POLITECNICO DI TORINO

DOCTORAL SCHOOL
Ph.D. in Computer and Control Engineering – XXVIII cycle

Dissertation

Accessible Human Computer Interaction

Video Games and Assisted Living for Persons with Severe Disabilities

Sebastián Aced López

Advisor
Fulvio Corno

Ph.D. Coordinator
Matteo Sonza Reorda

April 2016

Acknowledgements

I have to thank many people that have “walked” with me the long route that has brought me here, supporting me, teaching me and encouraging me. First I have to thank Fulvio Corno, my advisor and mentor during these years of research. He believed in me, and was very patient, he guided me well and I learned so much from him. I have to thank also to Luigi De Russis, “my second” teacher, who friendly helped me to become a better researcher each day. I want also thank the other members of the e-Lite research group and, in particular, Teo for his company. Thank you! A special thanks to Sara, Elisabetta and the people from the Local Health Agency for their time, energy and shared knowledge.

Agradezco a mis papás y a mi hermana que desde la distancia me apoyaron siempre y no me dejaron desfallecer nunca.

Ma il ringraziamento più speciale va ad Agnese, che iniziò con me questa avventura del dottorato come la mia ragazza, e oggi la finisce al mio fianco come mia sposa.

Contents

List of Tables

List of Figures

Introduction

Overview

Nowadays, the world is brimming with interactive technologies that enable an increasing number of different activities. In particular, by studying who is going to use a certain interactive technology, how they are going to use it and where will it be used, professionals in the field of Human-Computer Interaction develop new ways to support users in everyday tasks, such as instant communications, ubiquitous entertainment, remote healthcare support, among others.

Progress in Human-Computer Interaction (HCI) has contributed to the improvement of accessibility of interactive applications, leading to the concepts of *unviersal access* and *design for all* (according to Stephanidis in [62]), which transcend the traditional view of accessibility and usability (i.e., often product-centered and environment-centered). In fact, ongoing research on accessibility focuses on human-centered design and interaction. Today, researchers recognize that being able to use information technologies effectively affects deeply the life quality of users and the people around them. This is especially true for people with disabilities who depend on digital interfaces for communicating, learning and even having fun; and for the caregivers that support those disabled persons daily. Therefore, the study and development of assistive technologies becomes essential in our modern information society, as these empower persons with disabilities with software and hardware solutions that allow them to overcome their conditions of disadvantage in order to access information systems for different purposes, which range from entertainment to access to healthcare services.

Although giving a definition of *disability* is not an easy task, the World Health Organization (WHO) defines[1] it as *"an umbrella term, covering impairments, activity limitations, and participation restrictions. An impairment is a problem in body function or structure; an activity limitation is a difficulty encountered by an individual in executing a task or action; while a participation restriction is a problem experienced by an individual in involvement in life situations."* Therefore, living

[1] `http://www.who.int/topics/disabilities/en/` (last visited on April 8th, 2016)

with disabilities is not an illness nor a health problem. It is a complex experience that reflects the interaction between the unique characteristics of a person's body and mind with the environment in which she lives and the people around her.

Accessible human computer interaction, as presented in [17] refers to the study of interactive technologies, digital interfaces and information systems designed and developed with universal accessibility in mind. This enables persons with different levels of ability to share the same experience (e.g., a game, a lesson or simply a conversation) with others at the same time, while adopting their own preferred input/output mechanisms. In the particular case of gaming, research on accessible human computer interaction aims at developing interfaces and input/output devices that allow disabled players to access video games, giving them the opportunity to enjoy games similar to those that their normally developing peers usually play. Brain computer interfaces (BCI) or eye-tracking interfaces are examples of alternative interaction modalities that allow players to control game objects through novel hardware, when traditional input devices such as the mouse or the keyboard, prevent them from accessing gaming devices. Other solutions that do not use additional hardware, exploit novel software solutions to offer accessible interfaces to those with impairments; a famous example of this type of accessible solution is apple's iOS Switch Control[2], that allow iOS users to use their devices with just single switches.

Similarly, as universal accessibility takes into account the environment and the people that comes in contact with the disabled persons, some research in the field of accessible HCI aims at supporting the former while they take care of the latter. Ambient assisted living (AAL) technologies, wearable/mobile interfaces and IoT systems have been integrated for supporting persons in dependency conditions, such as the elderly or people with severe disabilities, in their own homes and in structured environments such as hospitals. Now, healthcare support systems are also being researched as useful tools for caregivers in new contexts such as nursing homes.

Motivation

Accessible Human Computer Interaction is a very wide area of study, which covers many topics and addresses several interesting problems; but there is a common goal that researchers of this field usually share: to use technology for improving the quality of life of persons with disabilities. In fact, this thesis stems from the will of helping persons with disabilities in different moments of their lives (i.e., during their childhood and in their adult age), by using different interactive technologies.

In particular, this document explores two challenges: first, the problem that children with motor disabilities face as they cannot access dynamic video games as their normally developing peers do, leading them to reduced participation at leisure

[2] https://support.apple.com/en-us/HT201370 (last visited on April 8th 2016)

and playful educational activities, and finally to a potential social exclusion. The second challenge is faced by professional caregivers that work with adults motor and cognitively disabled, within assisted living facilities. Such caregivers need to effectively monitor the people under their care, as well as to be alerted of potentially hazardous situations that happen to these persons while they are alone.

Currently, both problems have been very little explored in literature: the total number of scientific papers related to accessible gaming found in the ACM Digital Library was as low as 155, which was further reduced to 22 when the results were filtered out to ignore those related to visual and hearing disabilities, keeping those related to motor and cognitive disabilities[3]. Similarly, few studies focus on how to support caregivers in assisted living facilities for people with severe disabilities, since research in the field has mainly focused on two topics: how to improve the quality of life of *patients in their own houses*, and how to support *doctors and nurses within hospitals* in the specific tasks their jobs entail.

Finally, the research presented throughout this document is also motivated by the hope of contributing to fill the gap that still exists between the know-how of engineers and the HCI community, and the knowledge and experience of healthcare professionals, such as speech therapists and caregivers.

Contribution

It is clear that there are many possible ways to improve the quality of life of persons with motor and/or cognitive disabilities. It can be accomplished by enhancing their communication possibilities, their participation and social inclusion, their access to education or their chances to have fun. Likewise, the life quality of persons with disabilities can be improved indirectly, by aiming at supporting the people that surround them (such as family and caregivers) or by aiming at adapting their environment.

The objective of this thesis is to contribute to the improvement of the quality of life of persons with motor and cognitive disabilities, by supporting them in specific situations through different moments of their lives: in their childhood, by allowing them to play dynamic video games; and in their adulthood while they live and are cared by caregivers in assisted living facilities. Moreover, the research presented in this document constitutes a potentially valuable contribution to bring together the technical capabilities of engineers and HCI researchers, with the experience and knowledge of healthcare professionals that work daily with persons with disabilities.

[3]The search was made on November 11, 2015 with the following query: `((NOT(deaf) ANDNOT(blind))AND(((videogames)OR(videogames))AND((accessible)OR(accessibility) )AND((chil-dren)OR(kids))AND((disabilities)OR(disabled)OR(impairments) OR(impaired))AND(motor)))`

The results reported in this document are relevant for the accessible human computer interaction community as they comprise substantial advancements in the fields of accessible gaming and ambient assisted living. In particular, this research presents the first software framework that allows to create dynamic one-switch video games and the playability results of a series of video games based on such a framework. Similarly, the second part of this research presents an useful set of design guidelines for developing healthcare support systems for caregivers that work in assisted living facilities.

The main specific contributions achieved by this research are:

- **The GNomon framework:** a software framework that enables to make dynamic one-switch video games. This framework was designed in collaboration with a team of expert speech therapists and it was evaluated with 8 children with severe motor disabilities through a series of tests.

- **The GNomon-based mini games:** three original video games playable with just a single switch (without extra hardware), with different degrees of difficulty, which allow children with disabilities to freely select game objects from the screen without scanning. One of the games is a completely dynamic one-switch video game.

- **Three interchangeable GNomon widgets:** trhee interchangeable usability-tested widgets for the GNomon framework (a clock, a bar and a ball) based on different concepts according to the Griffiths Mental Development Scales.

- **Ten design guidelines for healthcare support systems:** These guidelines stem from a series of structured interviews with professional caregivers and they are especially derived for developing systems to support caregivers within assisted living facilities for persons with disabilities.

- **A prototype healthcare support system:** The design of this prototype, based on the elicited guidelines, exploits wearbale devices as well as intelligent environments, to support caregivers working inside assisted living facilities.

Organization

This thesis is organized in two parts: the first part covers the body of research related to accessible video games for children with motor disabilities, while the second part reports the work carried out related to assisted living for persons with disabilities and their caregivers. The remainder of this document is organized as follows:

Video Games for Children with Severe Motor Disabilities

- **Chapter 1** presents the motivation behind this fascinating research as well as the relevant background to better understand the field of accessible video games for children with severe motor disabilities. In addition, a review of several freely available one-switch video games is reported.

- **Chapter 2** describes the design and development of GNomon: a framework for developing dynamic one-switch video games. In particular, this chapter reports the main aspects of the interaction modality NOMON, which is at the base of the GNomon framework operation; it presents the design of the GNomon framework and it describes its implementation.

- **Chapter 3** presents three GNomon-based video games and its design considerations. The games presented are: One-Switch Demo, One-Switch Ladybugs and One-Switch Invaders.

- **Chapter 4** reports the results of the playability evaluation and the assessment of the rehabilitative potential of the GNomon-based games.

- **Chapter 5** explores three alternative GNomon widgets for the framework: a clock, a bar and ball.

- **Chapter 6** summarizes the main conclusions of this research and suggests how can other researchers can make use of this work. Moreover, a study that builds on top of this research, opening new lines of work in the area of accessible multiplayer games, is also presented.

Assisted Living for Persons with Disabilities

- **Chapter 7** describes the motivation behind this interesting research and provides the needed background to understand the current situation in the world of assisted living for persons in dependency conditions.

- **Chapter 8** presents a comprehensive user study aiming at understanding the needs and concerns that caregivers have while they take care of persons with disabilities within assisted living facilities. The study was conducted with a total of 30 caregivers in three different facilities for persons with physical and cognitive disabilities in Northern Italy.

- **Chapter 9** reports the results of the user study presented in the previous chapter and offers ten guidelines for designing systems that could effectively support caregivers in their daily tasks within assisted living facilities for persons with disabilities.

- **Chapter 10** proposes a general design for a prototype healthcare support system, based on some of the guidelines reported in the previous chapter. Although such a prototype was not deployed nor evaluated, its feasibility was confirmed in-lab and its user acceptance was qualitatively explored with a group of 8 professional caregivers through a questionnaire.

- **Chapter 11** reports the main conclusions of this part of the research and suggests how can other researchers make use of this work. Moreover, a new research, which already has stemmed upon this study is presented.

