use cases will be taken in consideration over the development of the system design.

This chapter also explained the system's architecture starting by its organization. The application is structured on a main activity which holds a view. Each component has its own defined function. After we explained how the game engine works in order to provide a flowing game play. The player possible actions and game interactions were explained over activity diagrams.

After the presentation of the low-fidelity prototypes for each puzzle game mode, we presented the system implementation, explaining in detail all the developed applications and puzzle modes. The first developed application was the multimodal puzzle game, which has three puzzle modes: visual, audio and haptic. The player is able to define puzzle size, difficulty level and mode, and can also select pictures and songs from their own library. A special version of this game was developed to be deployed on the Android market. The second developed application comprises the audio mode without visual feedback. The last one was the multiplayer game which allows for cooperative and competitive game modes.

Chapter 4

System Evaluation

Taking inspiration from different puzzle learning strategies and learning environments, we designed a study which aimed at assessing the strategies used to solve puzzles across different modalities. In particular we wanted to determine if users tend to prioritize particular puzzle pieces or if they solved the puzzle in the order the pieces are presented to them. We present a study comparing puzzle solving strategies between different puzzle modalities. This chapter will be divided in a preliminary informal evaluation and three main system evaluations.

4.1 Preliminary Informal Evaluation

Shortly after the first functional multimodal puzzle game was ready we aimed at testing all developed modes in order to acquire some useful information, as well as to perform bug tests. The application was distributed within our colleges, under 20 people, and was requested that they play it and tested on work breaks. We were able to gather 70 game logs that provided some important and useful information. First of all, the data was too dispersed – 50% were visual games, 35% were audio games, and only 15% were haptic games. Approximately 65% of the visual mode games had a puzzle size of 25 pieces, 83% of audio games had 16 pieces, and 54% of the games played in haptic mode had 9 pieces per puzzle. In light of these results, the haptic mode was considered to be too challenging for the players, leading us to exclude it from the study herein presented. We were also able to define the ideal puzzle size for the visual and audio modes – 25 and 16 pieces accordingly.

4.2 Multimodal Puzzle Game

In this system evaluation we conducted an experiment whose goal encompassed analyzing whether players would use a solving strategy akin to the one applied in completing a visual puzzle in the completion of an audio puzzle. Another goal encompassed identifying which puzzle solving strategies yielded the best performance according to a set of metrics. This experimental period lasted for two weeks, involving three researchers supervising the tests and providing support to subjects as requested.

4.2.1 Goals

The primary goal of the experiment was to assess if players use similar strategies to solve an image puzzle and an audio puzzle with the multimodal puzzle game. We are particularly interested in analyzing the order in which puzzle pieces are correctly positioned as well as if the order by which pieces are presented in the strip has any effect in the order in which the puzzle is solved. Another goal pertained to the identification of which of the assessed strategies yielded the best results according to 3 different parameters: completion time, number of moves for completion and player score. This second research goal aims at reinforcing our previous results by providing empirical evidence on the advantages and disadvantages of specific puzzle solving approaches. We tackled the puzzle solving order from three perspectives: piece sequential number within the puzzle; piece sequential number within the strip area; and piece type classification.

Piece Type Classification

To assess piece positioning order we recurred to a special classification of pieces in both the visual and audio mode, performed manually in pre-execution time. This classification is done according to how emphasized some areas are in the whole puzzle (be it visual or audio mode). The default challenges used in the Multimodal Puzzle Game are comprised by pieces of 3 different types. Although the classification can be applied for all 3 of the default images or default songs, we will exemplify each type by observing the rightmost image depicted in Figure 27:

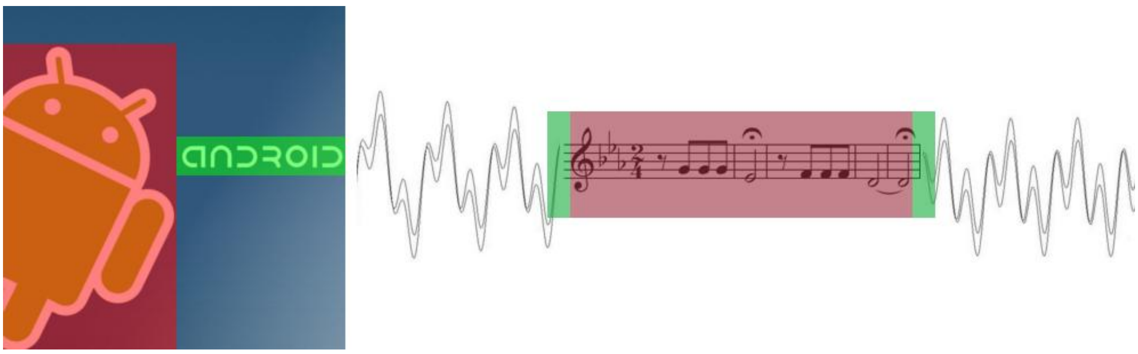

Figure 27 – Piece Type Classification Representation

- **Type-1**: Type-1 pieces are the most prominent sections of a puzzle. In the case of a picture puzzle we can define it as being the main blob of an image or its main focal point, while in a song it can be defined as a salient segment of the score piece (the first 6 seconds of Beethoven's 5th Symphony is an adequate example). In Figure 27, the red rectangle over the android figurine represents the approximate Type-1 zone for that image. In the default song for the audio mode, Type-1 pieces correspond to the 5th Symphony's segment.

- **Type-2**: Type-2 pieces are salient but not the main focus of an image or audio puzzle. In the case of a picture it can be a second focal point or a prominent image in the background, while in an audio puzzle it can be a special tune played over the repeating one which is slightly emphasized. In Figure 27, the green rectangle over the text label represents the approximate Type-2 zone on that image. In the default song for the audio mode, Type-2 pieces correspond to the transition between the 5th Symphony's segment and the remaining song.
- **Type-3**: Type-3 pieces are areas which do not stand themselves from everything else. The background of a picture (a blue sky, for instance) or a repeating background beat in an audio puzzle are examples of Type-3 pieces. In Figure 27, Type-3 corresponds to the area not covered by either the red or the green rectangles. In the default song for the audio mode, the Type-3 pieces correspond to the repeated beat produced for the game.

Currently we do not possess any automatic classification mechanisms which would be optimal for inclusion when players pick an image or song from their library, as this classification can be somewhat subjective.

4.2.2 Research Goals

The following are our research goals for this experiment:

- **RG1** – provide empirical evidence that players will place Type-1 pieces first in different images in visual mode. Additionally, players put Type-3 pieces last in visual mode.
- **RG2** – show that players will place Type-1 pieces first in different songs in audio mode. Additionally, players put Type-3 pieces last in the same audio mode.
- **RG3** – provide empirical evidence that piece presentation order in the strip area influences directly the order in which pieces are solved in the puzzle for both analyzed puzzle modes.
- **RG4** – find the most appropriate strategy to solve visual and audio puzzle games based on puzzle completion time.
- **RG5** – find the most appropriate strategy to solve visual and audio puzzle games based on total number of movements for puzzle completion.

- **RG6** – find the most appropriate strategy to solve visual and audio puzzle games based on the attained score.

4.2.3 Variables

In this experiment we controlled 4 different variables: the picture puzzle the players had to solve, the audio puzzle needed to be completed, the order in which puzzle pieces were displayed in the strip area of the game, and the puzzle size for each mode. As for the dependent variables, we kept track the order in which pieces were placed in the unsolved area and the order in which each piece category was placed.

Independent Variables

- **Puzzle Image** – To analyze whether players used the same solving strategy across different images we provided three different images for the players (the Multimodal Puzzle Game default ones: Figure 15). Albeit three distinct images, their core components are similar in a sense that all include a prominent image of an android character, a small text area and then a simple background. We controlled the usage of the image in the experiment, alternating it between tasks.
- **Puzzle Song** – Similarly to the previous variable, we provided three different songs for players (the Multimodal Puzzle Game default ones). Again, an excerpt of the background beat is represented in Figure 16 and is present throughout the whole song. At key instants (at second 2, 6 and 9), the initial segment of Beethoven's 5^{th} Symphony (Figure 17) is played. This segment acts as a Type-1 set piece, the transition between the two beats is considered a Type-2 set piece and the background beat is considered to belong to Type-3.
- **Puzzle Strip Order** – The third independent variable is the order in which puzzle pieces are presented in the strip area. We believe this order might influence the solving order of a puzzle. As such we controlled the way in which pieces are ordered in the strip. Three different variations were implemented: the first scatters the pieces randomly throughout the strip; the second places mostly all Type-1 and Type-2 pieces at the end of the strip; the last places mostly all Type-1 and Type-2 pieces at the beginning of the strip.
- **Puzzle Size** – Considering a trade-off between challenge and average time to complete each puzzle (in order to not alienate players) the puzzle size was fixed in 25 pieces for the visual mode and 16 pieces for the audio mode. The discrepancy in puzzle size is due to the amount of time spent in solving the audio mode puzzle which is significantly higher than in the visual mode.

Conversely, we want to provide a challenging deployment of all modes thus being able to stress strategies and improve user engagement.

Dependent Variables

- **Piece Category Solving Order** – there are 25 available correct moves for the visual mode and 16 for the audio mode in this experiment. With this metric we intend to analyze in which order the different piece categories are solved in the puzzle.
- **Strip Position Solving Order** – We intend on assessing if players position the pieces correctly based on the strip order or based on any other criteria. For this we logged the order from which players pulled pieces from the strip and to which correct move position order they fall in.
- **Puzzle Sequence Solving Order** – Assemble a puzzle by a sequential order is also a possible solution. In order to analyze if players solve puzzles by a sequential order we recorded the piece sequential number over a correct placement.
- **Game Time** – This metric will help us understand which strategy yields a faster completion time.
- **Total Number of Moves** – Total number of moves further details a player's performance while solving a puzzle. By analyzing the number of moves that was taken to complete the puzzle we can reveal the strategy that uses less movement to place pieces into proper place.
- **Player Score** – Once more the rules for score are: +3 points for each piece in the right place, only for the first time, and -1 point for each one on the incorrect place; the score purpose is forcing players to think before acting.

4.2.4 Participants

24 subjects aged 21 to 27 (M=24.25; 20 male, 4 female) participated in this experiment. Individuals were students from different departments in our university. All of them had solved physical puzzles in the past (30% regularly still solve puzzles) and were proficient with modern smartphones, although the large majority had never played a puzzle game in a smartphone, let alone an audio version.

It is important to say that 40% of users had musical formation beyond the mandatory given at the high school level (either from specialized courses or through self-learning approaches).

Participants were handed Android smartphones (Samsung Galaxy Mini) to play the game. All devices were previously loaded with the Multimodal Puzzle Game.

4.2.5 Procedure

The experimental period started with a pre-experiment interview to characterize the subjects (e.g. age, gender, experience with modern smartphones, music theory knowledge, etc.). The main experiment’s procedure was as follows: players were randomly assigned to play either 9 visual mode games or 9 audio mode games. The assignment resulted in 12 subjects playing the visual mode and 12 users playing the audio mode, leading to 108 played for each mode, for a total of 216 games.

The 9 mandatory games that subjects had to play had the following characteristics:

- Players played 3 games with each one of the 3 default images or songs, depending if they were assigned to the visual or audio mode. The differences between each image and song were disseminated previously.
- For each image/song players were confronted with a different piece order in the strip area:
    - In one of the games Type-1 and Type-2 pieces were randomly scattered throughout the strip.
    - In other setting, Type-1 and Type-2 pieces were forcefully put at the end of the strip.
    - In the last configuration, Type-1 and Type-2 pieces were forcefully put at the beginning of the strip.

The order of these 9 games was randomly assigned per participant.. A post-questionnaire was employed to assess the users’ opinions, in order to classify the game into four different categories, using a 5-point Likert scale.

4.2.6 Results

We will now address the results for the visual and audio modes.

Visual Mode

Results for the visual mode can be observed in Figure 28, Figure 29, Figure 30 and Figure 31. In Figure 28 we can visualize a graph displaying the percentage for the three types of category distributed by all 25 correct move positions. It is clear that Type-1 pieces are the first to be solved and Type-3 pieces are saved for last. The distribution presented in this graph holds true independently of the strip order, meaning users prefer solving the most prominent areas first, even if they do not appear at early sections of the strip. The trend is also clear to comprehend: players dedicate the first correct movements for the most prominent areas of the puzzle, saving the most unclear or abstract portions of the image for last.

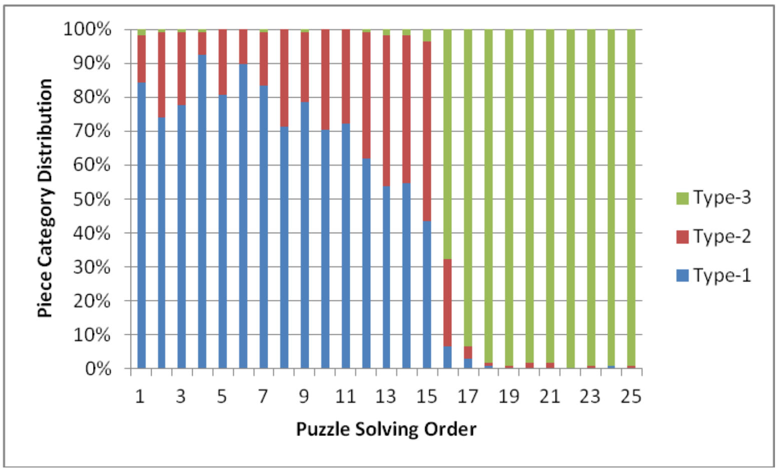

Figure 28 – Piece category distribution across puzzle solving order (visual mode)

Figure 29 displays a box plot graph, with the average, first quartile and third quartile, showcasing a relation between the correct move slots and the positions of the pieces pulled from the strip. While the chart is not completely unquestionable, there is an early trend which points that players do choose pieces based on the position in the strip area (the ones in early positions are the first ones to be solved).

