Puzzle Games: Player Strategies across Different Interaction Modalities

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ABSTRACT
This paper presents the design of a puzzle game for the Android platform along with a study on puzzle solving strategies across different interaction modalities. Solving puzzles is among the oldest challenges and entertainment activities available to us. However, despite major technological advances, the design of such games has never provided individuals with challenges beyond visual puzzles. We capitalized on this opportunity to tackle the design of puzzles which go beyond visual cues, utilizing sound and vibration feedback as well to offer a fresh challenge to players. Along with the design of this game, our research focused on analyzing puzzle solving strategies applied by users. In particular, this paper details a study in which we analyzed if players apply the same strategy to solve a visual and a audio puzzle. Results point that players often opt to solve prominent areas first, leaving more abstract zones to the end, independently from the interaction modality involved.

Author Keywords
Audio Puzzles, Puzzle Games, Play Strategy.

ACM Classification Keywords
H.5.2 [**User Interfaces**]: Interaction Styles.

General Terms
Performance, Experimentation, Human Factors.

MOTIVATION
Videogames can be used for various ends, ranging from personal entertainment [2][17], as a catalyst for social interaction [12], as a support tool for teaching and learning process [18] or as an experimental platform for new technologies or design concepts [11]. In the education domain, games are of particular importance for students to develop learning skills which allow them to easily create abstractions of concepts or algorithms [10]. 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. Hill [5], Levitin [9][10] and Ross [15] have defended utilizing puzzles and games in general as a motivating factor for a diversity of courses. Ginat [4] has also explored the usage of puzzle games as a catalyst for students in learning environments. Outside the education domain, there has been a deployment of a puzzle game to foster communication and collaboration between children with autism spectrum disorder [1]. 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.

In the entertainment domain, and with the proliferation of various types of mobile devices [3], videogames are currently widespread across different platforms [11][12][16]. Furthermore, given the increased computational power [7] and number of features present in modern mobile devices, developers are recurring to different modalities [14] to provide players with alternative challenges which would not have been possible before [6]. Yet, 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 [2], 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.

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 or audio 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. Taking inspiration from different puzzle learning strategies and learning environments, we designed a study which aimed at assessing if players use similar strategies for solving multimodal puzzles. In particular we wanted to determine if

Fun and Games' 2012, Toulouse, France — September 4-6, 2012

users tend to prioritize particular puzzle pieces or if they solved the puzzle in the order the pieces are presented to them. This paper presents a study comparing puzzle solving strategies between visual and audio puzzles.

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.

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 Multimodal Puzzle Game comprises two game modes: a visual one and an audio 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. We will now address each game mode in more detail.

Visual Mode

In visual mode, all image puzzles are square shaped (a limitation to accommodate playing in smartphones). 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 1.

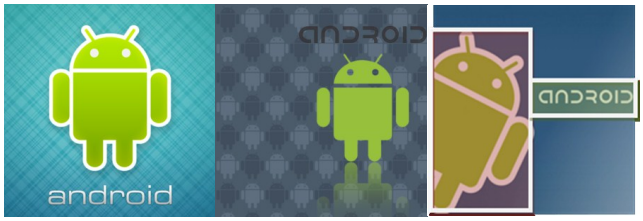

Figure 1 – Default images used for the visual mode puzzle.

- 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 the image accordingly to fit the playing area.

Audio Mode

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 3) which is interrupted by the initial excerpt (first 6 seconds) of Beethoven's 5th Symphony (Figure 2). The three songs are variations of each other, differing between them in the instant in which the 5th'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).

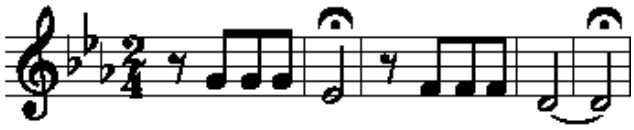

Figure 2 – Beethoven's 5th Symphony initial segment.

- 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.

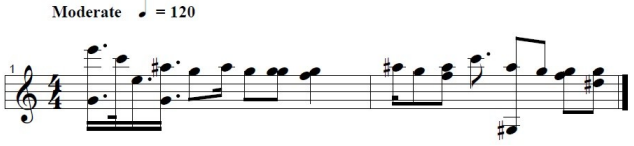

Figure 3 – Beat excerpt created for the default audio puzzle.

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 case of 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. 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. 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 & 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 4 (visual mode) and Figure 5 (audio mode). 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 2 seconds and then assumes its original image fragment (in the case of the visual mode).