Part I

Video Games for Children with Severe Motor Disabilities

Chapter 1

Motivation and Background

Determining what is and what is not a *disability* is not easy. Every disabled person is different. As already stated, the World Health Organization (WHO) defines *"disabilities"* as an umbrella term, which covers impairments, activity limitations, and participation restrictions. Moreover, according to the world report on disability of 2011 (see [5]), about 15% of the world's population lives with some form of disability, of whom 2-4% experience significant difficulties in functioning. People with disabilities may have different types of impairments, which range from moderate, severe and profound, which are often classified as follows:

- Physical: anything that limits the physical function of limbs or fine/gross motor capabilities.
- Sensorial: an impairment of one of the senses such as vision or hearing impairment.
- Cognitive: characterized for an impaired intellectual and adaptive behaviors that affect everyday life.

Persons with disabilities often grow up needing special support and services at home provided by their families or their caregivers, assitive technology that helps them to be more independent (i.e., wheelchairs or digital communicators), accessible public transport and buildings, among others. Nevertheless, they also need the same things that everyone else: ways to communicate and get information, opportunities for socialization with their peers, participation in public and popular culture, access to education and sources of entertainment and fun for a healthy and happy life. Things that children usually accomplish by playing games.

In fact, playing games is an essential skill during childhood [71] as it promotes the development of cognitive, motivational, emotional and social competences. In recent years, video games have become the most popular type of games (see the

United States [38] and Europe [45] statistics, respectively) and they are already an integral part of contemporary culture: in fact, as pointed out by [26], every single child was born into a world where video games are simply a fact of life. Modern video games offer interactive and engaging experiences through sophisticated interfaces and dynamic game mechanics mainly for entertainment, but they also have the potential to be powerful tools for supporting healthcare related processes (e.g., rehabilitation) or educational activities, as reported by [64].

However, many children with disabilities[1] do not have the sensorial, cognitive or motor skills for accessing off-the-shelf video games. These children encounter several obstacles that preclude them from having fun in their free time, learning in more stimulating ways or participating in interactive rehabilitation therapies. In particular, children with motor disabilities often lack the ability to use standard input devices such as keyboard, mouse or game controllers, and thus they are usually excluded from playing video games similar to those played by their peers. Moreover, children with *severe* motor disabilities that rely just on the use of single switches for interacting with electronic devices, find *dynamic* video games completely unplayable.

The interaction offered by the use of a single switch (a.k.a. one-switch interaction) is not suitable for playing dynamic video games because these are fast-paced games that require rapid decision-making and timely responses from the player in order to provide a satisfying experience; on the contrary, common one-switch interaction methods, such as *scanning*, are very slow [60] as they are not intended for time-dependent tasks or rapid decision-making processes. In particular, scanning is not suitable for interacting with dynamic video games as it requires the selectable elements to be stationary in rigid layouts, it takes time to be operated and it defines a fixed scanning order that cannot change automatically (i.e., without the user awareness). On the other hand, dynamic games are characterized by the presence of elements that can move around the screen and offer complex visual scenes which can change quickly at any time. As a result, one-switch users are usually limited to static, time independent, and barely interactive games.

The motivation for this study derives from the clear and still unmet need of dynamic video games, playable by children with severe motor disabilities that rely on the use of a single switch (i.e., the target children). Not only they *want* to play games similar to those played by their peers without disabilities, as found by Hernandez et al. in a year-long participatory study [42]; but it has also been shown (e.g., by [39] or [15]) that complex training environments such as video games, specifically dynamic or action ones, produce learning that transfers well beyond the training task.

[1]Living with disabilities is a complex multidimensional experience difficult to evaluate or to measure, nonetheless UNICEF [66] estimates that the 5.1% and 0.7% of children (aged 0 to 14) worldwide live with "moderate to severe disabilities" and "severe disabilities", respectively.

The objective of this first part of the thesis is to investigate whether it is possible to create dynamic one-switch video games that are playable and also suitable to be used in speech therapy with children with severe motor disabilities. For this purpose, a research structured in five phases was conducted. First, the design and development of GNomon: a software framework, based on the NOMON [24] mode of interaction, which allows to create dynamic one-switch video games. Second, three one-switch video games were created with different levels of difficulty, based on GNomon. Third, it was conducted a study for evaluating the playability of GNomon-based games through the assessment of the following properties: *learnability, effectiveness, satisfaction, errors, memorability* and percieved *fun*, by means of a two-session test. In the fourth phase of the research, a study for evaluating the potential of the GNomon-based games as useful tools for rehabilitation was carried out, by means of a focus group conducted with a team of speech therapists and psychologists from one of the Local Health Agencies in Turin, Italy. Finally, in the last phase of this research, and considering the results obtained by the children during the playability and rehabilitative suitability studies (especially by those children with additional cognitive difficulties), two alternative widgets for the GNomon framework were developed: a bar and a ball, to evaluate their usability along with that of the original clock widget.

In particular, this chapter presents relevant background useful to better understand the sections to come. First, it is presented the state of the art in the field of accessible video games for children with severe motor disabilities. In particular different modes of selection that allow these children to interact with video games are reported, which are based on direct selection and one-switch scanning. Moreover, a review of several freely available one-switch video games divided in three main categories is provided: cause/effect games, scanning based games and click timing games.

Accessible Video Games for Children with Severe Motor Disabilities

Before designing and developing an accessible video game for children with severe disabilities, it is important to understand the state of the art of accessible interfaces as well as to know which type of these accessible video games are already available. Therefore, a literature review was conducted with a two-fold objective: first, to define the current situation of accessible video gaming, including available games as well as evaluations of such games with real users; and second, to understand the type of interaction modalities that are used nowadays to allow players with disabilities to interact with video games.

The inclusion criteria (OR inclusive) for the related works throughout this section, were the following:

- Documents that present useful guidelines for the design and development of accessible interfaces for people with severe motor disabilities.
- Documents related to accessible games for persons with motor disabilities.
- Documents that describe an accessible game design.
- Documents that summarize available interactive technologies related to accessible gaming and entertainment.
- Documents that report evaluation of accessible games with real users.

Other sources of information, useful during the development of this research, were some game accessibility guidelines such as Includification: a practical guide to game accessibility by the AbleGamers foundation [6]. This report gives tips to developers abut how to improve the accessibility of their games. Similarly, the international game developers association (IGDA) has published a list of guidelines, inspired on the Special Effect's[2] Game Accessibility Wish List which is available at [2] that suggests ten easy-to-implement steps for making almost any video game more accessible. Even Microsoft, with its accessible technology group, has addressed game developers through the online article Making Video Games Accessible: Business Justifications and Design Considerations [3], in which it is explained to the developers who want to reach the accessibility community market how to design basic accessibility features for people with vision, hearing, speech, mobility and cognitive disabilities.

From the available literature, guidelines and actual video games currently available, it arises that the accessibility features of a video game are usually divided according to the classification of the types of disabilities reported before. Therefore, as this research focuses on children with severe motor disabilities, the literature review was narrowed further to the material that concerns people with physical or motor disabilities. In particular, to people that live with severe motor disabilities caused by traumatic injuries (e.g., spinal cord injury), diseases (e.g., Lou Gehrig's disease) or congenital conditions (e.g., cerebral palsy or spinal muscular atrophy), which usually interact with computers using assistive direct selection or using scanning interfaces.

One one hand, assisitive direct selection refers to the action of somehow pointing (e.g., with the head or with the gaze) or naming (e.g., voice-based selection) any desired item for selecting it. This is especially important for disabled users, as it allows

[2] `http://www.specialeffect.org.uk` (last visited on April 8th 2016)

them to interact with electronic devices hands-free, giving them the opportunity to successfully communicate, read, or play.

Playing, which is one of the most important activities for a child, can be done through eye-gaze interaction or voice-based commands, depending on the residual capabilities of each player. Eye-gaze interfaces support levels of interaction similar to those required by traditional *dynamic* video games, according to the study presented in [69], in which the results obtained with a group of young people with cerebral palsy and muscular dystrophy showed that eye-gaze interfaces help players to significantly improve their in-game characters control. Similarly, this kind of interaction supports other playful activities enjoyable by children (besides game playing), such as drawing. In [44], Hornof and Cavender present EyeDraw, a software program that allow children with severe motor impairments to draw with their eyes by just moving them. Likewise, in [68], Van der Kamp and Sundstedt propose a combination of gaze and voice commands for interacting with a paint style program. In their proposed application voice commands are used to activate drawing, allowing gaze to be used to move the cursor. Applications that use voice input to control the cursor movement for navigation and selection, two fundamental tasks for playing video games, are being demonstrated to be a powerful alternative for persons with motor impairments that still can speak out loud. Finally, Harada et al. report in [40] the encouraging results of a longitudinal study in which 5 persons with motor disabilities learned to use efficiently a vocal joystick after just 2.5 weeks, which can be used for playing or general communication purposes.

On the other hand, *scanning* allows the indirect selection of one element from the screen. The desired element can be selected by activating a switch when an indicator is highlighting it (for a short amount of time), and before it highlights the next element in sequence. Figure 1.1 illustrates a very simple scanning-based interface for writing. It can be seen a red square indicator signaling to the user that if she activates the switch in that moment, the selection will be the the letter *"D"*.

There are several scanning *patterns* and several scanning *control* techniques. The patterns are the layouts in which the selectable elements are arranged to be sequentially highlighted (in a predictable way) for selection; these can be linear, by blocks or hierarchical. The scanning control technique refers to the mode in which an indicator highlights the different choices from the arrangement. The most popular one-switch control technique is *automatic*[5], in which the indicator moves automatically, highlighting the selectable elements and waiting a short time (i.e., scanning delay) on each of them for an input to occur. Such an input is usually the activation of a single switch, which consists in just a "click" with timing information (i.e., the moment of the click, not its duration). The element that gets selected is the one currently highlighted when the input event occurs. Moreover, this control

[5]Throughout this document scanning and automatic scanning will be interchangeable concepts.

Figure 1.1. The figure shows a scanning interface for writing with the letter *"D"* highlighted as the next possible selection. If the user activates the switch, she will select it, otherwise the scanning indicator will skip to the next letter: *"F"*. Image adapted from *The Grid 2* interface[4].

technique can be *inverse*, in which the selectable elements are highlighted while the user holds down the switch and the selection takes place when the switch is released.

Although scanning is considered slower and more cognitively taxing than direct selection, it generally consists of a much simpler and inexpensive set up and it requires considerably less motor control to be used efficiently (see [13] for more details about scanning as an interaction method). Thus, scanning interfaces operated through single switches are very popular among children with physical disabilities for communication purposes.

Over the years, much research effort concentrated on improving one-switch selection mechanisms for enhancing the interaction capabilities of individuals with severe motor disabilities of all ages. In the book of [19], the author discuss diverse alternative access options to address complex communication needs, such as different scanning control techniques. [13], instead, systematically compares three basic modes of scanning (e.g., automatic, inverse and step) for supporting one-switch interaction of people with cerebral palsy. Other studies, such as [63] and [34], focused on designing entire systems to provide one-switch users access to computer applications, which is essential for participating in modern information society.