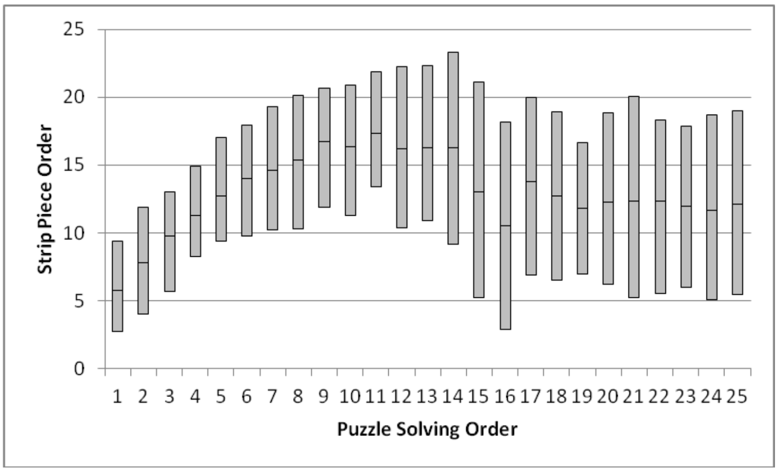

Figure 29 – Puzzle solving order according to strip position (visual mode)

Figure 30 displays another box plot graph, similar to the above, but showcasing a relation between the correct move slots and the puzzle piece order displayed on the solving area. This chart was created to analyze the possibility of the existence of another strategy involved in solving visual puzzles. The graph shows players did not opt to solve the puzzle according to its presentation order, as the user choices are distributed evenly across all available solving positions.

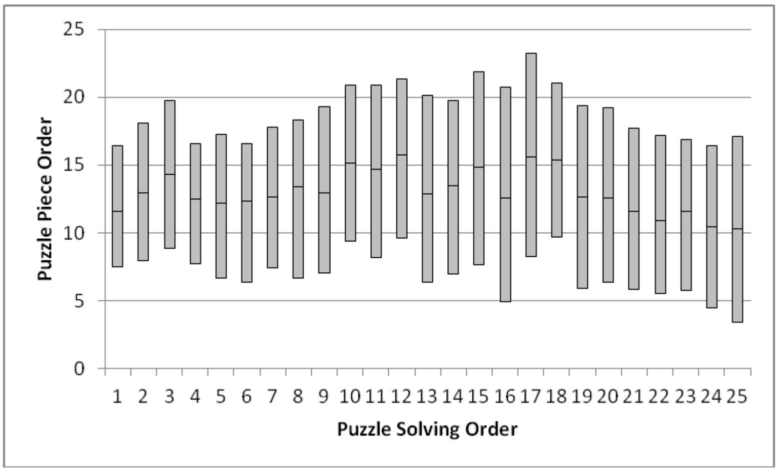

Figure 30 – Puzzle solving order according to puzzle piece order (visual mode)

Given the existence of a single solving strategy (by piece prominence), in Figure 31 we can see the average time it took to complete each game in visual mode, also as the number of movements and the score achieved. In a way to recall, the game has a total of 25 possible correct moves. For each completion the average amount of time spent rounds 150 seconds, about 2 and a half minutes, and takes 40 moves. The average score obtained is approximately 59 points.

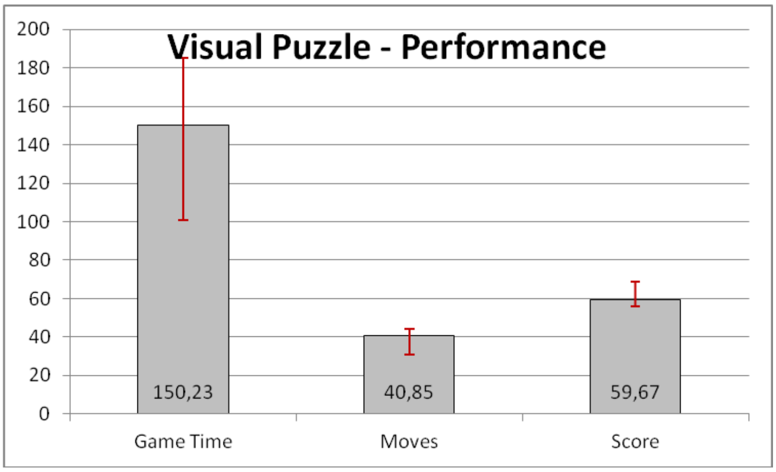

Figure 31 – Visual mode average metrics for time, moves and score

Audio Mode

Results for the audio mode can be observed in Figure 32, Figure 33, Figure 34, Figure 35 and Figure 36. Unlike the results obtained for the visual mode, the graph depicted in Figure 32 is not conclusive as to whether players solve the audio puzzle by prioritizing piece categories or not. In light of these results we proceeded to manually analyze all data, game by game, to check if there were other strategies involved in solving the music puzzle.

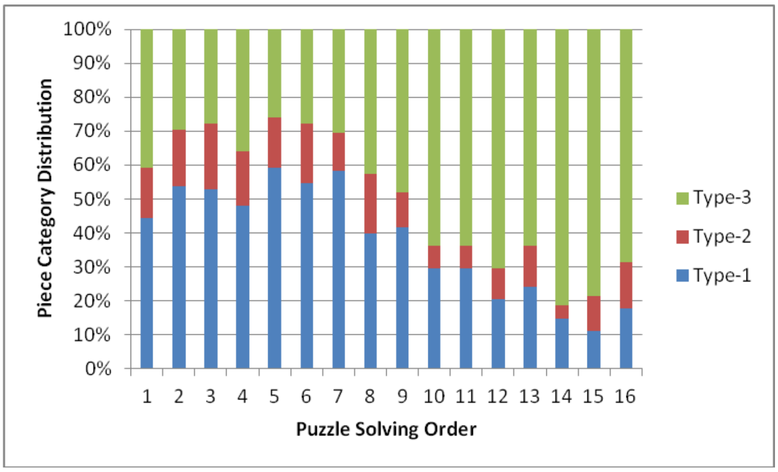

Figure 32 – Piece category distribution across puzzle solving order (audio mode)

Figure 33 contains a graph depicting the percentage of games solved according to three identified strategies: by piece category, by the piece strip order and by the puzzle's presentation order (e.g. first row, then second row, etc.). For 9% of the games we were unable to identify a noticeable strategy.

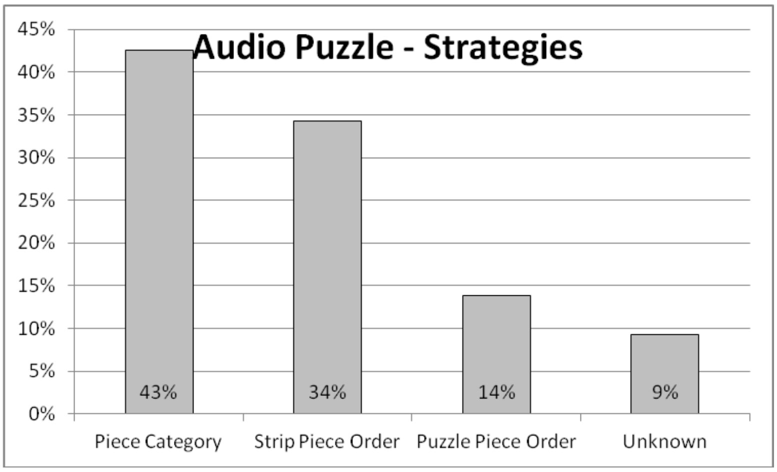

Figure 33 – Audio mode solving strategies distribution

Figure 34 displays the three main strategies discriminated in the same way that we did previously for the visual mode. For each different strategy we made three graphs: one displaying the percentage for the three category types distributed by all 25 correct move positions; the second showcasing a relation between the puzzle completion order and the strip piece pulling order; and the last one showcasing a relation between the puzzle completion order and the puzzle's presentation order. The graphs are clear for the identification of each of the considered strategies, being easy to pinpoint the trends for each strategy across all considered solving approaches.

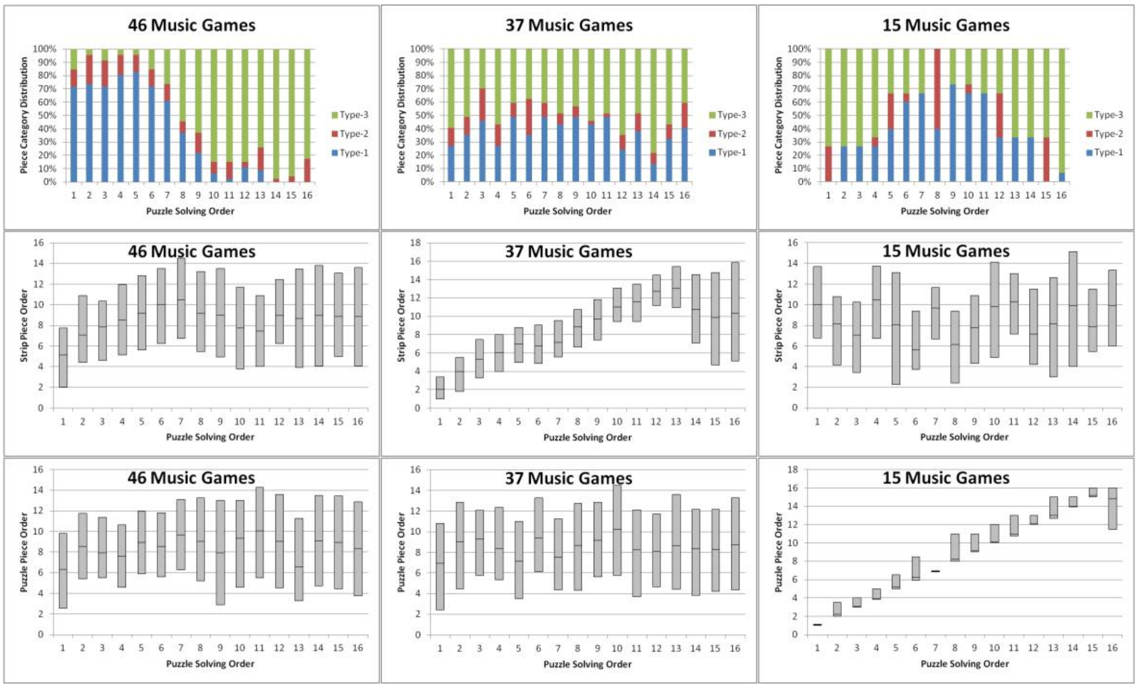

Figure 34 – First column: piece category strategy; second column: strip piece order strategy; third column: puzzle piece order strategy. First line: piece category distribution over puzzle solving order; second line: strip piece order over puzzle solving order; third line: puzzle piece order over puzzle solving order

In Figure 35 we have a simple comparative analysis for all musical puzzle solving strategies in regards to time, movements and score. The top first graph shows the average time it took to solve the audio puzzle for each of the strategies; on the second we can see the average number of movements needed to solve the audio puzzle; the last graph holds the average scores reached with each strategy. We also point in each graph the respective averages for the games considered as “unknown”, as a way of comparison and as a form of understanding the reasons for their exclusion from the data shown in the graphs above: very high number of movements and extremely low score, indicating a trial and error approach.