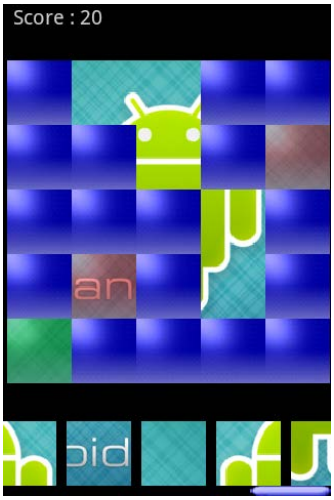

Figure 4 – Multimodal Puzzle Game: Visual Mode.

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.

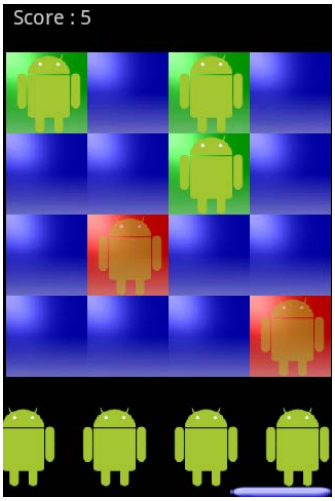

Figure 5 – Multimodal Puzzle Game: Audio Mode.

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 home button opens a quick menu with several shortcuts, namely 'New Game', 'Configuration', quick access to 'Help Type' and 'Exit Application'. Scores and player preferences are stored in both the Android app and on a XML file for backup. We are envisioning the usage of a centralized web repository to keep both player preferences and global scores in order to promote competitiveness among players.

EXPERIMENT

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. This experimental period lasted for two weeks, involving three researchers supervising the tests and providing support to subjects as requested.

Goals

The primary goal of the experiment was to assess if players use similar strategies to solve an image puzzle and an audio puzzle. 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.

Piece Type Classification

To assess piece positioning order we recurred to a special classification of pieces in both the visual and audio mode, performed 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 1:

- **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, the red rectangle over the android figure 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 1 (right), 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 1 (right), 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. We do intend on analyzing possible approaches towards a solution for this issue.

Research Goals

The following are our research goals for this study:

- **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.

Variables

In this study 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 a fixed 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 1). 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 3 and is present throughout the whole song. At key instants (at second 2, 6 and 9), the initial segment of Beethoven's 5th Symphony 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. 3 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.

Dependent Variables

Piece category solving order – there are 25 available correct moves for the visual mode and 16 for the audio mode in this study. With this metric we intend to analyze in which order the different piece categories are solved in the puzzle.

Strip pull position 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.

Participants

19 subjects (aged 21 to 27; 18 male, 1 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 from self-learning methods).

Tools & Equipment

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

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 7 subjects playing the visual mode and 12 users playing the audio mode, leading to 63 and 108 play samples respectively, for a total of 171 games.

The 9 mandatory games 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 in this paper.
- 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. As an incentive for participation, users were given a download code for the version of the Multimodal Puzzle Game for their Android devices.

Results

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

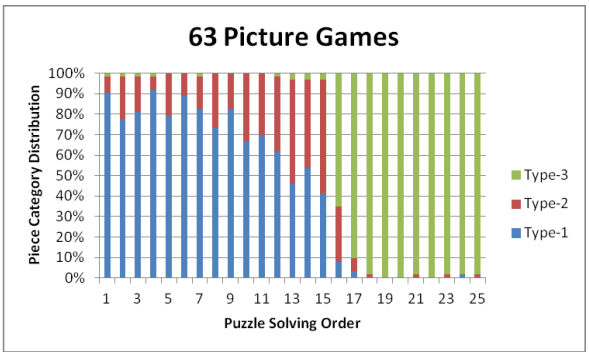

Figure 6 – Piece category distribution across puzzle solving order (visual mode).

Visual Mode

Results for the visual mode can be observed in Figure 6, Figure 7 and Figure 8. In Figure 6 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 7 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). This means that Type-1 pieces which are found in the beginning of the strip pull are the first to be placed in correct position.

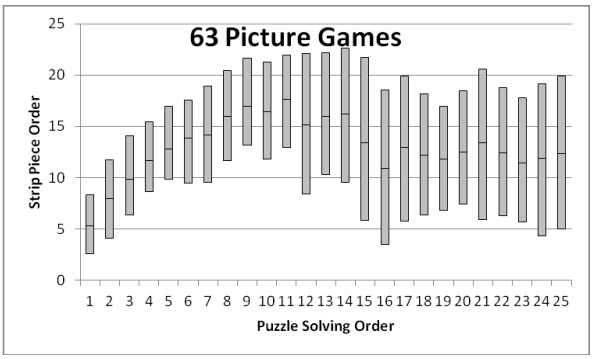

Figure 7 – Puzzle solving order according to strip pull position (visual mode).