Recent research in accessible HCI has been interested in universally accessible interfaces. See the early study by Stephanidis et al. presented in [61] for a definition of Universal Accessibility and its application in the universally accessible and fully-functional chess game presented in [31] and illustrated in figure 1.2. In particular, research on universally accessible games (a concept first introduced by Grammenos et al. in [37]) is improving the quality of life of many children with severe motor disabilities, which used to experience social isolation, by supporting their participation in education and entertainment along with their normally developing peers. Similarly, multiplayer games that balance for differences in player abilities are proving their effectiveness in fostering social interaction of children with disabilities. See the encouraging results of the ten-week home-based study presented in [41] with children with cerebral palsy playing the multiplayer game *Liberi*, or refer to the novel augmented reality computer game *Powerball*, designed to bring together children with and without disabilities, presented in [23].

Figure 1.2. UA-Chess main user interface

In the last decade, novel input methods for empowering disabled users to interact with electronic devices, such as brain computer interfaces (BCI) [58] and interfaces such as CameraMouse [18], a *free* program that allows to control the mouse pointer by moving the head, have been explored. Unfortunately, it is known that BCIs may be less accurate (as any other interaction modality based on physiological signals) than switch interfaces and tracking interfaces may require long times to be operated successfully, which is acceptable for navigation, text entry or menu selection, contexts in which

- selection sets are large and the occurrence of having to repeat an input is low,
- selection sets are known and static,

- single elements can be arranged in fixed positions to enhance selection speed and effectiveness,
- each element has a computable probability of being the next to be selected, given the previous selections.

Consequently, when the alternative input methods or the traditional one-switch selection mechanisms are utilized to enable children to interact with video games, the resulting experience is often frustrating, trivial or static, as illustrated in the following review of several free games (games listed in a popular non-profit website [32], mainly). The criteria for including the games in the review was that they can be freely played with just an affordable two-state single switch (without the need of holding it down). We identified three major categories of one-switch video games and the main barriers that prevent children to enjoy them:

1. *Cause/Effect games.* The goal on these simple games is to press the switch to obtain some effects (e.g., when the switch is pressed, a football player kicks a ball. These games are used to teach the children how to use the switch and to associate it to a trigger for different actions. The downside of many cause/effect games is the lack of interactiveness for cognitively able children due to the fact that they cannot make any decision to affect the outcome of the game, as the effect of pressing the switch at any time is completely random. Figure 1.3 shows the "Penalty Game" [70] before the switch is activated, during the activation action and at the end of the associated reaction.

Figure 1.3. Cause/Effect game "Penalty Game".

2. *Scanning based games.* Most of the available one switch games (e.g., chess, memory game, battleship, etc.) fall under this category. These are usually more complex than cause/effect games as scanning allows to select more than one element (or action) from an arrangement of options. However, it is not possible to interact with video games that do not have a *static* arrangement of selectable elements, a fixed scanning order and suitable game mechanics to allow enough time to make any selection even after a complete scan. Figure 1.4

shows the “Crazy Chicken” [53] game, in which the players have to drop eggs into a basket when a chicken (the highlighting indicator of the scanning) passes above it, while moving across different positions (selectable elements of the scanning).

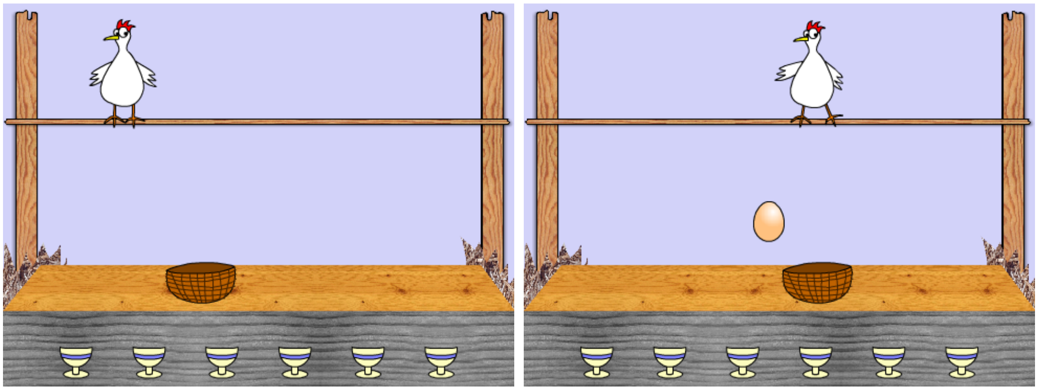

Figure 1.4. Scanning game. Crazy chicken game from “Shiny learning”.

3. *Click timing games.* This category of one switch games includes those in which the player has to press the switch with high precision to perform an action in a very specific moment. The problem with many of these games, such as Poto & Cabenga [43] and Strange Attractors [57], is that they are not fully accessible to children with severe motor disabilities because such games require a speed and precision that these children often do not have. Figure 1.5 illustrates the Poto & Cabenga game in which the player controls a running character which has to jump in precise moments to score points and to avoid being eaten by a monster.

Figure 1.5. Click timing game. Poto & Cabenga.

Chapter 2

GNomon: Dynamic One-Switch Video Games for Children with Severe Disabilities

This Section presents the design and development of the GNomon software framework. The main goal of GNomon is to provide the functionality needed for the creation of video games that support dynamic and time-dependent game mechanics, through the use of just a single switch. GNomon is based on the research conducted by Broderick and MacKay, presented in [24], about NOMON: a novel single-switch method for selecting any points on a two-dimensional computer screen. Therefore, a general explanation of NOMON is reported here, since it is useful for understanding operational aspects and design choices of the GNomon framework.

2.1 NOMON in a nutshell

NOMON is a one-switch mode of interaction that allows to select one element from a set of elements without extra special hardware (e.g., expensive eye trackers) and without requiring them to be arranged in any particular configuration or to be stationary. It is characterized by a set of widgets in the form of small *clocks*, each one appearing alongside one of many selectable elements. In Figure 2.1, a series of NOMON clocks associated to numbered options all over the screen is presented. Every clock widget has two clock hands: one red, fixed at noon and another black hand, which rotates with the same speed in all the clocks, but with a different phase. From the user standpoint, in order to select an element, she has to look at the clock associated to the element and try to press (click) the switch when the black hand is crossing the red hand (at noon), as precisely as possible. At this point, all the moving clock hands will reset to their initial positions (determined by their initial phases with respect to noon). The user repeats these actions until her desired element is shown to be selected.

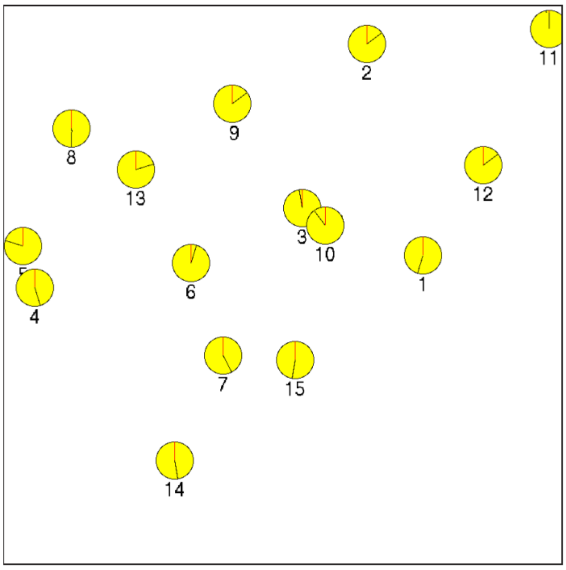

Figure 2.1. The figure shows 15 NOMON clocks associated to numbered options. These clocks can be as well associated to any other form of graphical element on the screen, even if it moves. This flexibility is leveraged by the GNomon framework, which associates the selection clocks to selectable game objects.

More in detail, after a click from the user, NOMON calculates for each clock the probability of being the intended selection, given the sequence of clicks thus far. Then, if the difference of probability between the two clocks with the highest probability of being the intended selection does not reach a predefined threshold, there is not a selection, the calculated probabilities accumulate for each clock and the clocks with a sufficiently high probability (but not enough to be selected) turn yellow. Finally, when the difference of accumulated probability between the two clocks with the highest accumulated probability is large enough, the clock with the highest probability of being the intended selection turns green and its associated element gets selected. As the number of clicks required to make a selection is variable and depends on: how precisely the user clicks and on how many selectable elements are available, the original NOMON mechanism *adapts* to the user performance. In this manner, NOMON allows precise users to click just a few times to make a selection, while it tolerates more errors from less-precise users without affecting the final selection result. The rotation period of the clock hands can be calibrated by the user.

2.1.1 Statistical model

NOMON works based on a statistical model elegantly explained by Broderick and MacKay in [24], which calculates for each clock the probability of being the user intended selection, given a series of clicks in time. The model allows to set *prior probabilities* (indicated by $p(c)$) to the selectable elements on the screen, a very useful feature in contexts in which some options are more likely to be selected than others. For instance, in a writing application, some letters are more likely than others. In contexts such as games, this feature could be used to tune the difficulty of the game by making some elements more easily selectable than others (e.g. in a shooting game, it could be easier to shoot some enemies than others).

The statistical model also assumes that the probability distribution of the user's r^{th} click time t_r around noon, $p(t_r|c)$, is known. Such a probability distribution, which is modeled as a normal distribution, depends on the chosen clock, the rotation period of the clock hand and of course the user clicking capabilities; thus, each user should spend some time generating enough data for determining such a distribution. However, the original NOMON implementation skips such a time-consuming and boring task and lets the user to start using the interface right away, assuming an initial distribution slightly offset from zero and learning for each click of the user in order to update the model online (see [24] for the complete click distribution study).

In Figure 2.2, it can be seen a schematic clicktime probability distribution around noon approximated to a normal distribution with $\mu = 0$ and $\sigma = 1$. For non-novice users, the starting click distribution of the original NOMON implementation is modeled by the normal distribution $N(0.05T,(0.14T)^2)$ and the default rotation is $T = 2s$.

After the R^{th} click of the user, NOMON calculates the *posterior probability* that each clock has of being the intended selection, given the clicks thus far, using Bayes' theorem. In the original NOMON model, the *weak* source of information provided by the times in which the user did not click were ignored. Therefore, the resulting posterior probability of a clock c of being the user intended selection, given a series of R clicks is:

$$p_{c,R} = p(c|t_{1:R}) * p(c) \prod_{r=1}^{R} p(t_r|c)$$

The clock c (and, by extension, the selectable element associated to it) is declared as the selected one if its posterior probability is higher than $1 - p_{error}$, where p_{error} is a pre-defined but configurable error rate.