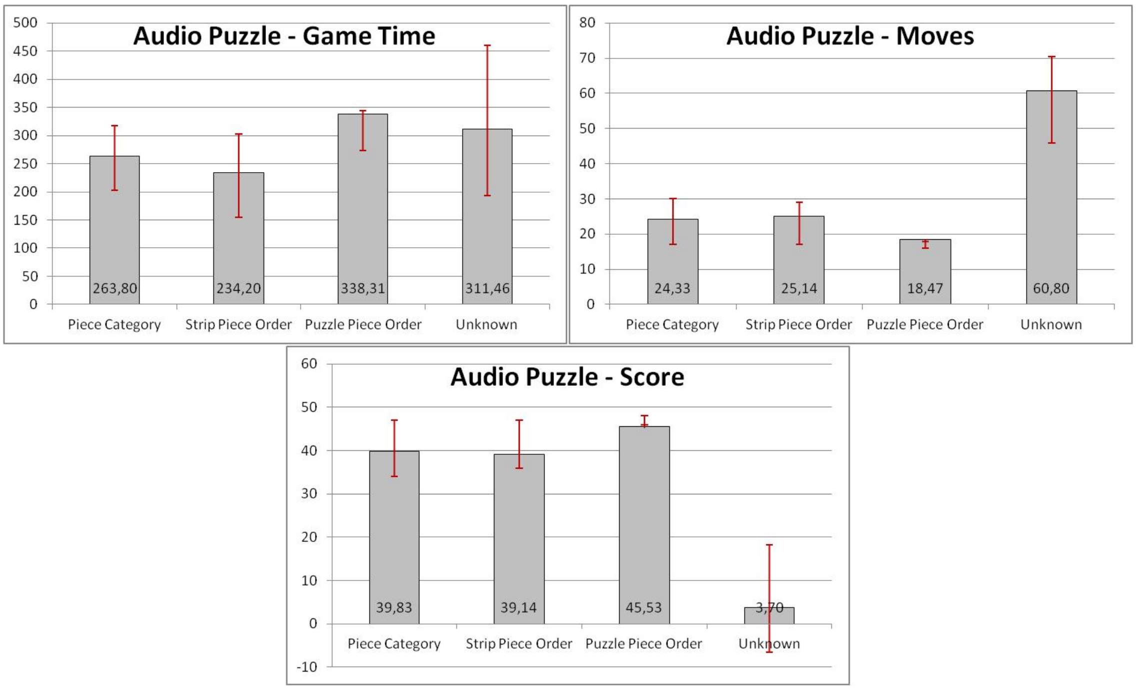

Figure 35 – Audio mode strategies comparative analysis for time (top-left), moves (top-right) and score (down)

We also assessed if players switched strategies over the course of the 9 mandatory games of the experiment: the intent was to check if players adapted over time to the strategies which resulted in higher performance values. The variations of those strategies over time are shown in Figure 36. In early games (1 and 2) there is an accentuation of the piece category strategy. From game number 3 to game number 7, we can observe a high variation in the adopted strategies, possibly due to player experimentation with different approaches. However, in the last couple of games we can visualize a confluence towards the strategies which yield the best performance according to the assessed metrics.

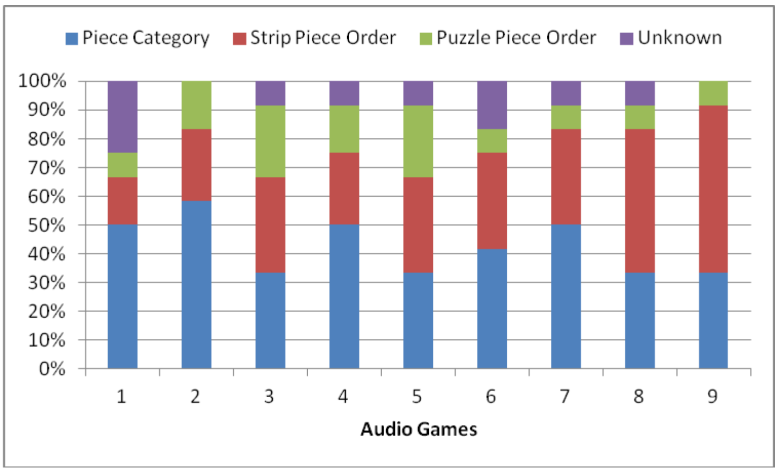

Figure 36 – Audio mode variation strategies over time

4.3 Simple Audio Puzzle Game

We undertook a user experiment to assess the flow of different mobile puzzle game approaches. Particularly, we focused on the differences and similarities between modalities as well as the users' opinion regarding fun and challenge. In what follows we detail our procedure and the results obtained in a user experiment with 24 people (12 blind) and comparing the new results with the previous experiment.

Preliminary sessions with two blind people suggested that the audio puzzle game was fun and that the users were able to use it effectively. However, these users accompanied the design application process and they had increasing experience with the concept. Furthermore, they represent a motivated and differentiated set of the target population (highly educated). To assess how the game performs regarding fun, difficulty, playability and challenge we performed an evaluation with blind people from broader backgrounds.

4.3.1 Goals

This experiment comprised one version of the mobile puzzle game: the simple audio mode. We defined a comparison with the previous experiment results, by using the same song (5^{th} Symphony at 6^{th} second) and number of pieces for the audio puzzle game. Both audio versions, as music-based puzzles, were parameterized with the same level of difficulty: 16 pieces. This was done as such so a comparison between the audio mode and a simple audio version is possible. We will use the visual mode results from the previous experiment as well. This mode varied in the number of pieces (25) and for comparison we will use the data from the games with the same image (first from Figure 15).

The audio version for the blind user set was parameterized with 9 pieces as this was a good compromise found in the preliminary assessments made with representative users from the target population. The reason for the decrease in the number of pieces is mostly due to the differences found between this set (older and less proficient with technology, mobiles and games) and the remaining sample.

4.3.2 Research Goals

The main purpose of this experiment is to assess the feasibility of different modality approaches of the same game while maintaining engagement. In detail, we aim to answer the following research questions:

- **RG7** – Can different modality versions of a same game maintain the game's challenge?

- **RG8** – Is multi-modality beneficial to user performance?
- **RG9** – Are playing patterns similar across different versions?
- **RG10** – Are we able to foster game inclusion through alternative modalities?

4.3.3 Variables

The selected dependent variables for this experiment were:

- Time to complete the puzzle,
- Number of placing attempts, and
- Number of individual helps and/or global helps required during a trial.

4.3.4 Participants

Twenty-four (24) people were recruited to participate in this experiment. This sample is divided in two sub-sets: the first one is composed of 12 (7 males and 5 females) sighted participants recruited in the university campus with ages comprehended between 20 and 33 years old (M=25.42); the second one is composed of 12 blind people (9 males and 3 females) recruited from a formation centre for the visually impaired with ages comprehended between 36 and 61 years old (M=49.8).

The experiment was composed of two groups of 12 people each associated with the simple audio mode puzzle game. No significant differences were observed regarding age between the sighted users set. Conversely, a significant difference was found between the sighted and non-sighted user's age samples.

We used the Samsung Galaxy Mini touch screen device, which runs Android operating systems. The device was previously loaded with the latest version of the Multimodal Puzzle Game. This was instrumented to manage and capture the session with each participant. In the audio version for blind people, instructions were provided via text-to-speech. Pico TTS was used as the speech synthesizer.

4.3.5 Procedure

The experimental period started with a pre-experiment interview to characterize the subjects, similar to the previous experiment. Upon the characterization phase, the participant was assigned to the simple audio mode game. With the help of the experimenter, participants started by learning the interface and were able to perform a 4-pieces training puzzle. All doubts and questions were answered during these tutorial sessions (within a maximum timespan of 15 minutes).

Each participant was asked to solve 3 puzzles. For sighted participants, each of these trials varied in the distribution of the pieces in the strip within the same song. In the first game, Type-1 and Type-2 pieces were randomly scattered throughout the strip. In other settings, Type-1 and Type-2 pieces were forcefully put at the end of the strip. In the last configuration, Type-1 and Type-2 pieces were forcefully put at the beginning of the strip. This order was purposely maintained for all participants. The song used is represented on Figure 27. At key instants, the initial segment of Beethoven's 5^{th} Symphony is played, starting at second 6 and endures for six more, stopping at the 12^{th} second. This segment acts as a Type-1 set piece, the transition between the two beats is considered a Type-2 set piece and the background beat is considered Type-3.

The methodology adopted with blind participants was slightly different. This group showed to be very distinct in expertise with technology, games, mobile devices and, in the overall, demographically. This disabled a fair comparison with other groups. On the other hand, assessing the feasibility of a puzzle game for blind people is still a challenge to be answered in this paper. The participants were asked to solve three music puzzles containing nine pieces each. Herein, a more realistic approach was employed. The pieces have a time period of two seconds. The songs selected were: Beethoven's 5^{th} Symphony, a more instrumental song, Ben Harper's "Diamond's on the Inside", and a national slow song with lyrics (Rui Veloso's "Porto Sentido"). In this setting, the order of the songs was randomized to counteract order effects.

All trials were video recorded and all interactions with the application were logged for further analysis. A post-questionnaire to classify the application in four different categories was employed, using a 5-point Likert scale.

4.3.6 Results

The evaluation was set-up with a between-subjects design where each group of 12 people performed three puzzles (puzzle trial) within a single puzzle mode. In order to perform a comparison with previous experiment results was considered a trade-off between challenge and average time to complete each puzzle. Direct comparisons were only performed between groups with the same experimental design (audio mode – 16 pieces).

The goal of this experiment was to assess how users cope with different modalities within the same game type: puzzle games. We started by analyzing each mode on its own revealing overall measures and trends within a method. Furthermore, we analyzed how the audio mode behaves in comparison to the simple audio version. This enables us to understand how multimodality may impact the performance and flow of casual games. We also look at patterns of gaming across methods trying to identify the differences and resemblances of the different modes. We end up assessing the feasibility of an inclusive audio-based puzzle game as well as depicting users' opinions to understand and compare their engagement with all versions.

Another goal was to assess if an audio-based version of the puzzle concept for blind people was feasible. Indeed, most participants stated to be ready for a harder puzzle after around 5 minutes of training. None required the whole training time (15 minutes) but still, four participants played the 4-piece training puzzle twice before they could say they were comfortable with it and the evaluation monitor could say that all interface elements were understood.

Visual Mode

For this comparison, the 3 games with the first image from Figure 15 played by the 12 players of the first experiment were selected. Playing the mobile visual puzzle game represents a similar challenge as the one in customary jigsaw puzzles. Figure 37 presents the average time taken by the participants to accomplish the different puzzles within the different evaluated versions. The visual mode, although parameterized with more pieces than all the remaining, shows to be faster to accomplish. This suggests, as we have previously mentioned, that this type of visual-based puzzle is less demanding than the audio-based versions.

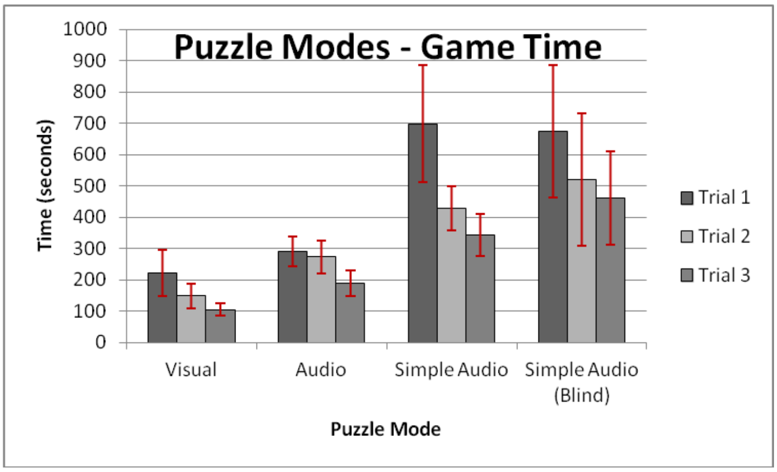

Figure 37 – Average time (in seconds) taken to accomplish each trial within each puzzle mode

The results show a trend of improvement from game to game regarding time in the visual mode. A Friedman test revealed significant differences between the three trials played ($x^2(2)=18.5$, $p<.0001$). A post-hoc test using Wilcoxon tests with Bonferroni correction showed these difference to be significant between Trial 1 and Trial 2 ($p < .05$) and between Trial 2 and Trial 3 ($p < .05$). Differences between Trial 1 and Trial 3 are implied. Conversely, no significant differences were found of puzzle trial on placing attempts, individual helps or global helps (Figure 38).

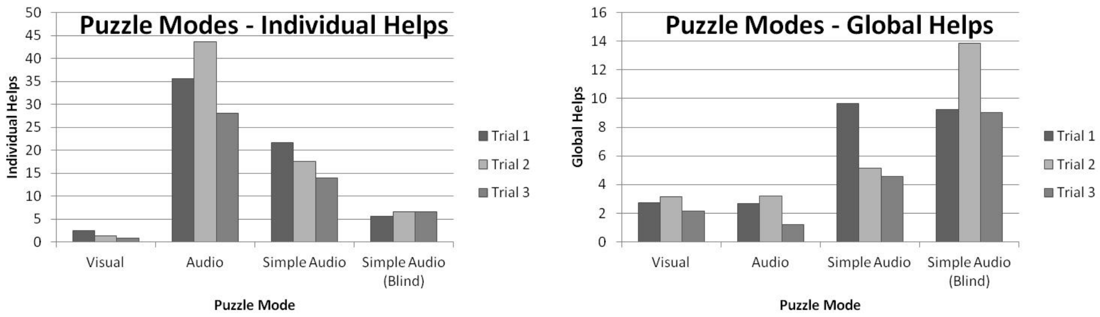

Figure 38 – Overall individual helps and global helps used in each trial within each puzzle mode

To better understand the performance obtained by the payers in this mode, Figure 39 shows the placing attempts and number of individual helps along with a visual representation of the piece. We can observe that most incorrect attempts are directly related to the background pieces and that all the Android figurine pieces are easily placed. The individual helps in this mode (as well as global helps) are rarely used.

