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***Abstract*—Gaming, both traditional and electronic, is a key activity for children of all ages, enabling them to learn skills, socialize with friends and family, and entertain themselves. Unfortunately, children with disabilities encounter several accessibility barriers that prevent them to participate in mainstream games, unless some adaptations are made to the interfaces. This paper tackles the problem of enabling children with severe motor disabilities to participate in multiplayer games with their peers, thus providing opportunities for socialization and fun inside families or classrooms. We present a collaborative two-player puzzle game, based on several levels of labyrinths that need to be solved by moving the two players' characters. The characteristics of the game (such as the absence of time constraints, and the need of the players to coordinate their moves) were defined in a study group involving computer scientists, psychologists and speech therapists. The game was designed and implemented to be controllable with a single-switch interface, thanks to the GNomon interaction method. A preliminary evaluation has been conducted with 5 couples of able players (mostly children) who enjoyed the game and gave us useful insights.**

I. Introduction

Playing games is an essential skill during childhood [1], [2] as it promotes the development of cognitive, motivational, emotional, and social competence (for a review, see [3] and [4]). In recent years, video games have become the most popular type of games and they are already an integral part of contemporary culture [5]. Modern video games offer interactive and engaging experiences through sophisticated interfaces and game mechanics mainly designed for entertainment, but they also have the potential to support rehabilitation or educational processes, as reported in [6].

However, most off-the-shelf video games do not meet the needs of children with sensory, cognitive, or motor disabilities. These children experience several barriers to accessibility that prevent them from having fun in their free time, or learning in more stimulating ways. Providing suitable educational and entertaining activities is part of the goals of the *pedagogical rehabilitation* process [7] (also known as rehabilitation for children). Standard input devices such as keyboard, mouse, or game controllers, are often difficult or impossible to be used by children with motor disabilities. The issue of allowing children with severe motor disabilities to access action-oriented videogames was tackled, e.g., in [8], where a special interaction method was developed to allow complex interactions with a single switch.

The goal of this paper is to explore accessible *multiplayer* games. The ability of playing with their peers (or family) enables children to increase their social and communication abilities [9], [10]. Special care must be taken when including a child with disabilities and a typically developing peer in the same game, to ensure that both have fun and no child's gameplay is sacrificed for the needs of the other (e.g., we want to avoid situations where the able player does all the gameplay, while the other is little more than a spectator, and the opposite case where the able gamer acts as an assistant for the disabled peer). For this reason we chose to explore *collaborative* games, where the contribution of *both* players is required to achieve the game objective. At the same time, cognitive and physical abilities must be considered in the definition of the game dynamics, e.g., gaming speed, interface complexity, etc. These aspects were considered, in our work, thanks to multidisciplinary design sessions, where different game aspects were discussed among a group of HCI researchers, developmental psychologists, and game programmers.

We initially focused on a target of children with severe motor disabilities, able to control a *single-switch* command interface. The resulting game design has been implemented and evaluated with 5 different pairs of gamers, one of which used the accessible interaction method (one-switch). Preliminary results show that the game is playable by children with a mental age of at least 6 years, but for completing the more complex game levels at least one of the players should have a mental age of at least 10 years. We also observed that the players actually developed collaboration strategies, according to the difference in their mental ages.

II. Related Work

Research on universally accessible games (concept introduced in [11]) improved the quality of life of many children with several types of disabilities. The survey presented by Yuan *et al.* [12] reports a large number of accessible games at the state-of-the-art in research and practice. The survey covers accessible games for different types of impairments (visual, hearing, motor, and cognitive) and across 8 specific game genres. For each type of disability, the authors extract specific strategies. The authors find that very few games are developed for players with cognitive disabilities, that popular game genres (mostly action-oriented) are not yet available for severely motor impaired players, and that the distilled strategies need some tradeoffs to avoid "ending off with a game that is not fun to play".