In practice, NOMON makes use of an approximation for declaring a clock (c) as the selected one (see [65] for a more detailed explanation): after ordering the clocks by their posterior probabilities, the most probable clock is considered selected when its posterior probability is higher than the posterior probability of the second most

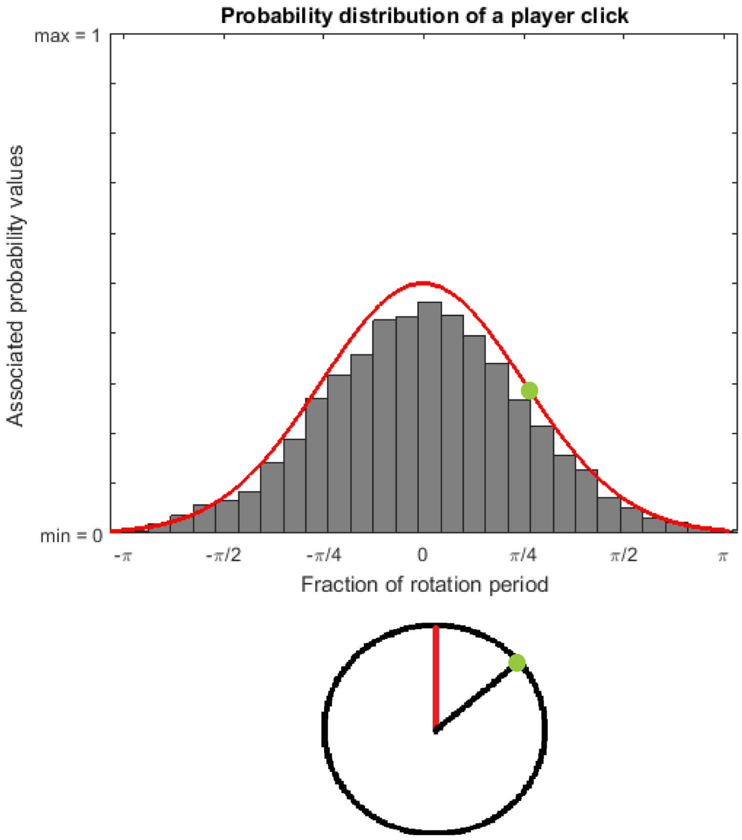

Figure 2.2. This Figure represents the relation between the click times t (representing different fractions of the BClocks rotation times) and the probability associated to them $p(t|c)$.

probable clock by at least a factor of α:

$$p_{(C),R} > \alpha p_{(C-1),R}$$

If no clock is chosen after a click, NOMON sets a new selection round by resetting all the clocks. However, NOMON chooses new relative clock hand offsets (with respect to noon) according to an heuristic, in order to help the two most probable clocks ($p_{(C),R}$ and $p_{(C-1),R}$) to diverge and satisfy the error criterion as quickly as possible in order to have a winner. The heuristic makes the most probable and second most probable clocks start with their moving clock hands at 180° angular separation. The next two most probable clocks start at 90° and 270° relative to the most probable clock, then the next four at 45°, 135°, 225° and 315°, and so on. In such a way, the chances of ambiguity between the most probable clocks in the new selection round, is reduced.

2.2 GNomon: The Design

GNomon (**G**aming **NOMON**) is a software framework that enables the creation of accessible and dynamic one-switch video games (the first idea about it was presented by Aced López et al. in [8]). It is based on the NOMON one-switch mode of interaction, presented by Broderick and MacKay in [24] and described previously, which allows to select one of many elements from the screen.

GNomon leverages the original operation principles of the NOMON selection mechanism as is illustrated in Figure 2.3 and summarized below:

- GNomon associates a small widget in the form of a clock face to each selectable element on the screen.
- Each clock widget has two clock hands: one red fixed at noon and another black hand that rotates with the same speed in all the clocks, but with a different phase.
- To select an element, the user has to look at the clock associated to the element and try to press (click) the switch, as precisely as possible, when the black hand is crossing the red hand (at noon). Then, for each clock GNomon calculates the probability of being the intended selection, given the sequence of clicks thus far. If the difference of probability between the two most probable clocks does not reach a predefined threshold, there is not a selection and those clocks with a sufficiently high probability (but not enough to be selected) turn yellow. Finally, when the difference of probability between the two most probable clocks is large enough, the clock with the highest probability turns green and its associated element gets selected.

In particular, the framework provides the functionality needed for creating sets of selectable game objects with associated clock widgets for enabling dynamic point-and-click game mechanics using a single switch. Unlike NOMON, the GNomon software framework allows these sets to be resized at any time by adding or removing elements, which is necessary for supporting common dynamic game actions such as the creation of new items or the destruction of characters. Moreover, in [9] it was demonstrated that the framework is also very useful to make static games (e.g., cause/effect games) more challenging by allowing selectable elements to be displayed without layout restrictions.

A participatory approach was adopted for eliciting the features and accessibility guidelines of GNomon, thus the work was carried out in close collaboration with a

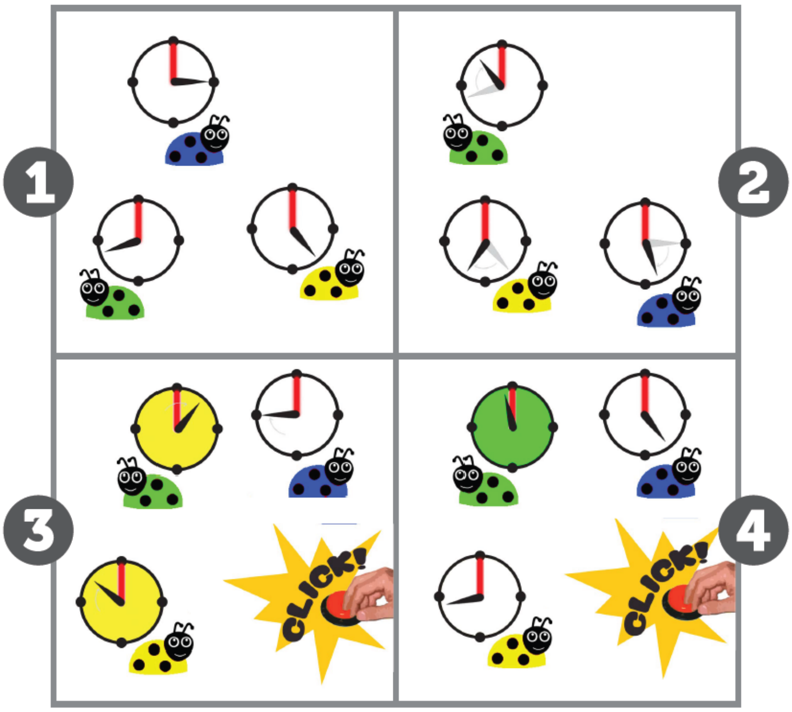

Figure 2.3. This figure illustrates the operation of GNomon. *a)* First, every element has an associated clock widget. *b)* All the clock hands rotate at the same speed and with different phase. *c)* The user activates the button and the probability of being the selection is calculated for each clock, those with the highest probability turn yellow. If there is not a winner, a new round starts again and clocks with similar probability of being the selection are assigned new and contrasting phases. *d)* Eventually, the difference of probability between the two most probable clocks becomes large enough to declare a winner, which signals it by turning green.

team of speech therapists, physiotherapists, and psychologists from one of the Local Health Agencies in Turin, Italy. They actively supported this research by guiding important design choices and proposing features on behalf of the children assisted by them. In total, five meetings with the experts were conducted for testing and collecting suggestions to improve the framework. Thus, several features of GNomon, mainly related to specific accessibility issues, were adapted to follow their valuable recommendations. The recommendations are the following:

1. Provide additional indicators for easing interaction. In particular, four circular marks were placed in the clock quarters (the three o'clock, six o'clock and nine o'clock) to facilitate the interaction of children with long muscular latent

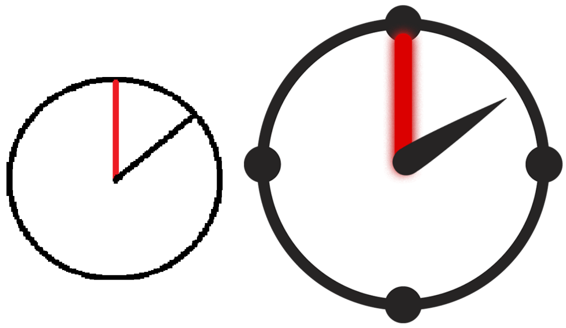

Figure 2.4. This figure illustrates the clocks used by GNomon for selecting game objects (right) and the original NOMON clock (left). The appearance of the new GNomon clock is based on the original design but with the important modifications suggested by the experts: enlarging the clock, thickening all clock lines, placing marks at clock quarters, rendering more eye-catching the red noon hand and making the moving clock hand pointier.

periods (i.e., the time elapsed between the movement command and the muscle movement) by helping them with clues about when to start "preparing" themselves for pressing the switch.

2. Make the clocks more eye-catching. Dynamic game objects are usually attractive, colorful and animated, hence they tend to concentrate the attention of children. Moreover, as the clocks are just the means for selecting game objects, it is normal that the former are less striking than the latter. However, the clocks' appearance was redesigned to be as eye-catching as possible (while keeping its simplicity) to prevent the less attentive children from ignoring the clocks. In particular, the clocks were enlarged, the colors were made brighter and more contrasting, the lines were thickened and the moving clock hand was made pointier. Figure 2.4 shows a comparison between the classical and new appearances of the clocks. The experts even recommended to "embed" the clocks into the game objects themselves. However, this recommendation was not adopted in the final design as it heavily limits the looks and appearance of the game objects.

3. Reduce the average speed of rotation of the moving clock hands and making it customizable. The rotation period of the clock hands ranges from 1 to 10 seconds, to allow children with long muscular latent periods to enjoy GNomon based games. The rotation speed can be set and changed easily by their parents or caregivers.

4. Give a visual feedback when a clock is selected. Besides the specific feedback and the actions triggered in each game when a clock is selected (e.g., the death of a character, or a jump of victory), the clock itself changes color.

2.3 GNomon: The Implementation

The GNomon software framework implementation incorporates the custom extended C# versions of the original NOMON Python libraries into a Unity [67] 2D plugin. In particular, the plugin consists, of 6 classes and 1 interface that are in charge of holding the data used by the GNomon model, updating it and providing the necessary information and functionality to implement graphic user interfaces (e.g. the clock widget) that allow users to interact with the model. However, a basic GNomon-based game can be made in Unity using just the core of GNomon, consisting of 3 classes and 1 interface, as illustrated in Figure 2.5.

2.3.1 The BClock class

Description

The basic class of the GNomon framework implementation is the BClock class, which is used to model the *selection clocks* associated to selectable elements on the screen. Instances of this class have four members and one public method, as follows.

Members

- *int Id*: Each BClock has a unique Id identifier used to associate, with loose coupling, the selection clock (BClock) to any selectable element on the screen (e.g. a character, an item, a vehicle etc.). Thus, to assign a BClock to a selectable element, it is enough to pass the latter the Id of the former.