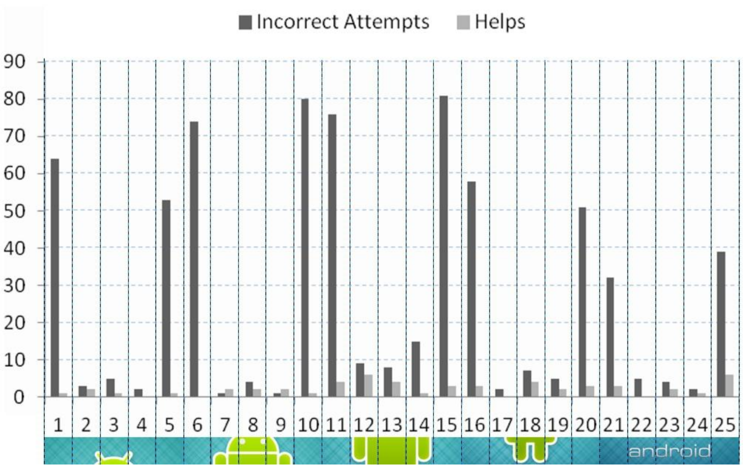

Figure 39 – Overall incorrect placing attempts and individual helps along with the sound waveform of each piece (visual mode).

Audio Mode

For this comparison, the 3 games with the Beethoven's 5^{th} Symphony at the 6^{th} second played by the 12 players of the first experiment were selected. This audio mode although providing a visual representation of the target areas and therefore enabling pieces to be placed anywhere on the puzzle, works over a different media: sound. Trials were conducted with the same song composed for the first experiment (Beethoven's 5^{th} Symphony on 6^{th} second). The chart in Figure 37 suggests smaller differences in time between the first two trials but a larger improvement in the third one. A Friedman test showed an effect of Puzzle Trial in Time ($\varkappa2(2)=7.167$, $p<.005$). Post-hoc tests showed these differences to be significant only between Trial 1 and Trial 3 ($p<.005$). No significant differences were found on placing attempts (Figure 40) or global helps

(Figure 38 – right). Significant differences were again found on individual helps (Friedman test, $\varkappa 2(2)=7.579$, $p<.05$) with post-hoc tests revealing them to be present only between Trial 2 and Trial 3 (Wilcoxon, $p<.005$). Indeed, a large increase is noticeable on the number of individual helps required from the first to the second puzzle played and an even larger decrease from Trial 2 to Trial 3. Figure 38 presents the number of individual helps for all puzzle modes illustrating this behavior. It suggests that the participants changed their strategy during the trials by first acknowledging the role of individual helps but then decreasing it with a better acquaintance both with the method and the song.

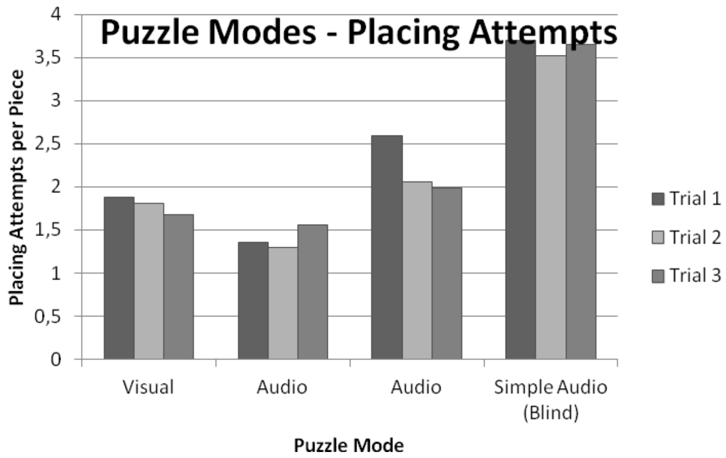

Figure 40 – Average number of placing attempts per piece for each trial within each puzzle mode

In Figure 41, we present the number of placing attempts and individual helps for each puzzle piece along with the audio waveform. All the pieces have in average a similar number of misled attempts to place a piece. On the other hand, the use of individual helps is high, but we can discriminate a slight difference on Beethoven's 5th Symphony excerpt (7 to 12 seconds in the waveform), exception made to piece number 10. Recurring less help requests is likely to be related with the knowledge of the music or part of it. The excessive use of help requests increases knowledge about the music and certainty, causing less incorrect attempts.

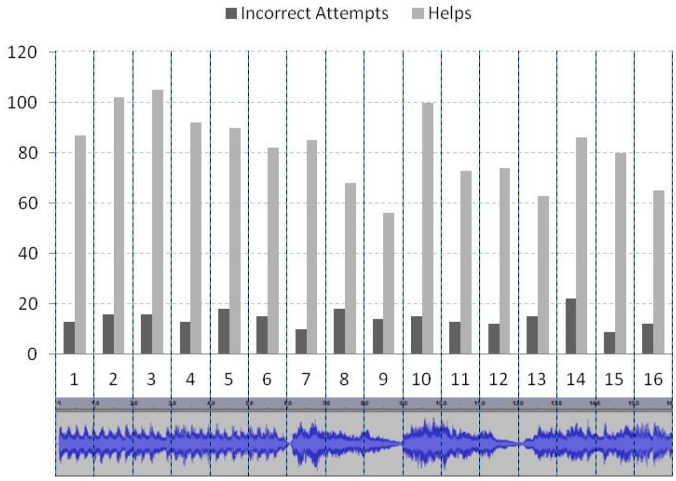

Figure 41 – Overall incorrect placing attempts and individual helps along with the sound waveform of each piece (audio mode)

Simple Audio Mode

The simple audio mode distinguishes itself from the audio mode by eliminating the square matrix target (and the overall need for a visual interface). Along, an important restriction is applied: the pieces are no longer placed anywhere on the target area; they are now placed in order from the first audio segment until the last. Looking back at Figure 37, it is noticeable that this leads to worse performances time-wise, particularly in a first contact with a song and an unorganized piece strip. This effect of puzzle trial showed to be significant on time (Friedman test, $\varkappa 2(2)=19.5$, $p<.001$) with post-hoc tests revealing this difference to be significant between all levels ($p<.05$). The number of placing attempts also presented differences between puzzle trials (Friedman test, $\varkappa 2(2)=13.35$, $p<.005$) . These have been revealed as significant between Trial 1 and both Trial 2 and Trial 3 ($p<.001$). Puzzle trial showed to have an effect on the number of global helps required (Friedman test, $\varkappa 2(2)=9.644$, $p<.01$). The number of both global helps ($p<.05$) and individual helps (not-significant but still observable in Figure 38) is higher in the first trial than in the remaining. This can be explained by the unfamiliarity with audio puzzle games and particularly with the increasing familiarity with the song in hands. Further experiments with different songs and counterbalancing order are required to distinguish between these effects.

Figure 42 presents the number of placing attempts and individual helps for each puzzle piece along with the audio waveform. High but decreasing attempts are associated with the background segment (exception made for the first piece which is easier to identify due to a starting silence) while lower attempts are associated with clear shifts in the sound waveform.

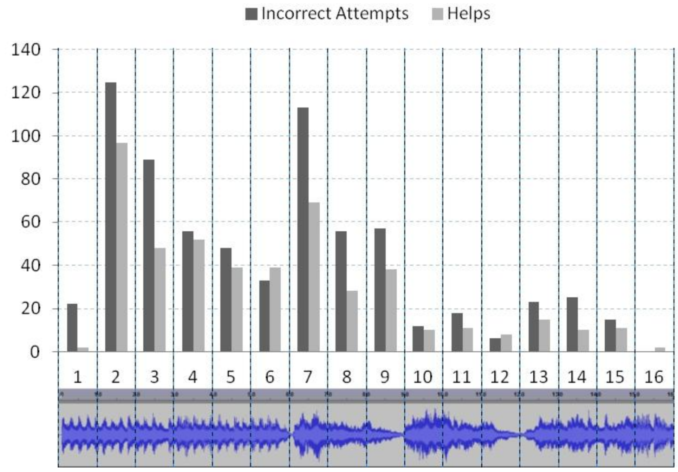

Figure 42 – Overall incorrect placing attempts and individual helps along with the sound waveform of each piece (simple audio mode)

Figure 43 presents the average time spent by the blind participants to accomplish the three puzzle trials. A significant effect of puzzle trial was found on time (Friedman test, x2(2)=6.5, p<.05) with post-hoc tests revealing that participants were slower in the first contact (M=651082 ms [10.9 minutes] , SD=369480 ms) with the application (Wilcoxon, p<.05) than the second (M=490172 ms [8.2 minutes], SD= 375467 ms) and third (M=437665 ms [7.3 minutes] , SD= 267450) trials. There was no significant effect of puzzle trial on placing attempts, global helps and individual helps suggesting that users are faster but they maintain similar playing patterns.

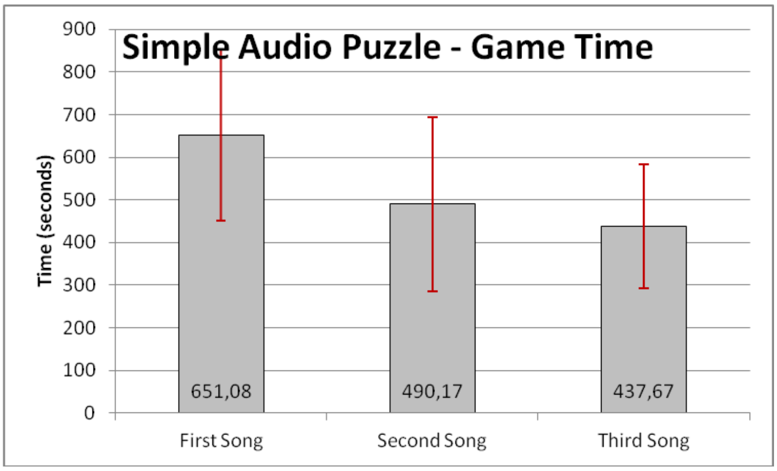

Figure 43 – Time (in seconds) taken to accomplish each audio puzzle independently from song (blind group)

Puzzle song showed to have no effect on time, placing attempts, individual helps or global helps. This means that users took in average the same time (and had similar playing behavior) with both instrumental and lyric-rich songs. Also, no correlations were found between individual attributes and playing behaviors. After each puzzle, the participants were asked about their familiarity with the songs (3-point Likert scale). These ratings also showed no correlations with the playing patterns and strategies.

Figure 44 presents the number of placing attempts and individual helps for each puzzle piece along with the audio wave form of Beethoven's 5th Symphony, Ben Harper Diamonds on the Inside and Rui Veloso Porto Sentido. In this music, the second piece was the most problematic since it blends musically with the fourth piece. Also, something to take note is the great musical similarity between pieces five and six. The first and third pieces also have similar sounds but with different music notes. The rest of the pieces are quite distinguishable. Individual helps are not commonly used (total of 57), but the total number of global helps for this music is one hundred (100), spread throughout the music.

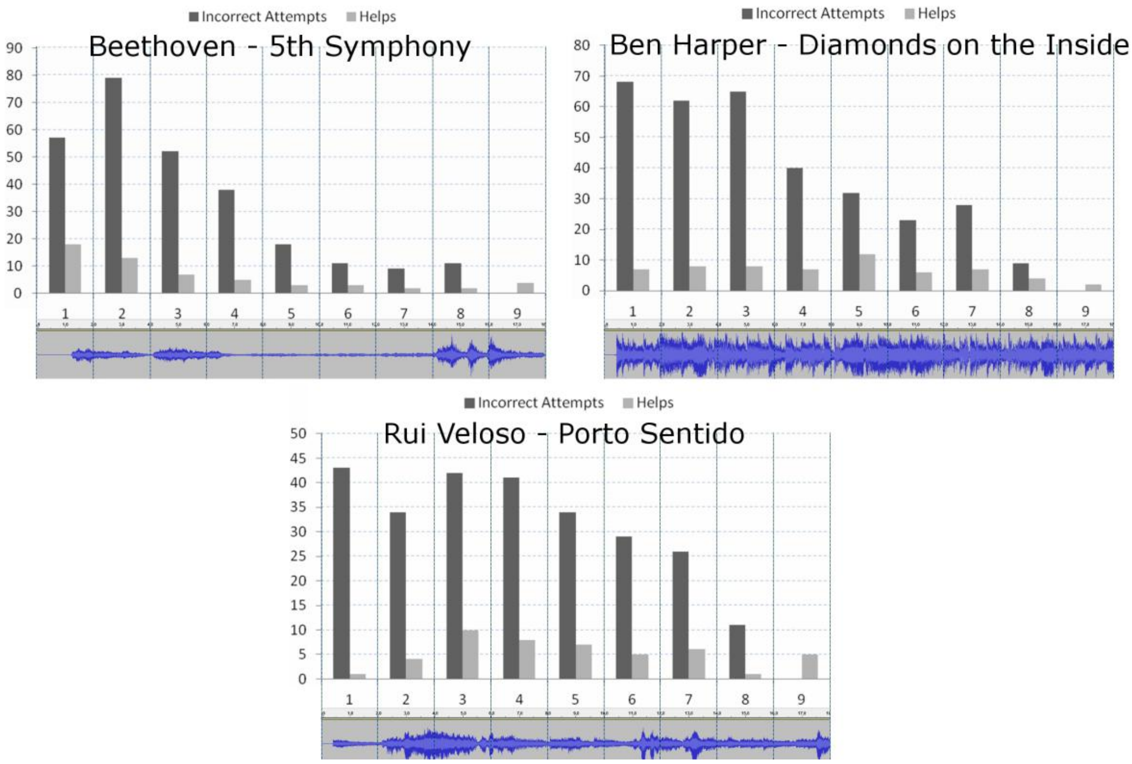

Figure 44 – Overall incorrect placing attempts and individual helps along with the sound waveform of each piece for Beethoven 5th Symphony (top-left), Ben Harper Diamonds on the Inside (top-right) and Rui Veloso Porto Sentido (down)

The second music, a song with English lyrics, was Ben Harper's "Diamonds on the Inside". Most segments of this song are lyric-based. Although the waveform is indistinct, the lyrics are very important in the disambiguation. Only two pieces, the first and the seventh, are purely instrumental. It was noticeable again the lack of use of the individual helps (62), in comparison with global helps (144). The low awareness of this music is more notorious than the previous, since it suggests more errors throughout the all music; greater number of errors in the early pieces (1, 2 and 3), and still relevant mistakes in the following (4, 5, 6 and 7).