Social interaction among children with and without disabilities was, instead, investigated in multiplayer games. Those games balance differences in player ability levels and they proved their effectiveness in fostering social interaction of children with disabilities. Encouraging results [13] stem from a ten-week home-based study with children with cerebral palsy playing the multiplayer networked game *Liberi*. Liberi focuses on how to design networked games that enhance social play among people with motor disabilities, by allowing frictionless group formation to balance for differences in player abilities and play styles. Also Durkin *et al.* [4] provide a literature review on video game uses by children with special needs, and they focus on the implications of developmental and learning disabilities, the potential to address special needs, and the social potential of gameplay.

pOwerball [14], on the other hand, was designed to bring together children with and without disabilities. pOwerball is a tabletop tangible augmented reality pinball game for 2-4 players aged 8-14, whose aim is to encourage social interactions. The evaluation of the game demonstrates that it stimulated social interactions and cooperation, especially through tactics requiring joint action.

III. Requirements Elicitation

The game was designed through a participatory design method, by involving experts and stakeholders in all phases. The design of the game structure and behavior was conducted by a multidisciplinary focus group (two HCI researchers, a game programmer, two psychology researchers and two speech therapists). The focus group had three physical meetings, interspersed by individual research and study.

The group initially defined the target users as children able to use a one-switch interface and with a minimum mental age of 5-6 years. Such users include children with severe motor disabilities, often coupled with mild cognitive impairments, that may be consequences of cerebral palsy, infant neurological traumas, or various forms of sclerosis. The work was then informed by an analysis of the specific needs of the target user group, and from the state of the art emerging from the literature, taking into account both accessibility issues and game playability.

The group set as its main objective the definition of the requirements for a *collaborative* videogame, for *two* players, on a *single* computer, where one of the two players was restricted to a *single-switch* interface.

In particular, the importance of the *collaboration* aspect was considered as crucial, both to avoid any frustration deriving from a competitive game, and to combat the "isolation" felt by children with disabilities, by better supporting their participation in the game. One of the main differences of collaborative games is the pleasure to play. In cooperative games everybody may participate and have fun, with a game style based on accepting the other, where everybody may find the best equilibrium within the group and always find new goals. In cooperative games everybody wins or loses together, and nobody gets excluded. Players do not challenge each other, but challenge themselves, their creativity limits, and their phantasy, to reach a common goal.

The choice of a *single computer*, instead of an on-line game, was also made to exploit the direct contact and non verbal communications among the players; it also enables adoption at home or at school.

The experience of 4 participants of the group in a previous experimentation of (single-player) accessible games (reported in [8]) was also leveraged in the discussions.

A the end of the process, the focus group defined a detailed set of requirements for the game to be implemented and experimented, listed below:

- R1 the timing of the game should be free: no time limits should exist for any game action;
- R2 the game controls for one of the players should be fully accessible with a one-switch control;
- R3 every feedback from the game should have both visual and auditory components;
- R4 icons should be preferred over text, colors should be vivid and catching;
- R5 graphically distracting elements, not needed for the game, should be avoided;
- R6 difficulty should gradually increase, to provide a satisfactory experience for children of all ages (or disabilities);
- R7 the collaboration between the players may be needed to successfully complete some game situations.

IV. Game Design

According to the requirements described in Section III, we designed the game *Monsters' Labyrinth*. It is a two-player game, where one of the players may have a disability that forces him or her to use the accessible one-switch interface, while the other player uses keyboard and mouse (R2). The game environment is a multilevel labyrinth, and the game characters are two "monsters" associated to each player. The goal of the game is to move each player's monster to a specific final position, marked by a button with the same color as the monster. When both monsters reach the end position, the level is completed.

The accessibility of the game with a one-switch interface is obtained thanks to the GNomon [8] framework. In a nutshell, GNomon attaches to each selectable game element (e.g., the pause button) and game action (e.g., move right) a rotating clock (Fig. 1). The black hands of the clocks attached to various elements rotate at the same speed, but with different angular offsets. When the player wants to select a command, he should press the switch as closely as possible to the time when the black hand of the associated clock crosses the red "noon" marker. The statistical model inside GNomon

Fig. 1. The GNomon clock

optimizes the angular offsets to ease the selection of most likely (and most useful) clocks, and offers a second chance of selection whenever the selection might be ambiguous (this satisfied both R1, since the clocks periodically offer the same selection options, and the statistical model favors the selection of the most likely actions, and R2, by making all relevant user interface actions controllable by the switch user). Details about GNomon may be found in [8] and the statistical model is adapted from [15].