- *int current_hour*: In theory, the rotation period T of a BClock hand is divided in a continuous series of times t, each one with a probability ($p(t)$) of being the time of the user click (t_r), given by the specific probability distribution of each BClock. However, in practice, click times are not continuous but discrete and grouped in a finite number of *hours* around the BClock. These hours represent the discrete difference of time (Δ_t) between the time of the user click (t_r) and the ideal time at which the moving clock hand crosses noon t_{noon}. The time t_{noon} varies from BClock to BClock, as it depends on the initial offset of the moving clock hand, but it is always identified by the hour 0. The grater the number of hours in which the selection clocks are divided, the more smooth is the functioning of the BClocks.

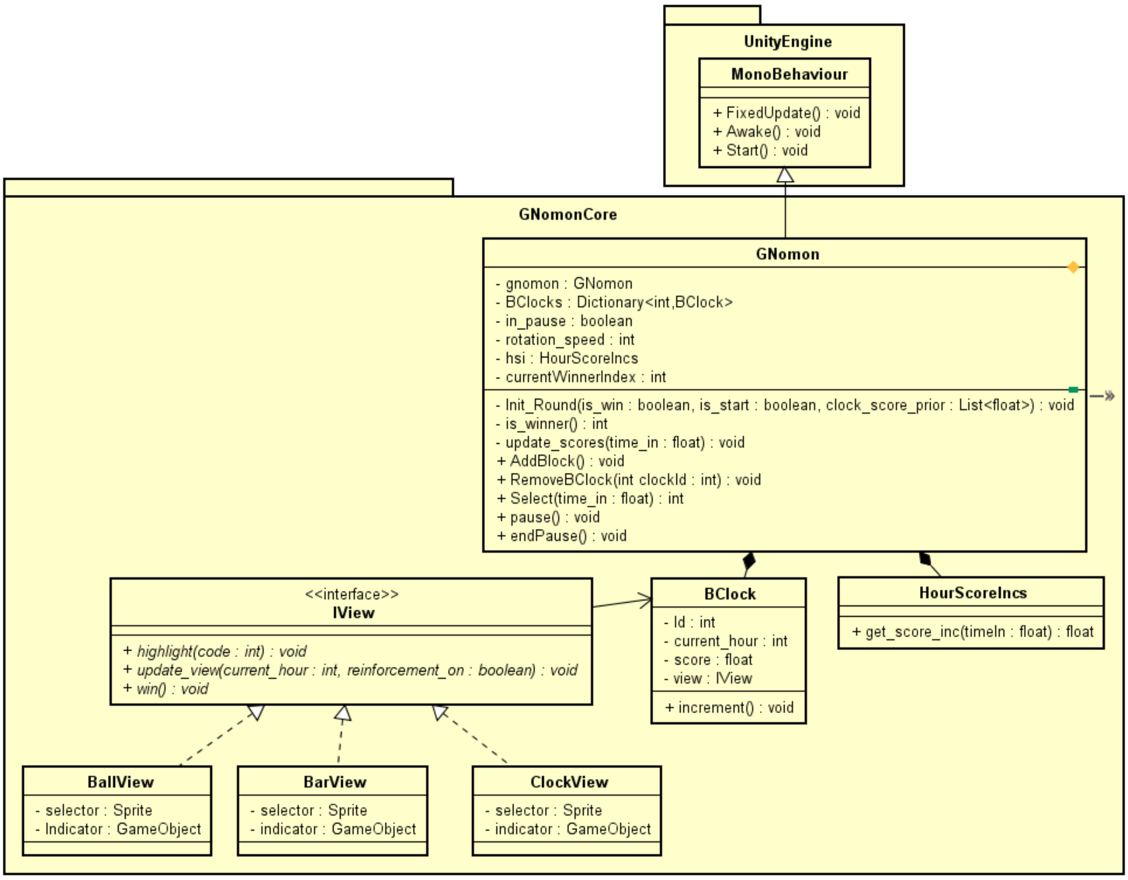

Figure 2.5. This figure shows a simplified class diagram of the GNomon framework core implementation, consisting of the GNomon Class, the BClock class, the HourScoreIncs class, and three classes that implement the IView interface. The GNomon class inherits from the MonoBehaviour class of the UnityEngine package.

Figure 2.6 describes the situation of 4 clocks at some given time t_x. It can be seen that the angular positions of the moving clock hands are different for each clock and that they correspond to different probabilities, according to the distribution probability of each clock.

- *float score*: The score of a BClock is determined by its posterior probability of being the user intended selection, given the series of clicks made so far. This variable, as in the original NOMON implementation, stores the unnormalized accumulated *log* probability ($p_{c,R}$) for each BClock.

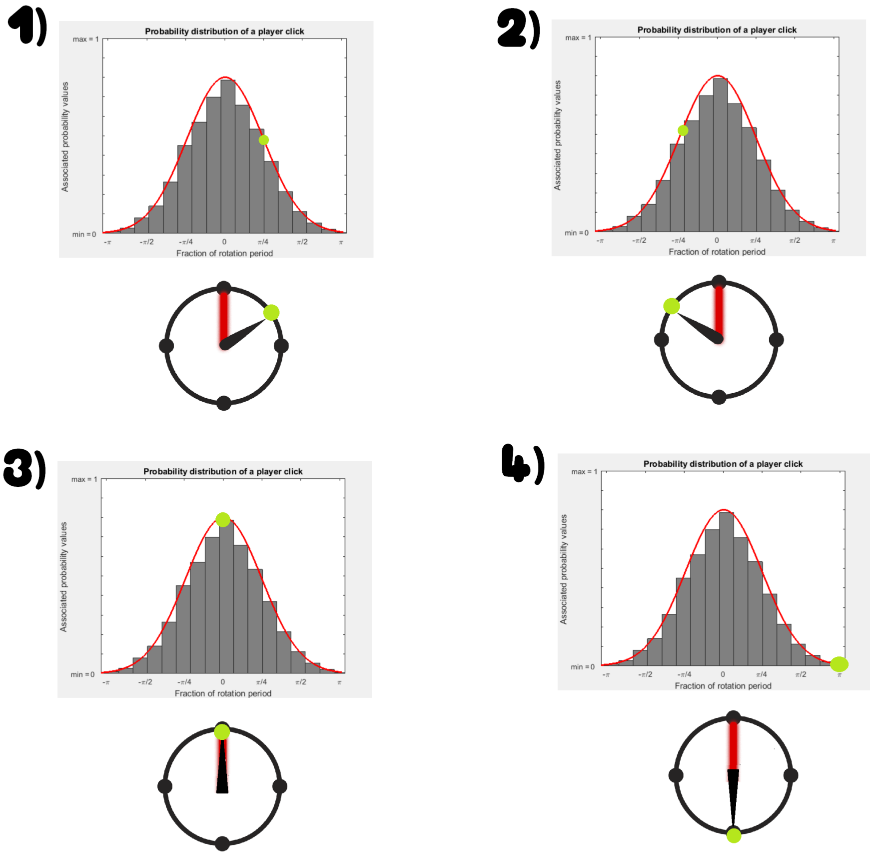

Figure 2.6. This Figure illustrates $n = 4$ GNomon clocks at a given time t_x. As their rotating hands are in different angular positions, their associated prior probabilities $p(c_n)$ at any given moment are also different. Nonetheless, clocks 1 and 2 share a similar probability as their absolute distance to noon is the same. On the other hand, the clock hands of 3 and 4 are opposite (the former is at noon and the latter at 6pm), thus the difference between their associated probabilities is maximum.

- *IView view*: This variable contains the widget in charge of giving visual feedback to the user about the GNomon model, while allowing him to interact with the BClocks associated to the selectable elements on the screen. The original widget of GNomon is the clock, however new widgets that implement the IView interface can be created, as explained later in Section 5.

Methods

- void increment(): When this BClock method is called it increments its own current_hour variable by one (in the case that the current_hour arrives to the maximum number of hours in which the BClock is divided, it is set to zero). Moreover, this method updates the state of the *view* widget by calling the *update_view* method of the IView interface. In the case of the Unity plugin that implements the GNomon framework, this method is called every fixed framerate frame.

2.3.2 The GNomon class

Description

The singleton instance of this class holds all the necessary information that the statistical model at the base of the GNomon framework needs to operate. Moreover, in the Unity plugin implementation presented in this thesis, the GNomon class extends the *MonoBehaviour* class of the UnityEngine. Thus it inherits the necessary methods to be automatically updated every fixed framerate frame, as any other game object.

Members

- *GNomon gnomon*: Is the single instance of the GNomon class used during a game.

- *Dictionary<int, BClock> BClocks*: This dictionary is the most important member of the GNomon class. It contains a set of BClock objects indexed by unique integer Ids (corresponding to the BClock Ids). These Ids allow a loose coupled association between the BClocks and the selectable elements on the screen, as the former do not need any details of the latter in order to operate. Using a key-value structure, such as the dictionary, to contain the BClocks (values) and their ids (keys) was a better design choice than using arrays, mainly due to the following reasons: the dictionary allows instant access to any BClock just by passing the appropriate key (the id) and viceversa. Moreover, changing or removing a BClock from the dictionary is straight forward and it does not affect other elements of the structure, while the case of arrays, removing an element changes the indexes of the remaining elements.

- *HourScoreIncs hsi*: This variable contains the instance of the HourScoreIncs class, which has the data structures and functionality needed to update the posterior probabilities of the BClocks, after a click.

- *bool in_pause*: This boolean expresses whether GNomon is running and accepting clicks from the user with a *false* value.

- *int currentWinnerIndex*: Contains the index of the BClock that has been selected in the last selection round. If no BClock is selected during such a round, currentWinnerIndex is -1.

- *int rotation_speed*: As all the moving clock hands of the BClocks rotate with the same speed, the common angular velocity is stored just once as the integer member rotation_speed.

Methods

- *void Init_Round(bool is_win, bool is_start, List<float> clock_score_prior)*: This method is used by GNomon to start a new selection round by changing from the state A to state B. The function's parameters determine whether the new round has to start after a successful selection or as part of a chain of clicks that have not yet resulted in a BClock selection. Moreover, every round allows to assign to each clock a prior probability, which is useful to change the difficulty of the game by making a clock more or less easily selectable.

- *int is_winner()*: This method is called after every click from the player and returns the index of the BClock that has just been selected. If no BClock is successfully selected and a new selection round starts without a winner, this methods returns -1.

- *void update_scores(float time_in)*: This method updates the score of every active BClock after a click is done. The update_scores method receives the *time* (i.e., the fraction of rotation period) of the click event, as a float parameter. Then, the method uses the time value to calculate the new corresponding scores of the BClocks, which depend on the position of their moving clock hands at the moment of the click.

- *void AddBClock()*: This method creates and appends a new BClock to the BClocks dictionary.

- *void RemoveBClock(int clockId)*: This method removes the BClock identified by index clockId from the BClocks dictionary.

- *int Select(float time_in)*: This is the method that is called when a click (i.e., switch activation by the player) is done in order to update the BClocks scores, determine a new BClock winner (if it exists) and to evolve the FSM for starting a new selection round.