Figure 8 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.

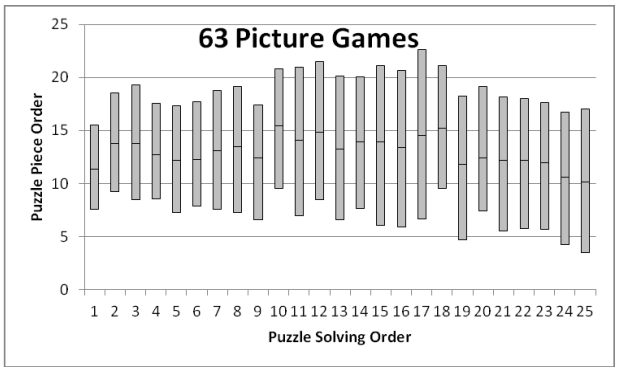

Figure 8 – Puzzle solving order according to puzzle piece order (visual mode).

Audio Mode

Results for the audio mode can be observed in Figure 9, Figure 10 and Figure 11. Unlike the results obtained for the visual mode, the graph depicted in Figure 9 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.

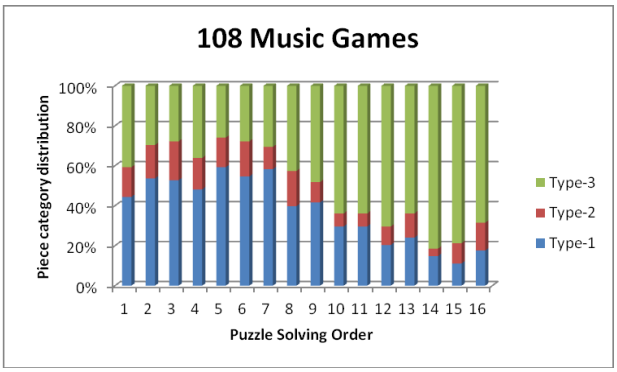

Figure 9 – Piece category distribution according to puzzle solving order (audio mode).

Figure 10 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.

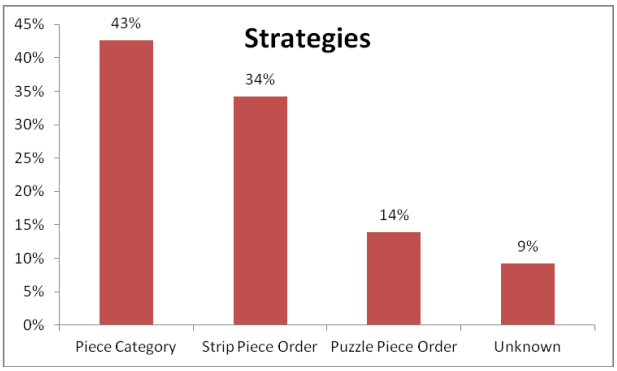

Figure 10 – Audio mode solving strategies distribution.

Figure 11 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 types of category 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 explicitly clear for the identification of each of the considered strategies, being easy to pinpoint the trends for each strategy across all considered solving approaches.