In the last music, we chose a song with Portuguese lyrics (Rui Veloso's "Porto Sentido") in order to discover whether it was easier to solve. This particular song has three pieces of pure instrumental sound, the first, the fifth and the eighth, all different from each other. And once again, all the other pieces have lyrics, which may facilitate distinguishing the specific pieces. The relative difference of failed attempts is observable (smaller than the other two songs). The total number of incorrect attempts is the lowest of the three songs along with the total number of individual helps (49); the total number of global helps (121) is higher than in the Beethoven's but smaller than Ben Harper's song. This suggests that knowledge over the playing song enables less failed attempts and reduces the usage of help requests, making it easy to resolve (these results were not statistically significant tough).

Case studies (Blind)

In this section we will give special attention to two particular cases. The first highlight belongs to the best performance in all aspects, achieved by a 36 years old person, who is the only participant with some experience with tactile devices. She presents an average puzzle resolution time of 216 seconds, (1st: 370 seconds; 2nd and 3rd: about 140 seconds). Her average number of placing attempts is 13, an interestingly low value given that the minimum amount of movements required being 9. This participant only used 2 global helps per game, and hardly used the individual ones. The other person stands out also for is good performance but also for his age, a 60 year old male. His average completion time was 325 seconds. He had more difficulty in the classical music, taking 619 seconds. In the other two songs (lyric-rich) the times were quite constant, around 178 seconds. The total number of movements was in line with the previous results, worst in the classical music, with 40 moves, while the other two were constant (21 for each). As to global helps, this user used around 2 per game, and the individual helps were strongly used on the 5th Symphony (8). In sum, users with marked different profiles and backgrounds were able to play the game and find it challenging and fun. Even an older participant was able to enjoy the game in a first contact with puzzle games and touch devices, and show improvements during game play. These results proved that is possible a development of a game concept engaging accessibility.

Assessing the Impact of an Extra Dimension

Figure 37 shows that in a first contact with the puzzle game application, participants were slower accomplishing the puzzles with the simple audio mode than in the audio one; showing that the ability to place a piece anywhere on the destination puzzle improves performance over a structured approach like in the simple audio version. A higher number of help requests was asked to complete the puzzle in the audio mode (Figure 38). Also, Figure 41 reinforces that users rely on listening the target areas several times (individual helps) before placing the piece, while in the simple audio mode the number of help requests goes along with the number of movements made (Figure 42). Here it is visible that there are pieces more challenging than others while in the audio mode that is less visible as the strategy seems to cope with this variability in difficulty. Again, by looking at Figure 37 it is observable that users' performances tend to improve more in the simple audio mode getting closer to the performance achieved in the audio mode (around 300 seconds). Alas, this can be observed within a single game as the participants have an almost stable interaction pattern during the audio puzzle (Figure 41) while they seem to reduce helps requests and placement attempts towards the end on the simple audio puzzle (Figure 42).

Different modes seem to imply different patterns and strategies along with slight changes in performance. However, both games seem to be engaging and enable a fun and interactive experience.

Fostering Inclusive Gaming

By deploying games that resort to different modalities and interaction channels we intend to foster inclusion and increase the possible usage scenarios. In particular, by providing mobile games that neglect all visual feedback we are automatically including all users unable to receive such information. This includes blind people but also those that are situationally blind. In a casual gaming scenario, it is plausible to encounter situations where looking at the screen may not be advisable or possible (e.g. screen glare or pocket interaction). Results show that although the simple audio mode is slower it is considered as challenging, playable and fun. Also, by inspecting the charts in Figure 38 and Figure 40 one can observe that the differences in the interactions performed with the screen are not significantly higher than in the remaining modes. Looking in detail into the participants' results, a significant effect of puzzle trial was found on time (Friedman test, $\varkappa 2(2)=6.5$, $p<.05$) with post-hoc tests revealing that participants were slower in the first contact with the application (Wilcoxon, $p<.05$). Figure 43 shows high error bars for the blind user group which means high standard deviations which can by turn be explained by individual differences in ability within the target population. However, no correlations were found between the time taken to finish the tasks and users' age or expertise with puzzles, technology or having musical formation. No significant differences were found in the number of placing attempts or in any of the help types.

4.4 Multiplayer Puzzle Game

For the multiplayer puzzle game evaluation we conducted an experiment whose goal encompassed analyzing whether players would use a similar solving strategies across different modalities (visual and audio modes) over different multiplayer game modes: cooperative and competitive. Another goal encompassed a comparison between results from previous user experiments regarding existing solving strategies and user performance. This experiment involved two researchers supervising the tests and providing support to subjects as requested.

4.4.1 Goals

The primary goal of the experiment was to assess if players use similar strategies to solve visual and audio puzzle games under a multiplayer context. We once more wanted to analyze the order in which puzzle pieces are correctly positioned as well as if the order by which pieces are presented in the strip had any effect in the order in which the puzzle is solved. Another goal pertained to the compare to previous results according to three different parameters: completion time, number of moves for completion and player score.

4.4.2 Research Goals

The following are our research goals for this experiment:

- **RG11** – provide empirical evidence that players will place Type-1 pieces first in different images in visual puzzle games in cooperative and competitive mode. Additionally, players put Type-3 pieces last in visual mode.
- **RG12** – show that players will place Type-1 pieces first in different songs in audio puzzle games in cooperative and competitive mode. Additionally, players put Type-3 pieces last in the same audio mode.
- **RG13** – Compare the results between the cooperative and competitive modes regarding puzzle completion, number of movements for puzzle completion and correspondent score.
- **RG14** – Compare the results to individual approaches regarding puzzle completion, number of movements for puzzle completion and correspondent score.

4.4.3 Variables

We selected the same dependent variables from previous experiments. For puzzle solving order:

- Piece category solving order,
- Strip position solving order and
- Puzzle position solving order;

For game metrics:

- Game time,
- Total number of moves and
- Player score.

4.4.4 Participants

Twenty-four (24) people participated in this experiment, aged 21 to 29 (M=25.21; 18 male, 6 female), forming 12 different playing pairs.

Participants were handed Android smartphones (Samsung Galaxy Mini) to play the game. All devices were previously loaded with the Multimodal Puzzle Game.

4.4.5 Procedure

The experimental period started with a pre-experiment interview to characterize the subjects, similar to previous experiments. After a short simple explanation of the game concept, users were able to try a 4-piece visual and audio puzzle game, only to gain some initial experience. The main experiment's procedure was as follows: each pair of users was assigned to play 4 games: a visual cooperative, a visual competitive, a audio cooperative and a audio competitive. All the games images and songs were randomly assign. Keeping the previous selected values, the visual modes have 25 pieces and the audio modes 16. Only for the visual cooperative mode was exceptionally selected the hard difficulty challenge; on this difficulty players are forced to cooperate in order to complete the puzzle challenge, players must rotate the pieces from one another. This difficulty was only applied to this game mode because of their cooperation characteristics. The piece strip order was evenly distributed over the piece type classification. A post-questionnaire to classify the application in four different categories was employed, using a 5-point Likert scale, to assess the users' opinions.

4.4.6 Results

We will now address the results for the visual and audio modes

Visual Mode

Figure 45 presents the percentage for the three types of piece category distributed for all correct move positions. In cooperative visual mode, each player have half of the pieces (one has 12 and the other 13), so the minimum number of moves is 13. In competitive visual mode both players have all the pieces in the same strip position, so the maximum number of moves is determinate by the highest number of correct moves of a particular player which, in our experiment, was found to be 21. It is clear that Type-1 pieces are the first to be solved and Type-3 pieces are saved for last in both multiplayer modes: cooperative and competitive. This trend is relatively straightforward: our findings reinforce what already had been verified in the first experiment (Type-1 first, Type-3 for last).

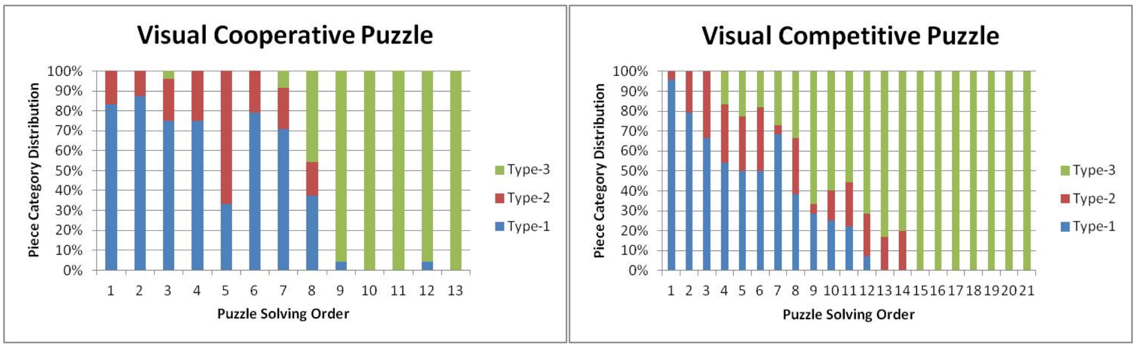

Figure 45 – Piece category distribution across puzzle solving order for cooperative and competitive modes (visual mode)

Figure 46 displays a box plot graph (average, first quartile and third quartile), showcasing a relation between the correct move slots and the positions of the pieces pulled from the strip. As showed before for the visual mode, there is an early trend which points that players do choose pieces based on the position in the strip area (the ones in early positions are the first ones to be solved) in both multiplayer modes.

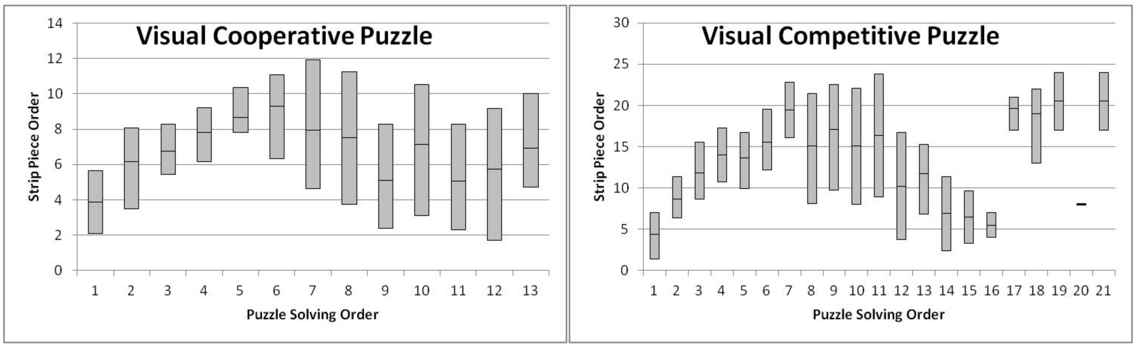

Figure 46 – Puzzle solving order according to strip position for cooperative and competitive modes (visual mode)

Figure 47 displays another box plot graph, similar to the above, but showcasing a relation between the correct move slots and the puzzle piece order displayed on the solving area. This chart was created to analyze the possibility of the existence of another strategy involved in solving visual puzzles. The graphs discard the possibility by showing that players did not opt to solve the puzzle according to its presentation order, as the user choices are distributed evenly across all available solving positions in both multiplayer modes.

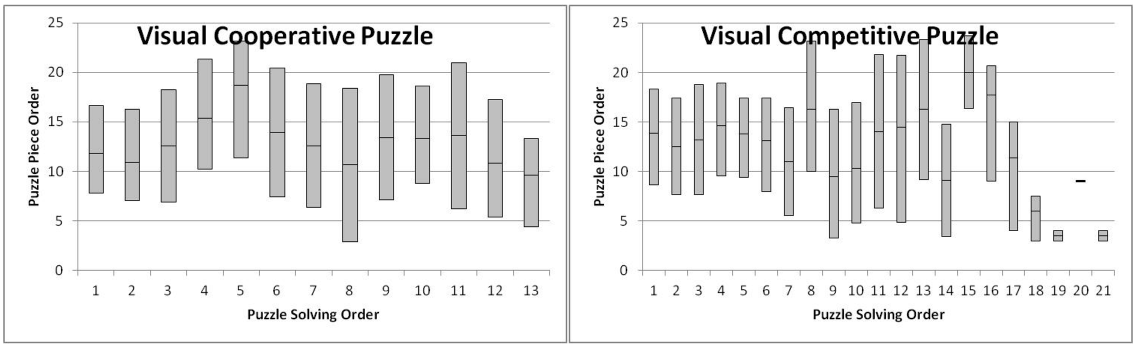

Figure 47 – Puzzle solving order according to puzzle piece order for cooperative and competitive modes (visual mode)

The completion time for cooperative and competitive mode is far apart (Figure 48) since the cooperative mode is much more demanding is terms of difficulty. This metric indicates that hard mode (first time tested) is in fact more difficult than the normal mode, regarding time. Both games have different difficulty levels, but this comparison was used in order to prove it. The individual visual puzzle game mode completion time is around 150 seconds, staying in the middle of the two multiplayer approaches. However the competitive mode shows a decrease in completion time (approximately 98 seconds) indicating that players strive to win by doing correct moves faster than the opponent.