- *void Pause()*: The method in charge of pausing the BClocks, avoiding new updates and selections.
- *void endPause()*: The method in charge of unpausing the BClocks.

2.3.3 The HourScoreIncs class

Description

The singleton instance of the HourScoreIncs class is in charge of calculating the new posterior probability of each BClock after a click is done. As this class is based on the original Python implementation of NOMON [4], the scores of the clocks are stored as the unnormalized log posterior probabilities, and can be updated by simple addition.

Methods

- *float get_score_inc(float timeIn)*: The only public method of this class returns the score associated to a particular time (a fraction of the rotation period of the BClocks), which is passed as the input parameter *timeIn*. When the player clicks the switch, this method can be called, once for each BClock present in the game, with the time that these had at the moment of the click. In such a way, the new scores of the BClocks can be updated by adding the returned value of the get_score_inc method with the accumulated score so far.

2.3.4 The IView interface

Description

IView is the interface that has to be implemented by any object in order to be used as GNomon selection widget (e.g., the clock widget). As it will be explained in a later section, a selection widget consists of at least two parts: a selector and an indicator; and by implementing the IView interface, all the GNomon selection widgets have three public methods that give visual feedback to the player of what is happening with the internal model of GNomon.

Methods

- *void highlight(int code)*: BClocks use visual cues to communicate their inner state to the user. In particular, a BClock can change color, shape or size in order to give feedback to the player about its current score to help him with the selection process. A game designer can define many states for a BClock that he wants to communicate to the user by using different *codes* or visual indications. In fact, the *highlight* method takes a specific integer code as input (that can be associated to different score ranges) and should react accordingly, showing different visual cues.

- *void update_view(int current_hour, bool reinforcement_on)*: This method updates the visual appearance of a selection widget according to the current_hour member of the BClock object that displays such a view (which implements the IView interface). In the case of BClocks that have a clock widget view, the current_hour parameter corresponds to the angular position of the moving clock hand of the view. Lastly, the reinforcement parameter indicates to the view whether it has to show a reinforcement at the optimal moment of the click.

- *void win()*: This method must be implemented if the selection widget of a BClock has perform some behavior when it is selected.

Chapter 3

GNomon: The Games

Three mini games with different degrees of difficulty which are fully playable with just one switch were designed in collaboration with the Local Health Agency and presented as prototypes in [9]. The final versions of the games are freely available for downloading at [1].

3.1 One Switch Demo

The first game is One Switch Demo, a cause/effect video game that allows children to make a ladybug jump when they select the clock associated to it. When the ladybug is selected correctly and it jumps, it also produces an auditory feedback to increase the child's reward. There are no scores or time constraints of any kind because the game has been designed mainly to explain how clock selection works. The aesthetics, as the objective of the game, are very simple to help the children with visual and attention difficulties to stay focused on the game mechanics. Figure 3.1 shows a screenshot of the game.

3.2 One Switch Ladybugs

The second game is One Switch Ladybugs, another mini game that allows children to make one of four ladybugs jump. Each ladybug has a different color (red, green, blue or yellow) and provides a unique auditory and visual feedback when it is successfully selected. There are no scores or time constraints of any kind, but unlike the first game the aesthetics are richer and there is background music playing in loop. The objective of the game is the same as in the previous game: to make a ladybug jump, but now the child may choose which one. Figure 3.2 shows a screenshot of the game.

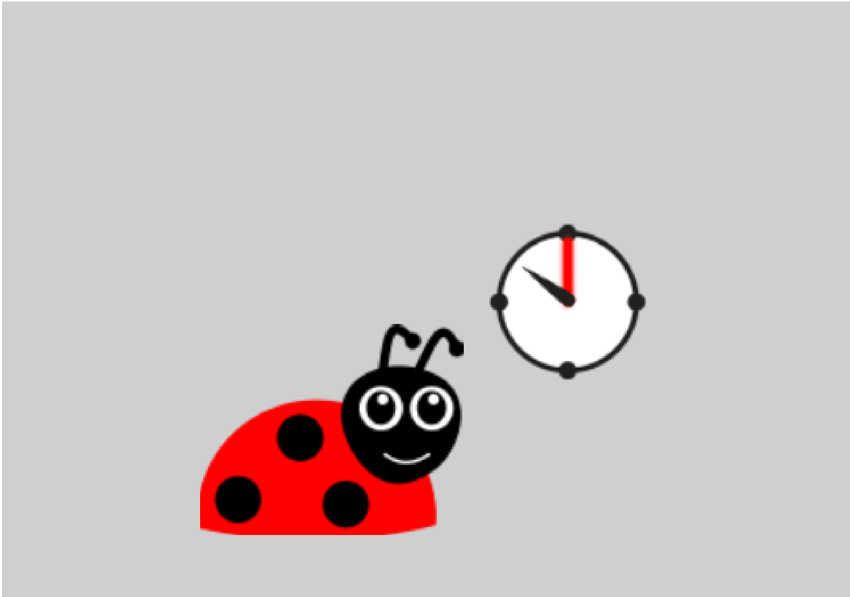

Figure 3.1. The figure shows a red ladybug and its associated clock during a One Switch Demo game.

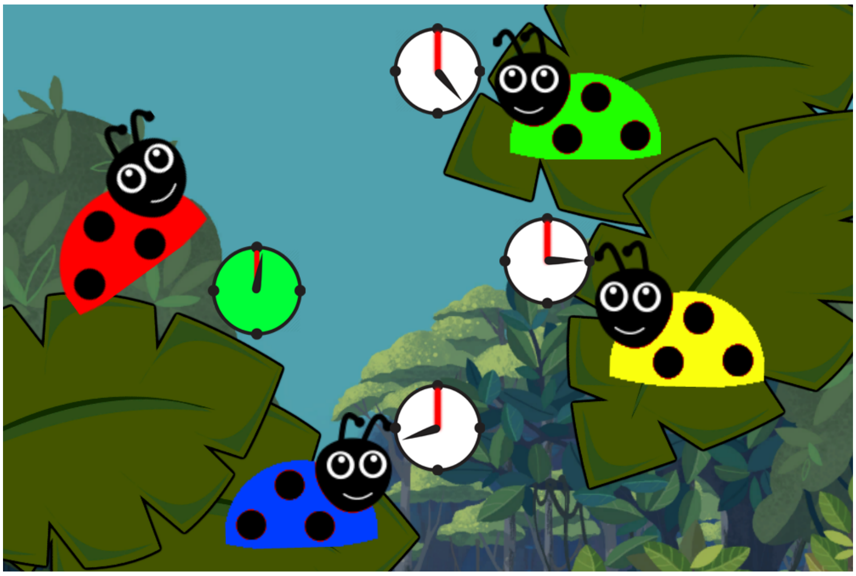

Figure 3.2. The figure shows the selection of the red ladybug (top left) during a One Switch Ladybugs game.

3.3 One Switch Invaders

The third game is definitely more complex than the first two and is called One Switch Invaders. It is an engaging *dynamic* one-switch game that does not require accurate timing or clicking precision to be played. The game has not a fixed layout, i.e., multiple selectable elements (aliens), moving around the screen, have to be selected with time constraints. The implementation of One Switch Invaders is not feasible by applying scanning control techniques because the elements are not static in predefined patterns and it is not possible to establish a scanning order without negatively affecting the game mechanics. The game objective is to score points by eliminating the aliens before three of them touch ground. There are aliens of five different colors (red, green, blue, yellow and purple) which constantly fall down the screen at a bounded random speed. Each alien is associated to a clock for enabling its selection and is generated in a random position at the top of the screen.

Figure 3.3. The figure shows six aliens falling down the screen while the green one (at the left) is being selected during a game of One Switch Invaders.

3.4 Design Considerations

The design features of the GNomon-based games aim at solving the problems of currently available one-switch games such as lack of interactivity, static gameplay and inaccessible requirements of speed and precision. Moreover, the design of the mini games (specially One Switch Ladybugs and One Switch Invaders) takes into account some of the valuable design recommendations by [42] for playable dynamic video games for children with cerebral palsy:

1. *Simplify level flow, reducing the number of decisions players need to make and reducing the demands on visual-spatial reasoning.* In One Switch Ladybugs, this is taken into account by presenting only four ladybugs which can perform just one action (jump). Although in One Switch Invaders the player has many aliens to eliminate, the decision of which one to eliminate first is simple: the lowest one, because the goal is to keep them out of the ground and all them fall with a constant speed.

2. *Reduce consequences of errors, ensuring that errors due to difficulties completing rapid or time-sensitive actions do not impair fun.* While in One Switch ladybugs there is no error penalty at all, in One Switch Invaders the players have three lives before they lose the game. Moreover, if a player misses the selection of an alien, she has more opportunities to kill it as its falling time is enough for allowing several clock hand revolutions before the alien touches the ground.

3. *Limit available actions, reducing the number of decisions players need to make, and enabling a simpler control scheme.* The control scheme of GNomon-based games consists of just one action: to press the switch. The only decisions that the players have to make, besides from *when* to press the switch for selecting the desired clock are: which ladybug jumps next in One Switch Ladybugs and which alien is better to eliminate next in One Switch Invaders.

4. *Remove the need for precise positioning and aiming, reducing the demands on manual ability and visual-motor integration.* This is part of the selection process itself. The player does not have to press the switch precisely when the clock hands are together for the interface to work. Moreover, if there is ambiguity between two or more elements, their associated clocks turn yellow to indicate it.

5. *Make the game state visible, reducing the need for attention to gameplay, and reducing the need for visual spatial reasoning to deduce game state.* Only One Switch Invaders has a state, displayed at the top bar, which consists in the number of remaining lives and points reached.

The main recommendations made by the Local Health Agency experts regarding the prototype games that were also taken into account during the design phase of the final versions are the following:

- The appearance of each game object (ladybugs or aliens) must be unique. This helps the children to remember the game object that they are trying to select if they lose track of it. For the ladybugs, this was achieved by assigning them four different colors and placing them in the four quadrants of the screen. However, in the case of the aliens this was not possible because there is not a predefined number of aliens that can be on the screen at the same time. Therefore, the solution adopted in the second game was choosing five colors to be sequentially assigned to each new alien. In this way, children that lose track of their game object can retrieve it without being confused with another near object that looks the same.

- Different game objects have to produce different visual and/or acoustical feedback when selected. This was easily achieved by changing the animations and sounds produced by different characters when selected (e.g., each ladybug jumps in a unique manner and produce a different piano sound).

- Although aliens can fall with different speeds, the maximum falling speed has to be bounded by a maximum value set by the player or a caregiver. However, for evaluation purposes, in this version all aliens fall at the same constant speed.

- In the One Switch Invaders game, the aliens wait until the first "click" to start falling. In this way, the player can observe the clocks and familiarize with the speed of rotation of the clock hands before trying to select one of them.

Chapter 4

GNomon: The Studies

This chapter presents the two user studies that were carried out for evaluating GNomon and the GNomon-based games. These studies aim at determining the *playability* and the *rehabilitative suitability* of the dynamic one-switch video games based on GNomon. The studies are presented separately as they were conducted: first the playability study, which consisted of two sessions, and then the rehabilitative suitability.