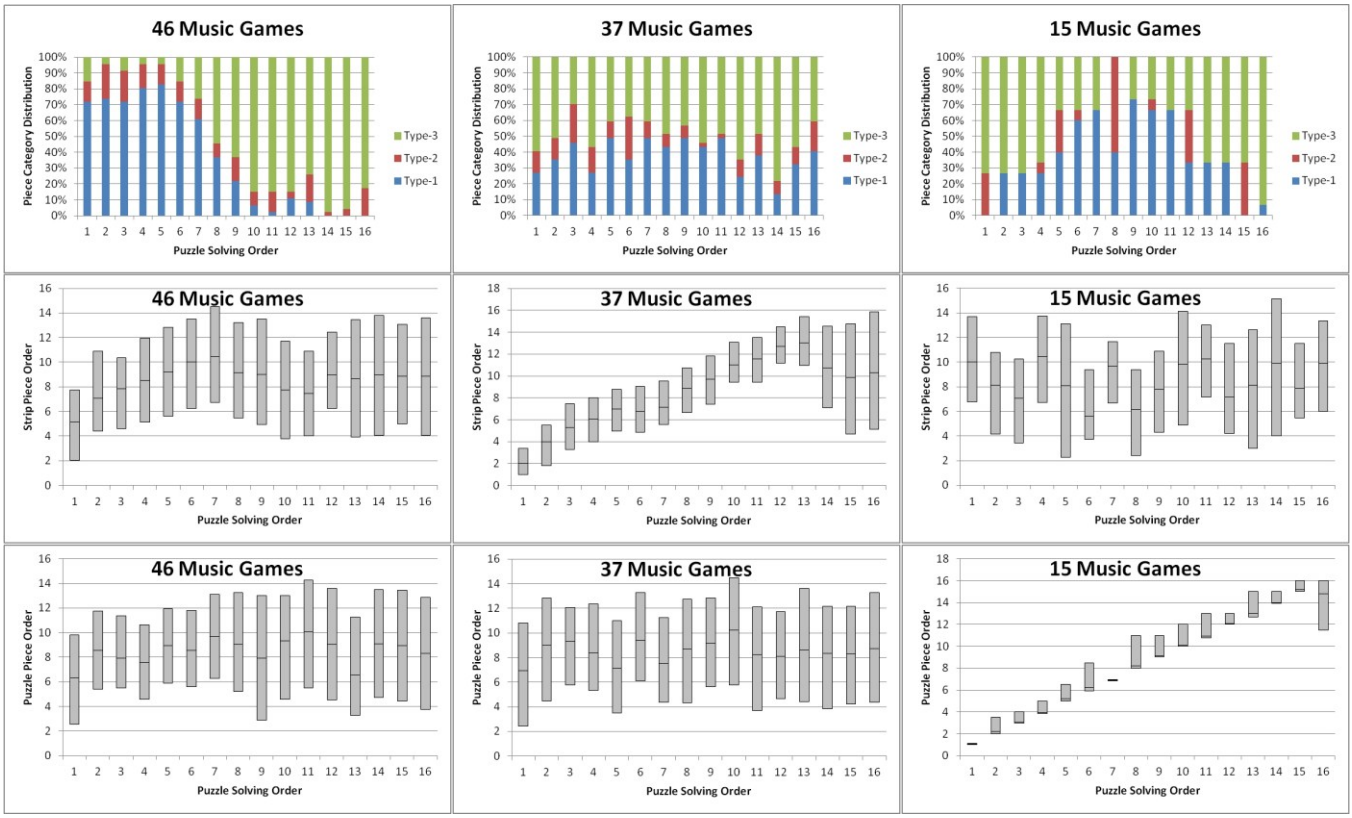

Figure 11 - First column: piece category strategy; second column: strip piece order strategy; third column: puzzle piece order strategy. First line: piece category distribution over puzzle solving order; second line: strip piece order over puzzle solving order; third line: puzzle piece order over puzzle solving order.

DISCUSSION

We will now discuss these results, taking into consideration the data gathered from visual and audio mode separately.

Visual Mode

The first conclusion from these results is straightforward: research goal RG1 was verified and RG3 as well for the visual mode. Figure 6 is particularly elucidative that players prioritized solving recognizable pieces immediately, forfeiting background sections of the puzzle to last. These 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 7 we consider this claim to be true, thus verifying RG3 for the visual mode. Figure 8 indicates that players did not solve the visual puzzles by the order of the puzzle itself.

Audio Mode

Results for the audio mode were not as homogeneous as the ones stemming from the visual mode. As Figure 9 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. This 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 observation are reinforced if we take into consideration the charts depicted in Figure 11. 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 even if players did prioritize this strategy, they still followed another 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 11 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 akin to 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 8^{th} 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 8^{th} 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. These results allow us to meet our research goals for the audio mode – RG2 and RG3.

CONCLUSIONS & FUTURE WORK

This paper presented the Multimodal Puzzle Game for Android devices. For the design of this application, 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 puzzles. The application allows 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.

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 2 strategies when solving puzzles in a mobile device: they attempt to identify the most salient areas of the puzzle (e.g. particular images or segments of a song) and solve those first by prominence order. 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. The main contribution of this study 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.

A cooperative and competitive version of the multimodal puzzle game has already been developed and is currently under usability evaluation. Our intent is to deploy this new version and to assess collaborative and competitive puzzle solving strategies, using an experimental approach similar to the one presented in this contribution. Additionally a new modality is also being explored and currently under evaluation: haptics. The intent is to assess the viability of haptic puzzles recurring to vibratory patterns to provide new and innovative challenges to players.

ACKNOWLEDGMENTS

This work was funded by FCT, through Individual Scholarship SFRH / BD / 39496 / 2007, through project PTDC/EIA-EIA/103676/2008 (InSIThe) and the Multiannual Funding Programme.

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