The game includes 60 levels, grouped in 6 stages of 10 levels each. Each stage introduces a new "special" game element, with a specific effect on the monsters' movements, therefore the levels become more and more complex to solve (R6). The completion of a level enables access to the next one, and the completion of all levels in a stage allows players to proceed to the next stage. Some sample levels are shown in Figure 2, where we see the purple monster, whose ending position is the purple button, and the green monster (bottom right) that must reach the green button (R4).

The players may move in any order (they do not need to alternate their turns). In each move, a player specifies one of the four directions (up, down, right, left), and the associated monster will move *all the way* into that direction, until it reaches an obstacle (a wall, the other monster, or a special element). Depending on the labyrinth shape, some positions may be easier to reach, while others may require a sequence of moves, by leaning on the right walls and obstacles (R6). In particular, a monster may be used as a leaning point for allowing the other monster to pursue an otherwise impossible path. Collaboration is therefore needed, in some levels, and with varying degrees of complexity, to allow both monsters to walk their optimal paths (R7). In some cases (in higher stages), due to the shape of the labyrinth and/or to the position of special elements, the players might reach a position from which solving the level is impossible; in this case, they may re-start the level.

Each level contains three prizes (represented as bananas), that can be collected by walking over them (R3, R4). Some of them lie on the optimal path towards the solutions, others require a detour to be caught. Each solved level gives up to 1,000 points (100 for the level completion and 300 for each caught banana). Additionally, each solved level is marked with a number of "stars" that depends on the number of moves spent (with respect to the minimum one). Points and stars act solely as a reward and incentive for the game, as they don't influence the access to further levels nor to additional features.

One player moves by using the keyboard arrows, while the other player moves by using the one-switch interface. In fact, the purple monster is overlaid with a set of arrows, from 1 to 4, depending on the number of free directions (R2, R5) that can be selected using the GNomon clocks (Figure 3).

Table I summarizes the 6 game stages. For each stage, we report:

- the special element that is introduced in that stage (except for the first one). The special elements are, respectively: a block that changes the direction of the monster (forcing it to a fixed direction) when it walks over it; a fragile wall, that allows leaning on it just once, and then disappears; a pair of teleportation terminals, that make the monster disappear and re-appear from the other terminal; a wall segment that can be destroyed by walking over a same-colored button, placed elsewhere in the labyrinth; and finally a one-time passage, that turns into a wall after a monster crossed it once.
- the cumulative number of special blocks used in all levels in that stage. Each stage may use the special blocks introduced in that stage and in all preceding ones.
- the number of levels, in that stage, for which a "stall" situation is possible, i.e., where the players are forced to re-start the level as a consequence of wrong moves, because the solution is no longer reachable from the current monsters' position.
- the number of levels in which the labyrinth is shared between the two players, thus allowing possible collaboration. In the other cases, each player has its own labyrinth (the two are not reachable from each other).
- the number of levels in which some form of collaboration between the two players is needed to complete the level. It may require a player to stop in a position while the other leans on him, or for a player to activate a special element (e.g., a button) to enable the passage for the other player, or similar situations.
- the minimum number of moves to solve a level (computed as the average across all the levels in the stage).
- the minimum number of moves to complete a level while gathering all bananas (average across the stage).

We may see that all metrics describing the levels complexity generally increase in the later stages.

It should be mentioned that all game elements (e.g., selecting game options, pausing game, restarting level, selecting level, etc., see Figure 4) and not just the monsters' movement have associated GNomon clocks, therefore the game functionality is fully accessible (R2). This is unlike many games, where the in-game experience is accessible, but game activation and/or settings require the usage of the mouse or keyboard.

The game has been implemented using the Unity[1] framework using royalty-free images, and is freely available for the Windows platform[2].