4.1 Playability Study

The third phase of this research consisted in the evaluation of the three GNomon-based mini games. In particular, this study answered the question of whether the GNomon-based video games are playable by children with severe motor disabilities. Therefore, a study was conducted, with 8 children, in which six main properties of playability were assessed (based on the concept and characteristics of playability presented in [36]):

1. *Learnability:* How easy is for children to understand and successfully start to play the GNomon-based games after they have been explained?

2. *Effectiveness:* How much time and resources do children need while playing the GNomon-based games for achieving the various goals of the games?

3. *Errors:* How many times, during the game, the elements selected do not match with the element that the players had in mind to select?

4. *Satisfaction:* Do children like to play video games with a GNomon-based interface?

5. *Memorability:* How easy the games are to remember after a substantial time-lapse between play sessions?

6. *Fun:* How fun do children have while playing GNomon-based games?

The test was divided in two sessions, with a one-month pause between them, mainly for assessing the *memorability* of the games in the second session. In addition, the assessments of the other playability properties were reinforced by means of the additional data collected in the second session, with the exception of *learnability*. The learnability was evaluated only when the children learned for the first time how to play the games, in the first session.

4.1.1 Evaluation

The two-session test was conducted in Italian at the Local Health Agency with children between 4 and 14 years old with severe motor disabilities which consistently use one-switch interfaces. The sessions were carried out at the Health Agency facility, a known environment for the children, to avoid making some children anxious about being in an unfamiliar place. A speech therapist (tester) held the sessions and two observers carefully took notes of the sessions. Only two observers were present during the tests, (one expert from the Health Agency and one HCI researcher) to prevent some children from distracting and being uncomfortable in the presence of many people. Moreover, all the tests were video recorded hiding the children faces, with the authorization of the children's parents, for later analysis.

Set-up and Materials

The children played the games in a 21" screen with a Big Red 5-inch mechanical switch (shown in figure 4.1) activated with the hand or with the head, depending on the capabilities of each child. The interface between the switch and a laptop was a Helpibox 16 (shown in figure 4.2). In the case of non verbal children, it was also necessary to use Alternative and Augmentative Communication (AAC) tables to allow them to answer the tester questions, in particular these tables contained the colors of ladybugs, the yes/no answers and the faces to indicate "like" or "dislike". Table 4.1 summarizes the materials used for carrying out the tests.

Participants

The participants of this study were 8 children, 7 boys and 1 girl, with severe motor disabilities. All of them were between 4 and 14 years old and rely on the use of single switch interfaces to access electronic devices. P1 and P2 were the only children that activate the switch with their heads, while the other do it with their upper limbs.

Figure 4.1. Big Red 5-inch mechanical switch

Figure 4.2. Helpibox 16

The severe motor impairments of the children have different causes, which in some cases entail cognitive disabilities as well (as in the case of some children with cerebral palsy). In fact, with the exception of participants P5 and P8 who are affected by spinal muscular atrophy (which does not compromise cognitive capabilities), the participants share a mental age between 3 and 5 years old. Instead, P5 and P8 have mental ages that nearly match their chronological age. See Table 4.2 for a detailed summary of the participants.

Given the fact that the participants are children which have special communication needs due to their disabilities, it was not possible for the tester to conduct the test exactly the same way for every child. Inevitably, for some children the therapist had to explain the requested tasks in more detail and avoided to ask open questions at the final questionnaire. Nevertheless, the results are completely acceptable as the contents of the information provided (and requested) by the therapist to (and from) the participants was essentially the same. Just the explanations of the games were adapted to better suit the capabilities of each child.

Materials
Intel i7 laptop with 8GB of RAM running 64-bit Windows 7
One Switch Demo game
One Switch Ladybugs game
One Switch Invaders game
Helpibox 16 interface
Big Red 5-inch switch
Logitech Orbit webcam with microphone
Adjustable school table
Alternative and Augmentative Communication (AAC) tables
21” VGA monitor

Table 4.1. Materials used for carrying out the tests

Participant	Age	Impairments	Diagnosis
P1	4	Non-verbal with spastic quadriplegia with dystonia	Cerebral Palsy
P2	4	Non-verbal with postural hypotonia	Aicardi-Goutières syndrome (AGS)
P3	4	Spastic quadriplegia, cognitive and communication difficulties	Cerebral Palsy
P4	6	Spastic quadriplegia, strabismus and cognitive difficulties	Cerebral Palsy
P5	7	Muscular dystrophy	Spinal Muscular Atrophy (SMA)
P6	7	Moderate cognitive difficulties	Down syndrome with right-side hemiparesis
P7	8	Cognitive, visual and coordination difficulties. Spastic quadriplegia.	Cerebral Palsy
P8	14	Muscular dystrophy	Spinal Muscular Atrophy (SMA)

Table 4.2. Participants with details about age (in years), impairments, diagnosis and body part used for operating the switch

Procedures

Each of the two sessions was conducted and video recorded at the Local Health Agency facility, in Turin, by a speech therapist with two observers: another therapist and a HCI researcher. The recruitment of the participants was straightforward since the Health Agency proposed and gathered the children and helped us to fix the appointments for the tests. The criteria for selecting the participants was that they had to be children that use a single switch for accessing electronic devices.

The tests were held in Italian and lasted between 7 and 18 minutes for the first session and between 8 and 15 minutes for the second session, depending on various factors such as the cognitive or visual difficulties of the children taking the test, their fatigue and how much they wanted to play each game. The sessions, although in a flexible way, were structured in three parts, one dedicated to each game. In the first part of the first session, the tester explained the scope of the One Switch Demo game (i.e., to make the ladybug jump) and how to accomplish it. The tester demonstrated twice the selection mechanism by making the ladybug jump. Then, the child tried to make the ladybug jump and could play for 2 minutes maximum. In the second part of the first session, the speech therapist presented the One Switch Ladybugs game to the child by saying that it was played in the same way as before, but explaining that this time it was necessary to identify which of the four ladybugs should jump and to focus on the clock next to it. As before, the tester exemplified twice. Then, he asked the children to make a different ladybug jump following a standard sequence (green, red, yellow and blue).

Finally, the child was asked to choose a ladybug to make it jump and to say it out loud (the non-verbal participants used an AAC table for this task) before selecting it. At the end of this part of the test, the child could play freely for 3 minutes maximum. The last part of the first session consisted in playing the One Switch Invaders game, but it was carried out only with participants P5, P6 and P8. This part of the test was not proposed to the other participants because during the preparation of the evaluation phase, the experts considered that it would be above their cognitive or visual-attentive capabilities, thus no reliable results could be expected from them. However, when the third part of the test was conducted, it followed a similar scheme than the one adopted for the previous two parts: the objective of the game was explained to the children, then the tester demonstrated twice how to kill the aliens and finally the children could play freely for 5 minutes maximum.

At the end of each game, three questions were asked to the participants:

1. Did you like the game?
2. What aspect of the game did you like the most?
3. What aspect of the game did you not like?

Likewise, at the end of the entire session, the children were also asked the following questions:

1. Did you remember how to select the elements while you were playing?
2. Was it difficult to select the elements?
3. Did you have fun?

At the end of all the first sessions, the recordings were carefully transcribed for further analysis, as well as the observation notes taken by the observers. Moreover, data from each session was also logged; in particular, it was collected information about the chosen rotation speed of the clocks, the falling speed of the aliens (in the One Switch Invaders game, only), the number of clicks performed and the time of each one of them, the selection of a ladybug in the One Switch Ladybugs game and the final score in the One Switch Invaders game.

One month after the first session, the children were asked to play the games again, but this time without any explanation or indication of what to do or how to do it. Before starting the second session, two questions were asked to the participants:

1. Do you remember the game with the ladybugs and the clocks?
2. Do you want to play it?

Likewise, before starting each game (but with the game on the screen) the participants were asked:

1. Do you remember *this* game?
2. Do you know how to play this game?

Observations

Before discussing the obtained data, some general observations are presented, to provide contextual information useful for understanding the results and discussion.

During the first session, there were minor difficulties while testing the games with the children at the Local Health Agency mainly related to the children's mood. In general, the youngest children with cognitive or attention difficulties (P1 and P3) became tired by the end of the first game (i.e., the one with a single ladybug) and faced the rest of the test with unfavorable attitude. In particular, P1 (which is a non-verbal child) started to stare at the door when the tester asked him for the fourth time to select a ladybug during the second game, indicating that he wanted to leave the room. Similarly, P3 at the end of the second game, did not want to freely play as he wanted at the end of the first game. Nevertheless, the experts that regularly assist these children agreed that it was normal that they were tired after trying new experiences that require them attention and concentration.

Another slightly problematic situation happened also at the first session with P2, a 4-years-old girl, as she was not being cooperative because she wanted her mother in the room. The tester and the observers decided to call in the mother in order to calm the child. However, although the child calmed down, she was very distracted by continuously looking at her mother and she was not able to perform at her best in the evaluation.

The second session ran more smoothly as it lasted less time (in average) and the children had the right amount of work to be challenged but without being frustrated or tired. Moreover, given that the test conditions were as identical as possible to those of the first session, the children found themselves in a more familiar environment: they knew the protocol, the researchers, and the procedure (i.e., playtime followed by some questions).

4.1.2 Results and Discussion

This section presents the data and information collected during the playability test, along with their analysis and the derived research findings. First, the qualitative observations made during the first and the second session of the test are presented, along with Tables 4.3 and 4.4, which summarize the quantitative measures taken. Secondly, it is presented the assessment of the *learnability*, *effectiveness*, *errors*, *satisfaction*, *memorability* and *fun* of the games, stemming from the aforementioned tables and from the careful analysis of the video recordings of each session.

First session

The first session lasted in average 13.13 minutes (SD: 3.52) and all participants, except P7, played at least the first two games (One Switch Demo and One Switch Ladybugs). What happened with P7 is that he could not make the single ladybug jump in the One Switch Demo. He was very distracted by watching the clock hand rotating or looking at the table, and given his lack of cooperation the tester decided to stop the test. On the other hand, P5, P6 and P8 were able to play satisfactorily all games, including One Switch Invaders.

The errors were higher in the case of children with cognitive or attention impairments than in the case of children with just motor disabilities. In particular, P3 and P4 were facilitated by hiding two of the four ladybugs from them in an initial phase. In such a way, the tester limited the visible options at the beginning of the free selection phase during the One Switch Ladybugs game, to help the children to concentrate on the ladybug they wanted. On the contrary, P5 and P8 had no errors when they tested all the three mini games, moreover they asked to play One Switch

Invaders again but with a faster falling speed (i.e., the speed at which the aliens fall down the screen).

All participants with the exception of P1 answered that they enjoyed and had fun playing the mini games. However, the negative answer of P1 to the question *Did you have fun?* is not reliable because it was at the end of the test when he was very tired, also it is in contrast with the notes taken by one of the observers which reported that the participant was "continuously smiling" while he was playing.