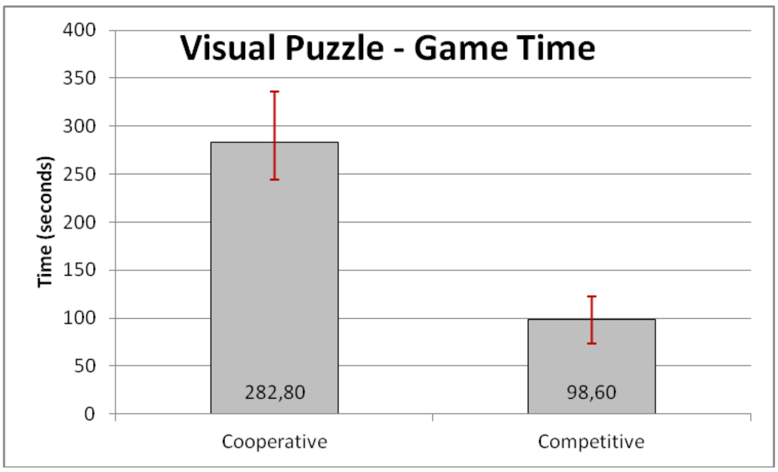

Figure 48 – Visual cooperative and competitive mode comparison average for time

Figure 49 indicates the average number of moves and average score for the multiplayer modes. In the cooperative mode the number of moves is relatively lower and the scores are consequently higher, while in competitive mode we witnessed the opposite – the number of moves was higher and the scores lower. The fact that both modes have different difficulty levels do not caused a great different in terms of placement attempts. In comparison with the individual visual puzzle version, the number of moves was slightly lower (40) on individual playing, and consequently the scores are higher (59). The lower number of moves on the cooperative mode indicates that, even with the pieces randomly rotated, players did not have many doubts on where to place them.

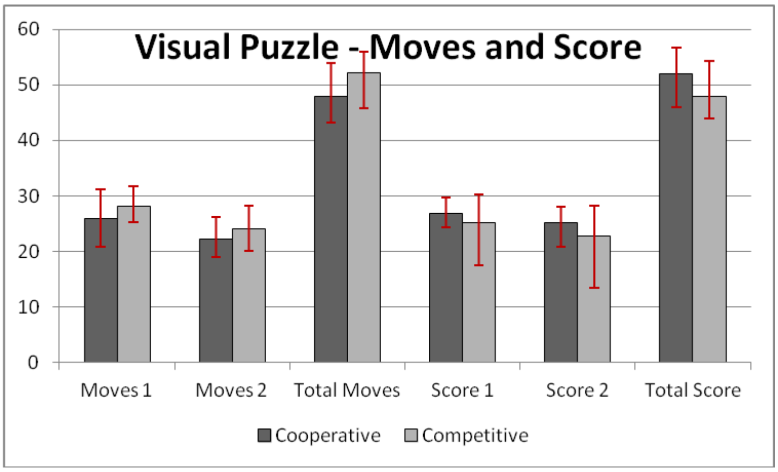

Figure 49 – Visual cooperative and competitive mode average metrics for moves and score

Audio Mode

Figure 50 presents the percentage for the three types of category distributed by all correct move positions. The maximum number of correct moves in cooperative audio mode is 8. For the competitive audio mode, as previously mentioned, both players have all the pieces in the same strip position, so the maximum number of moves is determined by the highest number of correct moves of a particular player which, in our experiment, was found to be 13. As before, the pattern is not clear to any multiplayer modes indicating that other solving strategies may possibly have been adopted. However, in cooperative mode, in the first four correct piece positioning actions Type-1 pieces have a higher percentage (around 50%). This trend may indicate that the main strategy is once more the piece category order.

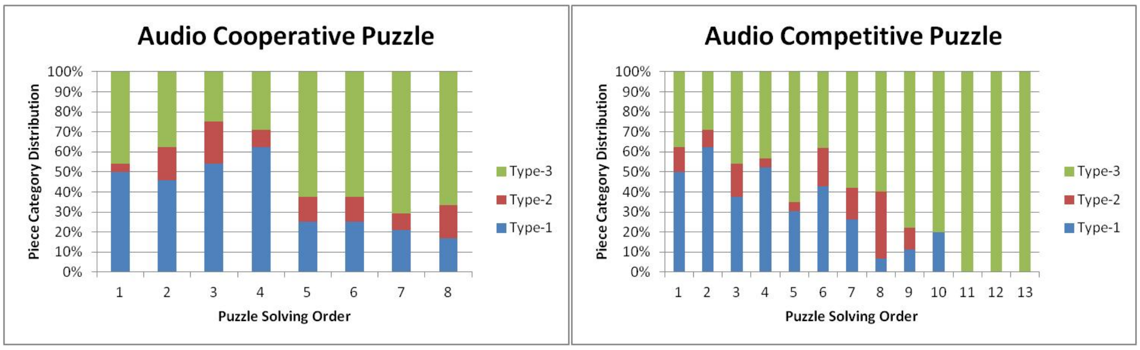

Figure 50 – Piece category distribution across puzzle solving order for cooperative and competitive modes (audio mode)

Figure 51 displays a box plot graph (average, first quartile and third quartile), showcasing a relation between the correct move slots and the positions of the pieces pulled from the strip. Here the expected early trend is not clear for each multiplayer mode. The cooperative mode reveals a high choice of Type-1 pieces on the early moves and of Type-3 on the last moves, but there are too subtle to take any strong conclusions, however could indicate that players do choose pieces based on the position in the strip area (the ones in early positions are the first ones to be solved). For the competitive mode the trend simply does not exist.

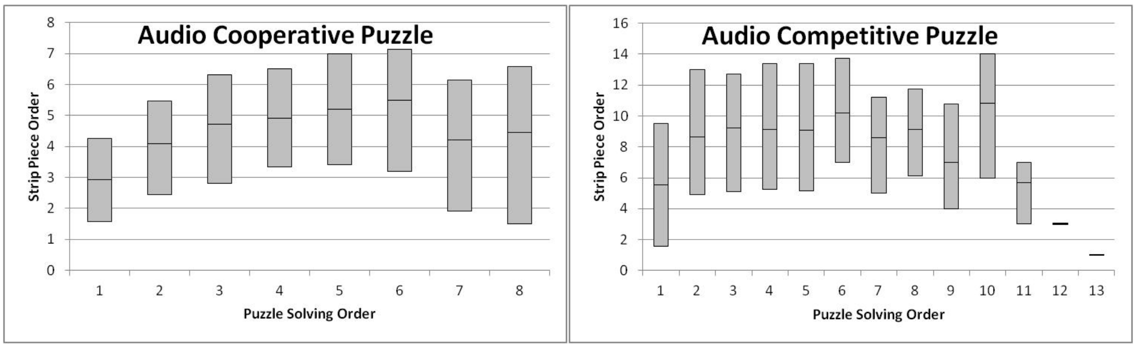

Figure 51 – Puzzle solving order according to strip position for cooperative and competitive modes (audio mode)

Figure 52 displays another box plot graph, similar to the above, but showcasing a relation between the correct move slots and the puzzle piece order displayed on the solving area. No pattern was revealed according to these graphs, showing that players did not choose to solve the puzzle according to its presentation order, as the user moves are distributed evenly across all available solving positions in both multiplayer modes.

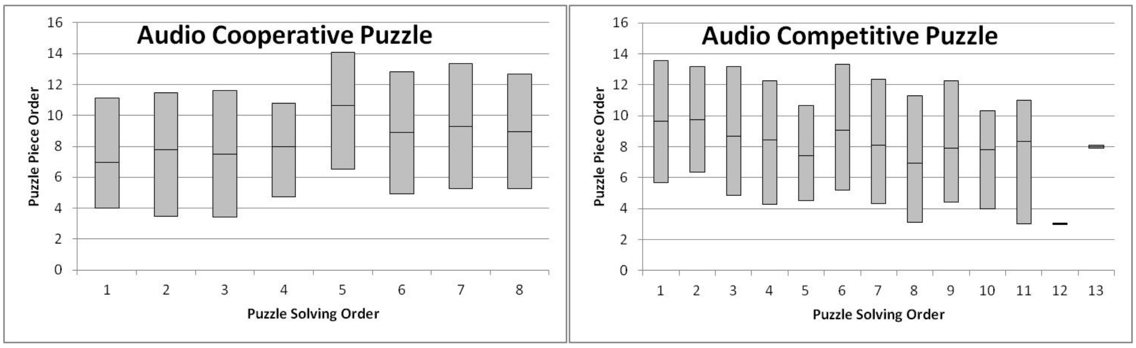

Figure 52 – Puzzle solving order according to puzzle piece order for cooperative and competitive modes (audio mode)

Figure 53 presents the average time to complete a cooperative and a competitive multiplayer audio puzzle. Competitive mode seems to promote a faster style of play, since completion time does not interfere with players' score; this indicates that players want to take advantage by doing more correct placements faster than the other player. Another conclusion for the multiplayer audio modes is that the overall completion time is lower than the individual version, for the same number of pieces and with the same songs.

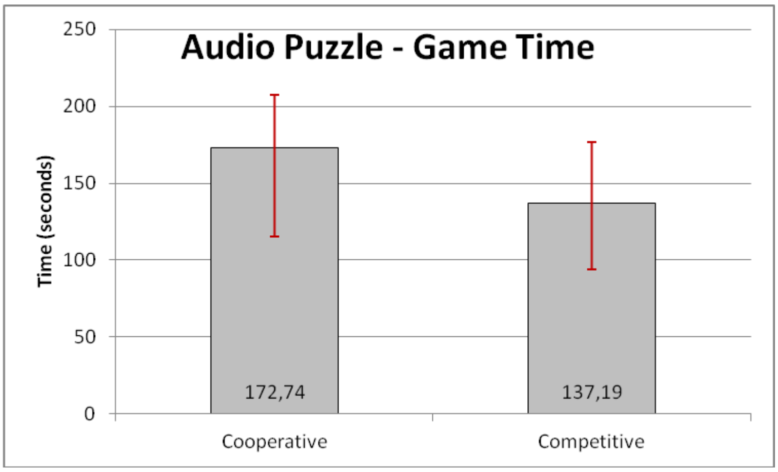

Figure 53 – Audio cooperative and competitive mode comparison average for time

The overall number of moves and attained score for each multiplayer mode is very similar (Figure 54). In comparison with the individual results, the total number of moves per game is much higher on the multiplayer modes. Each individual player (on the multiplayer game mode) does around 22 moves and a score of approximately 10 points, indicating the possible adoption of trial and error strategies since the average number of moves is 43 (for an audio puzzle game with 16 pieces). On individual audio versions the number of moves reaches an average of 22 with average scores of 41 points, with the exactly number of pieces (16) and same songs.

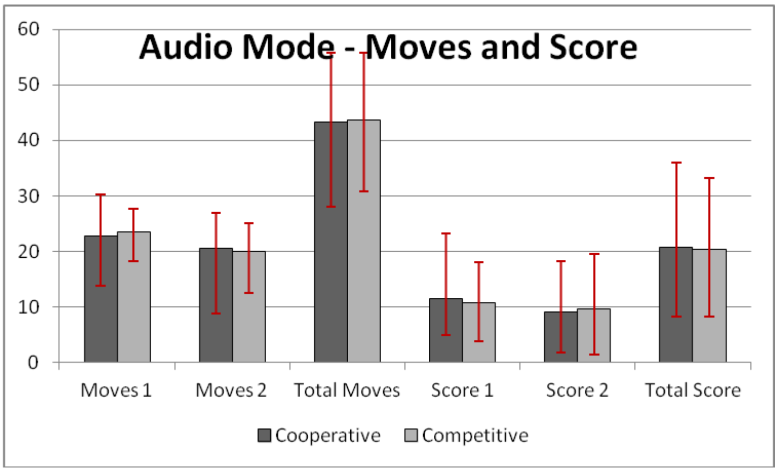

Figure 54 – Audio cooperative and competitive mode average metrics for moves and score

4.5 User Opinions

Table 2 presents a characterization of each sample group pertaining age, gender, habits in playing puzzles and computer games, and musical formation. Notable differences are observed from the blind group to all others in what concerns age, and the habits in playing puzzles and computer games. Among the sighted participants, there are some differences regarding the puzzling and gaming habits but not as marked.