[1]https://unity3d.com/, last visited Apr 2018

[2]download available from http://bit.ly/gnomon-games

Fig. 2. Some sample levels of the game

TABLE I
THE 60 LEVELS OF THE GAME

Stage	N. Levels	New special	Special blocks	Stall possible	Shared labyrinth	Collaboration needed	Min moves (avg)	Min moves for top score
1	10	–	–	0	7	4	4.3	5.1
2	10	Change direction	63	5	9	4	4.3	5.6
3	10	Wall self-destroys after touching	40	10	10	6	6.0	7.6
4	10	Teleportation	48	5	9	4	5.0	6.0
5	10	Button destroys wall	53	10	10	10	8.2	9.5
6	10	Becomes wall after passage	80	8	8	8	7.3	11.2

Fig. 3. Accessible monster movements (GNomon-selectable arrows for allowed directions)

Fig. 4. Accessible game controls (usable with the mouse or the single switch)

V. Evaluation

The evaluation of the game aimed at validating the characteristics of the game (in terms of playability, fun and collaboration) and at understanding its applicability (e.g., the suitable mental age, the required cognitive capabilities).

The evaluation was conducted in two steps. First, we presented the game to a team of speech therapists and psychologists, and gathered their feedback and comments (Section V-A). Second, we conducted a study with 5 different pairs of players of various ages, and collected qualitative and quantitative data (Section V-B).

A. Game Analysis

After the implementation of the game, we presented it to a team of 5 experts in children with disabilities (3 speech therapists, of which 2 already participated in the initial focus group and 2 psychologists, of which 1 participated in the focus group). The game design criteria, the gaming rules, and the control interfaces were illustrated, and the experts could spend some time to familiarize and play with the game. After the initial game presentation, the discussion was opened, and the experts provided the evaluation presented in this section.

The use of the game involves various cognitive abilities: the spatial organization capability, the capability to orient, to plan a path, and a strategy to reach the destination. It requires directionality (the sense of right-left and up-down), visual-spatial ability, and attention. Finally, it requires the children to be able to manage the collaboration with their peer.

A deeper analysis of the characteristics of the game, from the psychological point of view, reveals that a successful gameplay requires the following skills:

- *Cognitive flexibility*: capability to adapt to new learning situations and to easily move across various strategies to solve the problem posed by the game level [16]. In this game, levels are always different, and gradually new elements are introduced, that force the player to adapt. The strategy used to solve a level could not be adequate for the more complex ones.
- *Working memory*: this refers to the brain resources that handle the temporary storage and the manipulation of the information needed to accomplish cognitively complex tasks, such as understanding, learning and reasoning [17].

Specifically, to solve the more complex levels, a sequence of actions is required and the child should be able to keep them in mind.
- *Strategic thinking*: the ability of identifying and analyzing problems, of creating and controlling plans for their solution [18]. Strategic thinking is composed of three main parts: stating the problem to be solved; selecting the appropriate strategies for solving it; monitoring the progress towards the solution. Moreover, in a collaborative game, the strategic thinking should take into account also the partner's activities and possibilities to accomplish the task.
- *Ability to handle multiple information*: in the game, players have to discover the best paths, to find out how to interact with the other player and with the special elements, in order to solve the level and gain the maximum amount of points.
- *Planning*: it concerns the cognitive process that allows the execution of behaviors aimed at an objective, according to well-defined and ordered steps. This function is a basic skill for our daily life, and is used in tasks of various complexity [16]. In the more complex levels, a specific sequence of actions is needed to succeed.
- *Collaboration*: this is probably the most challenging component brought by the game, because collaborative play is still developing during school age. The child should be able to monitor the play partner's activity, to understand the role of each player in fulfilling the task, and to communicate with the partner to decide who is going to make a move, in which direction, at which moment, etc.

Thus, it is worth noticing that the game is suitable for children with physical disabilities whose cognitive functioning can meet the several abilities described above; moreover, the game can also be a fun activity to improve these competences and skills while interacting with peers.

B. Experiment

The second part of the evaluation was conducted through a preliminary experimental study, where the game was tested with 5 different families with kids of different ages. In this preliminary phase our objective was mainly to determine the best mental age for playing the game and the required cognitive abilities, to be able to propose it later to children with disabilities of the right age. At this stage, therefore, we did not involve children with disabilities, yet. However, one of the two players had to use the accessible one-switch interface to control his game character.