Table 2 – Characterization of the five participant samples recruited for trials

	Age [sd]	*Male*	*Female*	*Puzzler?*	*Gamer?*	*Musical Formation?*
Visual Group	24,8 [2,7]	75,00%	25,00%	41,67%	91,67%	25,00%
Audio Group	23,8 [1,5]	91,67%	8,33%	25,00%	100,00%	41,67%
Simple Audio Group	25,4 [3,8]	58,33%	41,67%	50,00%	100,00%	41,67%
Blind Group	49,8 [8,2]	75,00%	25,00%	0,00%	25,00%	41,67%
Multiplayer Group	25,2 [2,1]	75,00%	25,00%	41,67%	91,67%	41,67%

To assess the opinions of our participants towards the different game modes we have applied a post-questionnaire composed by four statements to be rated according to a 5-point Likert scale (from 1 – Totally Disagree to 5 – Completely Agree). The results are presented in Table 3 (median and inter-quartile ranges).

Statistical significance was found for the effect of puzzle mode in the first and third questions. Concerning difficulty (Kruskal-Wallis, $\varkappa2(2)=12.844$, $p<.01$), results show that participants think the audio mode is harder than the simple audio one (Mann-Whitney, $U=24.0$, $Z=-2.896$, $p<.005$). Although this contradicts the completion time results (Figure 37), it can be explained by a more structured strategy to complete the puzzle. In the simple audio mode, the users are forced to fill the puzzle following the order in the song while in the audio mode they are free to navigate in both the piece strip and the puzzle area thus increasing the interactions with the screen. Blind people also consider the simple audio version as harder to play than the sighted participants did

(Mann-Whitney, U=20.0, Z=-3.224, p<.005). Regarding challenge, results suggest that the simple audio and audio modes are more challenging than the visual one (not statistically significant). As with difficulty, blind participants seem to acknowledge this challenge: besides the comments to the engagement created by the challenge imposed, the participants also felt challenged by using the interface as they were not proficient with touch screen devices. As to playability, differences were once again found (Kruskall-Wallis, $\varkappa 2(2)=18.243$, p<.001) between the audio and simple audio modes (Mann-Whitney, U=24.0, Z=-3.005, p<.005).

Table 3 – Users opinions for puzzle game modes (Median [IQR])

	Visual Group	*Audio Group*	*Simple Audio Group*	*Blind Group*	*Multiplayer Group*
The puzzle game is difficult to play	2 [1,25]	3 [1,25]	2 [1,00]	3 [1,00]	3 [1,00]
The puzzle game is challenging	3 [0,25]	4 [1,00]	4 [1,00]	5 [1,00]	4 [0,25]
The puzzle game is playable	4 [0,25]	4 [1,00]	5 [0,25]	4 [1,00]	4 [0,25]
The puzzle game is fun	4 [1,25]	3 [1,00]	4 [0,25]	4 [0,25]	4 [1,00]

Blind participants enjoyed playing the game and felt challenged by it. Regarding performance, we did not notice particular disinterest from older blind people: they also stated that games for blind people are coming short and are welcome. Results show that blind participants were consistent in positively evaluating the application with low rating dispersion. They thought the game was fun, playable and particularly, challenging. This is very relevant as they were neutral about difficulty. This difference between challenge and difficulty shows that they did not see the game as inaccessible but as something they could and keep being engaged with. Most participants stated to have felt insecure, mostly in the beginning, about the interaction areas on the screen and the primitives performed (e.g., flicking gestures). This lack of confidence can explain why the participants were slower in the first contacts with the application but had similar number of interactions. Blind participants pointed out that the game would be interesting to pass time and to relax. Several participants said that the application was very interesting to play with at bus stops, while riding public transports or while at home. Most participants were thrilled with the ability to play with any music on their phones and tried songs of their own.

Overall, the opinions regarding difficulty, challenge, playability and fun regarding the four presented approaches (and between sighted and blind participants) seems to be comparable which goes in line with the idea that different engaging versions of the same concept can be deployed.

Table 4 – Users opinions for multiplayer modes (Median [IQR])

	Visual Cooperative	*Visual Competitive*	*Audio Cooperative*	*Audio Competitive*
The puzzle game is difficult to play	3 [2,00]	3 [1,00]	4 [1,00]	3 [1,00]
The puzzle game is challenging	3 [2,00]	4 [1,00]	4 [2,00]	4 [1,25]
The puzzle game is playable	4 [0,25]	4 [0,00]	4 [1,00]	4 [1,00]
The puzzle game is fun	4 [1,00]	4 [2,00]	3 [2,00]	4 [1,00]

For the multiplayer game modes we applied a post-experiment questionnaire with the same four statements (Table 4). From the analysis players felt the audio cooperative mode more difficult to play, the visual cooperative was consider the less challenging one, even though the hard difficulty was applied. The less entertaining version was the audio cooperative. In overall, all the versions were considered playable.

4.6 Summary

This chapter presented the most important section of this thesis, describing the user study and the correspondent data analysis and results. The user study is divided in three experiments, one for each different puzzle game mode. 24 people participated on the first user experiment, being divided in two groups, one for playing visual puzzle games and the other audio ones. The second experiment had 24 participants in order to test the audio puzzle game without visual feedback; 12 blind users were able to play successful 3 different songs. For the multiplayer puzzle game 12 groups of two people played in pairs cooperative and competitive puzzle games, in both visual and audio modes. Last but not least, was presented users' opinions over all the puzzle application, regarding four different classification aspects: difficulty, challenge, playability and fun. This study main objective was to find players solving strategies on the same game concept across different modalities.

Chapter 5

Discussion

We are now in position to discuss the results in order to answer the research goals proposed earlier in this document.

5.1 Multimodal Puzzle Game

In order to answer to the research goals proposed for the multimodal puzzle game we will divide the discussion in two different sub-chapters, one for the visual mode and another for the audio mode respectively.

5.1.1 Visual Mode

The first conclusion from the obtained results is straightforward: research goal RG1 was verified and RG3 as well for the visual mode. Figure 28 is particularly elucidative that players prioritized solving recognizable pieces immediately, forfeiting background sections of the puzzle to last. The results suggest visual cues are extremely important to solve a puzzle game as individuals will identify them first and attempt to put them together. Given that we attempted to fulfill these research goals with 3 different pictures (albeit and forcefully similar to each other) the gathered empirical data further emphasizes the usage of this strategy.

On a second note, we tested to check if the order in which pieces are presented to the players has any effect in the order per which the puzzle is solved. Given the results presented in Figure 29 we consider this claim to be true, thus verifying RG3 for the visual mode. Figure 30 indicates that players did not solve the visual puzzles by the order of the puzzle itself.

Players prioritized solving recognizable pieces immediately, forfeiting background sections of the puzzle to last. The results suggest visual cues are extremely important to solve a puzzle game as individuals will identify them first and attempt to put them together. Given that we attempted to fulfill these research goals with 3 different pictures (albeit and forcefully similar to each other) the gathered empirical data further

emphasizes the usage of this strategy. As only one strategy was found RG4, RG5 and RG6 cannot be verified.

5.1.2 Audio Mode

Results for the audio mode were not as homogeneous as the ones stemming from the visual mode. As Figure 32 was inconclusive in the identification of a main strategy we proceeded with an individual analysis game by game with the intent of finding prominent audio puzzle solving strategies. By analyzing each game individually we ended up identifying 3 main strategies: piece category prioritization, solving by strip order and solving by puzzle order. Piece category prioritization was the most popular strategy with 43% of the games following this strategy. Even though a majority of at least 50% of samples was not reached for this strategy, it is plausible to state RG2 was met for the audio mode. The result emphasizes the importance that players give to prominent regions/segments of a puzzle, which ultimately leads to sharing puzzle solving strategies even across different interaction modalities.

All these observations are reinforced if we take into consideration the charts depicted in Figure 34. Here, each column pertains to a single strategy with graphs depicting how players prioritized piece categories, the puzzle piece strip pulling order and the puzzle presentation order, from top to bottom respectively. If we consider the piece category prioritization strategy (leftmost column) we can observe in the topmost graph that players started to solve Type-1 and Type-2 pieces, leaving the Type-3 areas to the end of their playtime. As stated before, this behavior favors RG2. However, we need to take into account if players followed another strategy, even if they followed this one. The remaining charts in the same column show that there is a fuzzy distribution from solving the puzzle according to the strip order or the puzzle presentation order – therefore we conclude that players taking on the piece category prioritization strategy exclusively followed it to achieve their goal.

The middle column in Figure 34 pertains to players who followed a strategy based on the order by which pieces are presented in the strip. The piece category distribution does not follow a clear trend like in the previous strategy, making it clear players did not solve the puzzle prioritizing any particular segment of the song. Instead, by observing the middle chart shows an obvious trend that these players opted to solve the puzzle by the order in which pieces are presented in the strip area. The particularly narrow quartiles indicate that there is, indeed, a focus on solving these pieces as they are queued in the strip area. The observation of the distribution according to the puzzle presentation order (bottommost chart) shows that these players ignored the puzzle presentation order when employing their main solving strategy. Given the still significant percentage of games following this strategy we can state that RG3 was also met.

Finally, the rightmost column relates to players who opted to employ a strategy based on puzzle presentation order. From the observation of the two topmost charts we can conclude these players neither prioritize solving according to piece category, nor by the strip order. Nevertheless, we must make a small note here: if we carefully visualize the topmost chart, we can discern a bell like distribution for Type-1 and Type-2 categories. The reason for this is explained by the songs used in the experiment – the first and last segments only contain Type-2 and Type-3 categories (as can be easily concluded from the chart). This means that all Type-1 pieces would be clustered in the middle positions, even for the 3 different variations of the song. Furthermore, the 8th segment of any variation of the song is always either a Type-1 or Type-2 piece, a fact denoted in the chart by observing the distribution of the 8th piece to be solved correctly. The final graph depicting the distribution according to the puzzle presentation order clearly dictates that players solved the puzzle strictly according to the order by which the puzzle is organized in the game area. In summary, for the audio game mode, players adopted three different strategies. Two of these are reminiscent of strategies employed in the visual counterpart. The obtained results allow us to meet our research goals for the audio mode – RG2 and RG3.

In order to answer to RG4, RG5 and RG6 we need to analyze Figure 35. In terms of average time to solve the audio mode it is clear that puzzle piece order is the slowest one with almost 338 seconds (more than five minutes); the fastest is the strip piece order strategy with 234 seconds (nearly four minutes); the piece category strategy stood in the middle with an average of 264 seconds (a little more than four minutes). That being said, the RG4 answer is the strip piece order strategy. The top second graph in Figure 35 helps us figure out which strategy requires less moves to solve a puzzle in audio mode. On average, piece category and strip order strategies are virtually identical with 24 and 25 movements respectively, while puzzle piece order only requires 18 moves, thereby earning the right to verify RG5. The last metric we considered was the player's score. Here we can verify that on average, once again, piece category and strip order strategies display identical results, with 40 and 39 points respectively. Nevertheless, the answer for our RG6 research goal appears to be the puzzle piece order, providing players with the highest average score at 46 points.

By carefully analyzing the chart in Figure 36, we can claim that there is no significant convergence towards a single strategy – the distribution for both piece categorization and strip order strategies constantly fluctuates over time; on the other hand the puzzle order strategy obtained a relatively stable number of followers. It is also important to state that four players did not alter their strategy across all 9 games, and the game in which most users altered their strategy was game number 6. This may have occurred for two reasons: a) due to player fatigue – since the audio version of the experiment lasted for a significant period (averaging more than 40 minutes per subject) we believe a few players were looking for a fast way to end the experiment, and thus changed strategies halfway through it (at around the 22 minute mark of the experiment); b) due to the questionnaire break introduced in game 5 – we asked users to respond to a short survey after game 5, leading us to assume this pause prompted players to explore alternative strategies when they resumed the experiment.

5.2 Simple Audio Puzzle Game

Both simple audio and audio versions showed to be challenging but still engaging and fun, this information is represented on Table 3 and answers to RG7. The challenge was increased when the visual modality was withdrawn. The visual puzzle game was proved as easier than the remaining. When asked, participants supported the idea that the different modes were engaging and challenging showing a slight preference for the Audio mode.

When comparing the audio and simple audio versions in terms of completion time on Figure 37, one can state that indeed multimodal output presents benefits as it maximizes the bandwidth of information (access to more information from several different source modalities) and interaction possibilities (allows the user to interact with different approaches). However, participants showed a slight preference for unimodal approaches suggesting that unimodal options are advisable, but real multimodal variations (several channels within the same game) can reduce the engagement. One must have in mind that a casual game needs to be simple and natural – multimodal approaches often seem to fall in that category. For the same versions, in terms of used help requests (Figure 38) and placement attempts (Figure 40) over the 3 trial games, the results converge to similar values. The simple audio mode was the highest ranked regarding playability (Table 3), suggesting that it was the most appreciated by the players, by its simplistic way of playing with only a few possible finger interactions. With the achieved results RG8 is hard to verify.

Overall, strategies seem to be comparable across all methods, thus verifying RG9. Nevertheless, there are observable differences mostly regarding the usage of help requests which is expected as some game modes promote their usage (e.g., audio mode). One important aspect is that these suggested behaviors seem to affect the user’s ability to improve performance. For example, in the audio mode participants overly rely on hearing several pieces before placing the piece in hands. In the simple audio mode, as this kind of verification is not possible, improvements during the trials are more noticeable.

RG10's straightforward answer is yes. The simple audio mode was considered fun but also challenging by the blind participants. The blind user group, even with low technologic skills and no experience with mobile touch screen devices, presented acceptable results in a first contact and a noticeable improvement in the remaining trials. Also, they were able to play the game with similar strategies as the sighted group showing that these technological handicaps were easily surpassed with an adapted version of a puzzle game.

After the game trials several blind participants said that they would like to have a way to compare their scores with their friends and other members of the association. This suggestion leads us to believe that sharing scores with all players on a server could enhance the player amusement and cause performance improvement.

5.3 Multiplayer Puzzle Game

The research goals proposed for the multiplayer puzzle game will be answered in two different sub-chapters, one for the visual mode discussion and another for the audio mode respectively.

5.3.1 Visual Mode

In the multiplayer cooperative and competitive visual mode the same puzzle solving strategy was found: players prioritized solving recognizable pieces immediately (Type-1), forfeiting background sections of the puzzle to last (Type-3). Figure 45 verifies RG11 for both multiplayer modes. Figure 46 shows, as proven before, that the initial game actions are directly affected by the strip piece order.

Regarding puzzle completion time, the results can be consulted in Figure 48. Completion time for the cooperative mode is higher than competitive mode and visual individual versions (RG13 and RG14), due to a steeper difficulty selection. On the other hand, the competitive mode has the lowest time from all the 3 visual modes, meaning that completing a visual puzzle, with the same number of pieces and equal images, will tend to be faster with two persons playing than solving alone.

For other evaluating metrics, moves and score, the results on Figure 49 claim that there is no evident pronounced difference when comparing the cooperative and competitive mode (RG13). Observed values are too similar but with a higher number of moves and worse score for the competitive move. This may be explained by the heat of the competition between players which promotes a faster style of play and, ultimately, can cause more errors during game. In comparison with the individual visual versions (RG14), the number of movements is lower and scores are higher when playing alone.

5.3.2 Audio Mode

The audio multiplayer solving strategies are not as evident as in visual mode. The main strategy adopted appears to be the same one identified for visual mode: solve recognizable pieces first and leave background beat for last. This seems to be the most used solving strategy, not rejecting the possibility that there may be other ones. This can be observed in Figure 50 and Figure 51 verifying RG12 for the main used audio strategy.

Completion time for competitive mode was revealed to be faster than cooperative mode (RG13), meaning that in fact players felt forced to act quicker than their opponent while solving the puzzle (Figure 53). Both multiplayer modes have faster completion times than individual versions (RG14), having used the same number of pieces and the same songs – this suggests it is faster to resolve audio puzzles with two players than with only one player.

On comparing the number of moves and the correspondent score, Figure 54 shows that the values for cooperative and competitive modes are almost the same (small differences found), leaving us to believe that the solving strategies over different multiplayer audio modes are constant (RG13): players use the same solving strategies over cooperative and competitive modes. In individual audio versions the number of moves is lower, leading to a higher score than both multiplayer modes (RG14).On cooperative and competitive modes, the number of movements for a player is similar to the individual mode, but in multiplayer mode, both players' moves must be combined in order to obtain the total number of necessary movements to complete a puzzle game. Overall, comparing with individual mode, the total number of moves reaches almost the double (and consequently the total score falls to half).

5.4 Development Guidelines

It is necessary to consider some important guidelines in order to developed mobile casual puzzle games:

Visual mode:

- Piece size and puzzle size selection: for a visual puzzle game, the size and number of pieces is very important, because they keep a direct relationship with the solving difficulty. Each mobile device has a different screen size. The maximum puzzle size is directly related with the minimum piece size. The possible minimum piece size is also directly related with the device screen size, because it must be possible to see the pieces and place them.

- Piece strip for selection: in order to enable a fluid piece selection for every puzzle size, was developed a strip of pieces controlled by the player – finger swipe right or left will uncover more pieces.

Audio mode:

- Song segmentation: in order to play an audio puzzle a song must be divided into several different pieces. It was selected a fixed time per piece for this division. This metric (time per piece) is directly related with the solve difficulty, meaning that with less time to recognize a single piece the puzzle will be harder.
- Maintain the same piece layout: all audio pieces should have the same layout, in order to prove that players' piece selection was only based on the audio part of that piece (avoiding visual selection). Some users complain about this game characteristic, being hard to keep track of the pieces. Monitoring users' proceedings reveal a solution – placing selected pieces between the solving area and the pieces strip, without check his final position, only to distinguish them. Other implemented solution was a different layout for the last listened piece on the strip – this way, users gain a temporary reference.

Accessible audio mode:

- Support social aspects of game play: some blind users wondered about the possibility of comparing their scores with their friends' and colleagues'. A great improvement should be the inclusion of leaderboards, sharing the players' performances, for instance, using a centralized server.
- Information must be accessible: an application without any visual feedback should be able to attend the users' needs. Audio and haptic feedback was used as output modalities to inform the user of their actions and options. These development choices were well received by users over the trials – users became pleased with the provided interaction and had no complaints or suggestions.
- The game interaction must be kept simple and intuitive: simple finger gestures (such as double tapping and finger swipes) were selected as input modalities to enable users playing options. The selected gestures must be simple in order to be easily comprehended and memorisable. The total number of gestures should be low in order to not alienate the player with too many similar moves.
- Support multimodality while playing to promote inclusion: with a multimodal audio puzzle game (non-visual) we provided different playing options that are

important to reach more people. We created a puzzle version that is accessible to blind people and on impaired context situations (such as sun blindness).

Multiplayer mode:

- Support multiplayer game connection in order to promote player to player engagement and interaction: as said before, a low-range wireless network connection was selected in order to force a closer player interaction. For a cooperative mode this was a great choice allowing players to communicate, aiming to solve the puzzle as a team. As for the competitive mode, it was a good choice as well, allowing users to feel each other reactions over the game – players will giggle upon a successful play, brag over the other player when winning and curse the other player upon losing. It is possible to enrich the competitive mode with a centralized server for network gaming.

General:

- Provide proper challenges and features that offer feedback over player improvement: on game trials players often complained about puzzle repetition (mostly about audio song), demanding more challenges with more pieces and different images and/or songs. Players' final performance was proven to be very important, being used as base values for improvement on next game trial. Goals and gifts are also good props to enrich the game.
- Provide the possibility to affect, modify and/or interact with game features and options: the developed applications have a great number of available options, from puzzle size, to difficulty level, through puzzle mode. Players need to define game available preferences in order to set the desired puzzle challenge.
- Support various types and generations of mobile devices: covering a greater number of people, from different ages and social strata. Despite using the same smartphone model in the user trials, the game application on the market covers a wide range of models and form factors, from smartphones to tablets.

5.5 Summary

This chapter presents a final conclusion regarding all the developed applications and the performed experiments. We also present important guidelines for the development of mobile puzzle games. The results provide empirical evidence that players employ similar puzzle solving strategies across all different modalities: first the players solve the more easily identifiable pieces of the puzzle game, leaving the fuzziest to the end of the game. This proves to be true for all the tested game applications over different modalities, though there were additional solving strategies. All the applications proved to be playable, challenging and fun. Although there are differences in the average of users' opinions they are very close and similar, proving that it is possible to create similar games, through different modalities, using the same game concept.

Chapter 6

Conclusions and Future Work

This chapter presents the drawn conclusions after all the work has been performed, as well as an analysis of prospects for future work.

6.1 Conclusions

This thesis presented three game applications for Android mobile devices: the Multimodal Puzzle Game, the Simple Audio Puzzle Game and the Multiplayer Puzzle Game. For the design of these applications, we capitalized on the lackluster offer of puzzle games involving challenges beyond visual images. As such we created a game for Android devices which allows players to solve not only image puzzles, but also audio and haptic puzzles. The applications allow users to tackle on a set of puzzles (both image and audio) created specifically for this game or pick images and songs from the device's own library.

This thesis also presented a user study divided in three different experiments, one for each developed application. The users were asked to play visual and audio puzzle across the different modalities. This study aimed at finding solving strategies over different modalities on the same game concept.

All in all, despite more puzzle solving strategies being found in the case of the audio mode, we can state that players primarily recur to one strategy when solving puzzles in a mobile device: first they attempt to identify the most salient areas of the puzzle (e.g. particular images or segments of a song); secondly they solve the puzzle based on the order pieces are delivered to them even if they can navigate through all pieces. Both these conclusions hold true to the visual and audio modes of the Multimodal Puzzle Game. In audio mode, a third approach was found in which players solved the puzzle according to its natural presentation order. Each strategy found reveals different performance results, some being more suitable to finish quickly and others to achieve higher scores.

The main contribution is the insight on player strategies which can prompt developers and designers alike to build puzzle game UIs to accommodate the users' preferred strategies or those which can maximize player performance.

Accessibility is other important issue addressed in our study. The results regarding the Simple Audio Puzzle Game experiment tend to respond to this problem, offering a puzzle game application without any visual feedback. The variety of demands behind nomadic contexts suggests for flexibility in the way we are able to interact with mobile applications. The user experiments revealed that the variations deployed are challenging and fun to play. Furthermore, they enable the inclusion of disabled groups, who are unable to use the conventional versions. This also suggests that this availability of alternative modality-based versions of a puzzle is likely to include a wider range of mobile contexts.

By deploying games that resort to different modalities and interaction channels we intend to foster inclusion and increase the possible usage scenarios. In particular, by providing mobile games that neglect all visual feedback we are automatically including all users unable to receive such information. This includes blind people but also those that are situationally blind. Results show that the audio mode is considered as challenging, playable and fun by blind people. Also, a detailed view on the results presented the audio-based puzzle game as an application accessible for a diverse set of blind users (different backgrounds and abilities).

For the multiplayer cooperative and competitive versions, the users' solving strategies were found to be similar to the ones found for individual modes, for both visual and audio puzzle games. Both multiplayer modes were consider challenging, playable and funny to undertake as a casual game; the competitive mode showed to be more affinity as a multiplayer game than the cooperative version; but the cooperative version (as a closer ranged multiplayer game) reveal to promote player communication along the game play.

This thesis contributes with a new insight about the use of multimodalities and collaborative stances in classic games, particularly jigsaw puzzles. The understanding of user's strategies and of best strategies in all variants and modalities combinations provides relevant hints for the design of puzzle games and particular learning systems based on these types of games. Moreover the work also contributed to show the feasibility of completely substituting the main modality of classical puzzles, vision into audio, as a way of coping with intrinsic users' disabilities, in this case the blind, or opening the way to situated impairments, so common in mobile contexts.

6.2 Future Work

For future work we plan to undertake a longitudinal study encompassing a large number of players. The deployment of a version in the Android Market was the first step and will enable monitoring the usage of puzzle games in real life scenarios. With increasing download numbers we aim at retrieving thousands of game logs for the visual and audio puzzle versions, enabling us to tackle a large-scale study.

Furthermore, although ill-explored until now, we will strive to achieve a more usable version of the haptic game as it holds the promise of another inclusive modality both in situations and possible users. There are two strong ideas to give a clearer objective to the game concept:

- Use the created Morse code haptic version in order to transform the puzzle game in to hidden words or even phrases; with this concept, players will have the objective not only to identify the vibratory patterns but also to set up the letters with some logical order. One problem is the repeated letters that should be treated specially for each puzzle game.
- Other concept is to transform any song waveform into a vibratory pattern, then split it into pieces. In other words, the music will be translated into vibratory patterns. The music rhythm will be printed over a set of vibratory code of numbers for each piece. This concept seems to be hard to understand and explain, but with easily recognizable songs it should be suitable in puzzle form.

The simple audio mode can benefit from a refreshed menu layout and improved interactive mechanisms increasing inclusion for users with visual disabilities and to contextual impairments. With a responsive menu, as the user passes his finger over an interactive item, audio and/or haptic feedback is triggered, which eliminates the need of visual feedback. The user will have the possibility to selected game modes and puzzle features without even looking to the device's screen.

Other important improvement emerged from a suggestion over the simple audio mode experiment; several blind users would like to be able to know the scores of their friends and from other members of the association. The creation of leaderboards sharing the scores of all the players on a server will improve players' amusement and their performance as well, by fostering a more competitive approach to the game.

Other possible improvement is on the multiplayer mode since it has great potential. Several alternative game modes can be created in order to provide new and alternative forms to play puzzle games, using different modalities:

- A haptic mode can be integrated on the available multiplayer cooperative and competitive game modes, after finding one viable version.

- Create a multiplayer game without visual feedback, using the available version and/or the collected knowledge about building such applications.
- Create new multiplayer modes, different challenges and features, for example: create a centralized server allowing the players to tackle puzzle challenges with other people over the network; new game modes with team players cooperating within the same team and competing with the other team, offering new challenges; new features such changing pieces with other players or request a specific piece can bring new and different play strategies.

Another future application consists in a geo-located puzzle game, where the player assumes the role of a puzzle piece and must place him/her self over the right position and face the right direction in order to rotate the piece. This approach may adopt both an individual and a multiplayer mode. In the latter, several players run around to place more correct pieces than other players and in order to gather more points; changing pieces or requesting specific pieces are important features on this multiplayer mode, in order to evaluate if player solving strategies change with game points or physical wearing.

Chapter 7

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