We recruited 5 families for the experiment, from our direct contacts.

Experiments took place in each family's home, under the supervision of a psychologist experimenter. In every family, we set up a test station, composed of a Windows PC, an accessible switch (Figure 5) connected to the PC through a switch-to-USB interface. Depending on the case, the players were siblings, friends (one friend was invited for the purpose of the experiment), or father and child.

Fig. 5. The Accessible Switch used in the experiments

TABLE II
EVALUATION RESULTS

Pair	Player 1	Age	Player 2	Age	Duration (min)	Levels
1	P1	adult	P2	10	80	60
2	P3	adult	P4	6	60	29
3	P5	12	P6	9	80	48
4	P7	10	P8	10	60	40
5	P9	6	P10	5	200	45

The experimenter explained the objective of the test, the rules of the game, the specific GNomon-based accessible control, and then left the players to enjoy the game. The experiments have been video recorded, and the experimenter took notes of the interesting facts or sentences spoken by the players. The version of the game played during the experiments was modified to record in a log file all moves and actions by the players, with their corresponding time stamp.

Table II reports, in the leftmost columns, the characteristics of the players, by reporting their age. The adults were admitted to play only when a second child was not available for the experiment. All participants had previous experience with computers, and all children already played with videogames (on consoles, smart phones or tablets).

The two rightmost columns in Table II show the results of the game play, by reporting the total game duration (in minutes) and the number of levels that have been solved by the players. The experiment ended when the game was solved (Pair 1) or when the players got too tired or lost interest (all other pairs).

During the experiments, players were free to communicate and to coordinate the moves of their characters. Only in one case (Pair 3) the players decided to switch their roles (keyboard vs. one-switch) because the one-switch interaction was felt as slow and limiting; in all other cases, one player consistently used the switch and the other the keyboard.

After the few initial levels, the players discovered that they needed to coordinate their moves, and two different patterns emerged: in some cases, the two players discussed together the best strategy, and then executed the moves; in other cases, especially when one of the players was significantly younger, one player decided the moves, and ordered to the other when to execute them. In this second case, the gameplay was less balanced, and in one case it even led to a verbal fight.

From the overall observation of the 5 experiments, the analysis of the log files, and the notes taken by the experimenter, we may draw the following main results. From the point of view of the attained collaboration, the results show that a large (mental) age difference between the players can prevent the partners to actually collaborate, as one becomes the "leader" and the other the "executor"; thus, to support a real collaboration, the age of the partners, or their cognitive functioning, should be similar. The game is playable for children starting with a mental functioning of 5-6 years (Pair 2, Pair 5). Some levels were found too difficult for the younger children, and the experimenter had to give some hints (Pair 5): we are considering to rearrange some levels according to their perceived difficulty. For successfully solving the stages from 3 on, at least one of the players should have a mental age of at least 8-10 years (Pairs 1, 3, 4). Finally, the players generally enjoyed the game, found it challenging and engaging, and endured a long play time (over one hour, up to about three hours for Pair 5) without problems.

VI. Conclusions

The Monsters' Labyrinth is a promising game: it proved to be fun and to support children collaboration. Interestingly, when the age difference between the partners was too high, the collaboration did not work as effectively, as one became the leader and the other the mere executor. To better support the collaboration, the two partners should be similar with respect to their cognitive functioning. In this case, it is also possible to observe that the game can become a learning activity between the children: a less skilled child can improve his or her competences thanks to the interaction with a slightly more skilled peer, who helps the partner to move through the Zone of Proximal Development [1]. The same effect was observed with adult players, who took the role of mentors as well as players.

Further research is needed to test the accessibility and usability of the Monsters' Labyrinth with children with severe motor disabilities; data could also be collected to test if the game will support these childrens playfulness while playing with peer partners. This first study results allow to better identify the children with disabilities who could successfully and playfully use the game, according to their cognitive abilities, i.e., a cognitive functioning correspondent to the range 6-10 years.

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