The rotation speed of the clock hands was initially determined by the tester on the basis of the previous knowledge that she had about each participant. However, when necessary, the rotation speed was modified after the first mini game. The rotation speed is expressed as an integer between the linear interval [1-20], where 1 represents a rotation period of 10 seconds and 20 represents a rotation period of 1 second. Setting the right rotation speed was not an easy task, especially when the participants had attention difficulties because setting a fast speed increases the difficulty of successfully selecting the intended ladybug, while a slow speed gave some participants enough time to be distracted and forget about the selection task.

Table 4.3 summarizes information regarding the following aspects: the number of games actually played by each participant, overall duration of the test, the error ratio during the One Switch Ladybugs game (i.e., the number of selections that were not the intended selection by the participant vs the total number of selections), clock hand rotation speed and the answer of each participant to the final question *Did you have fun?*.

Participant	Games played	Duration	Error ratio	Speed	Had fun?
P1	2	14 min	55%	5	NO
P2	2	15 min	50%	7	YES
P3	2	18 min	53%	8	YES
P4	2	11 min	62%	6	YES
P5	3	10 min	0%	10	YES
P6	3	15 min	29%	8	YES
P7	1	7 min	-	6	YES
P8	3	15 min	0%	10	YES

Table 4.3. First session observations

Second session

The main goal of this session was to evaluate the *memorability* of the GNomon-based games, as well as tracking the individual improvements in the other playability properties. The second session was carried out with the same group of experts and with the same conditions of the previous session. Nevertheless, there was an unexpected problem as participant P5 abandoned the Local Health Agency, thus he did not take part in this session.

Each second session lasted in average 10.86 minutes (SD: 1.86) and this time all participants were able to play the first two mini games (One Switch Demo and One Switch Ladybugs). The same participants that successfully played One Switch Invaders in the first session (P6 and P8) were the only ones that could play it during the second session.

Similarly to the previous results, the errors during the second session were higher in the case of children with cognitive or attention impairments than in the case of children with just motor disabilities. This time all the children, with the exception of participant P6, improved their error rate. In particular, participant P2 decreased her error rate from 50% to 33% and participant P7, who did not have an associated error rate for not being able to play One Switch Ladybugs during the first session, was able to play it getting an error rate of 55%.

During the second sessions there was no need to facilitate the tasks to any participant by hiding them any of the ladybugs in the One Switch Ladybugs game, as it was the case in the first session with participants P3 and P4. Moreover, participants P1, P2, P4, P6, P7 and P8 played with a higher clock hand rotation speed than the one set for the first session. Participant P3 played with the same speed in both sessions. Notably, participant P8 was able to score 17 points at One Switch Invaders with a rotation speed of 19 (almost the double of his first session maximum rotation speed).

Again, all the participants with the exception of P1 answered that they enjoyed and had fun playing the mini games. However, this time the negative answer of P1 to the question *Did you have fun?* was in line with the attitude he showed while playing: he was very nervous and angry, and he took more time to complete the tasks in this session than he did in the first one.

Finally, the memorability of the GNomon-based games was better than expected: 5 children out of 7 answered affirmatively to the question "Do you remember the game with the ladybugs and the clocks?" and described correctly how they had to play the games. One of the participants (P7) answered that he remembered the games but he did not actually remember how to play them. Participants P6 and P8 which were the only children that played the third game One Switch Invaders, remembered it very well and P8 described without doubting not only how to eliminate the aliens but also the strategy to win the game: "you just have to eliminate the aliens as soon as they appear on the top, do not give them the chance to move".

Table 4.4 summarizes information regarding the following aspects evaluated during the second session of the tests: the number of games actually played by each participant, the error ratio in the One Switch Ladybugs game, overall duration of the test, clock hand rotation speed, the answer of each participant to the final question *Did you have fun?* and the answer of each participant to the question *Do you remember the game with the ladybugs and the clocks?*.

Participant	Remembered?	Games played	Duration	Error ratio	Speed	Had fun?
P1	YES	2	15 min	50%	8	NO
P2	NO	2	10 min	33%	10	YES
P3	YES	2	10 min	38%	8	YES
P4	YES	2	11 min	62%	6	YES
P6	YES	3	10 min	25%	10	YES
P7	NO	2	10 min	55%	8	YES
P8	YES	3	10 min	0%	19	YES

Table 4.4. Second session observations. P5 did not take part to this session.

Playability Assessment

Stemming from the results of the playability study, it is possible to answer positively the research question of whether it is possible to make playable one-switch video games, based on GNomon. The playability, assessed through the properties of *learnability*, *effectiveness*, *errors*, *satisfaction*, *memorability* and *fun* of the GNomon-based games is adequate and very promising. In particular, all the children that played the games learned and were able to use the GNomon-based interface and the selection mechanism to play the games, while having fun. Moreover, the participants who tried One Switch Invaders (3 out of 8) indicated that it was the funniest of the three video games, and also that they had never played anything similar. At the end, participant P8 asked if he could have the One Switch Invaders game for playing it again at home.

The research findings regarding the playability properties are reported in detail below:

1. *Learnability*

   It took, in average, 2 activations of the switch for the children to understand the mechanism and to be able to consistently make the single ladybug jump (on the One Switch Demo game). There were cases (P5 and P8) in which the participants understood and were able to use the GNomon selection mechanism immediately, but in other cases (P7) it could not even be determined if the mechanism was comprehended.

Two of the questions at the end the first session helped us to determine if the selection mechanism was difficult to grasp: *Did you remember how to select the elements while you were playing?* and *Was it difficult to select the elements?*. Not all the children were able to answer the first question because it was very difficult for their cognitive and communicative skills, but all of them (of those who played at least two games during the session) agreed that it was not difficult to select the elements. Even P4 said that it was easy to select the single ladybug, but he emphasized that selecting one of four ladybugs was not an easy task. Moreover, the observers agreed that, in general, the children understood how the selection mechanism works, even though some of them had trouble operating it by themselves.

The results presented here suggest that a game with a GNomon-based interface is learnable by children with severe motor disabilities, especially if they do not have additional cognitive or visual impairments.

2. *Effectiveness*

   The evidence suggests that using GNomon-based mechanism is effective, since it was certainly possible for 7 out of the 8 participants to play and complete the tasks of the first session, despite of the errors, in less than 20 minutes. Moreover, during the second session in which the participants were already familiarized with GNomon, all of them were able to play satisfactorily (even participant P7, who could just play one game during the first session).

3. *Errors*

   In the first session, the error ratio was 49.8% (SD: 12.44%) in average, excluding the two outlier cases (P5 and P8). This significant error ratio can be explained by the additional cognitive impairments that the participants had, with the exception of P5 and P8. In fact, those two outlier cases, which had a 0% error rate, do not encounter the difficulties that some participants have to *plan* the movement as both of them have normal latent periods (i.e., the time elapsed between the movement command and the muscle movement).

   However, it is worth noticing that the average error ratio decreased to 43.8% (SD: 14.13%) during the second session, excluding the outlier cases as before (i.e., 0% error rate). This is very promising since participants increased the rotation speed of the clocks during the second session, and may entail that performance over time can be improved with training.

4. *Satisfaction and fun*

   The children that were able to answer the question *What did you like the most?* in the first session (P5, P6 and P8) said that they liked how the ladybugs jump and also the ladybug moving around. For the One Switch Invaders game, they answered that they liked the falling aliens and to be able to kill them. These answers suggest that the dynamism of the games, in particular in the case of the last game, was really appreciated by the players as something new that they were able to try. In the second session, participants P6 and P8, answered this same question referring almost exclusively to the One Switch Invaders game.

   Moreover, at the end of the second session, P8 (the oldest participant, a 14 years old boy) was very excited and wanted to talk more about the games: he explained better that One Switch Invaders gives him the emotion of having to score points knowing that he could lose at any time, he said *' 'In this game I do not know how many points I will score, while in the other games I can play I know that I can't fail and there is not emotion there"*. He said that many times the games he plays are those he can control and not necessarily the ones that he would be interested in; as an example he showed the researchers an online scanning-based game for making cakes in which he picks up ingredients and places them in predefined positions on the cake base. He explained: *"This game is ok but not like killing the aliens, but I can play it and it is entertaining"*. It is clear that games with dynamic mechanics facilitated by GNomon are not only satisfactory, but a very exciting new alternative for children that cannot freely choose what they want to play, but are forced to play what they can operate with their single switch.

   Lastly, other children expressed their satisfaction while playing the games in diverse ways that were noticed and written down by the observers. This is the case of participant P3, who yelled "More, more" when the tester announced him that the time for freely playing One Switch Ladybugs, in the first session, was over. Similarly, participant P2 indicated through an AAC table that she wanted to continue playing the second game when the tester gave her the chance to stop due to her apparent lack of interest. P5 and P8 also asked, on their own initiative, if they could play more at the One Switch Invaders game after finishing the first session, which clearly indicates that they enjoyed playing the game.

   Consequently, it is evident that engaging in the GNomon-based games was not only considered satisfactory but also fun by the children during the tests. Moreover, the children that had the cognitive and visual capabilities to play a dynamic game such as One Switch Invaders indicated that was the one they liked the most.

5. *Memorability*

   All but two participants (P2 and P7) answered that they remembered the games. However, the two participants that answered negatively to the questions related to the memorability of the games were the most distracted during the first session: P2 was constantly looking for her mother, ignoring sometimes what was happening around her; P7 was so distracted during the first session that the tester decided not to present him the second game (One Switch Ladybugs) and he only played the One Switch Demo game. Therefore, it is understandable that after one month they did not recall having played the GNomon mini games.

4.2 Rehabilitative Suitability Study

In the fourth and last phase of this research, it was conducted a second study aiming at assessing the suitability of the GNomon-based games as useful tools in the rehabilitation of children with disabilities. In particular, there were a lot of interest in answering the research question of whether the game mechanics and the control interfaces based on GNomon (more than the individual games themselves) are suitable to be exploited by the healthcare experts that work with children with severe motor disabilities everyday, within their therapies.

4.2.1 Evaluation

To answer the research question, a semi structured interview was conducted in the form of a focus group with two speech therapists and a physiotherapist with whom we collaborated throughout the GNomon design and playability study. The focus group lasted 90 minutes and the audio was recorded for later analysis. Two HCI researchers participated in the interview: one as the moderator, proposing the questions and guiding the conversation, and the other one carefully took notes to be integrated with the recorded audio. The actual questionnaires, the answers and the conversations between participants and the moderator interventions were in Italian; thus, all the material was fully translated into English. The issues discussed during the interview are the following:

- How important is for children to play *dynamic* video games?
- What other types of video games do children with severe motor disabilities play?

- What about non-digital games? Do children play them? Do these games have *dynamic* components?
- For children with severe motor disabilities, what are the rehabilitative, educational or leisure benefits of playing dynamic video games?
- Do GNomon-based game mechanics are suitable for which kind of games? Which benefits can derive from playing GNomon-based games?
- What do you think are the reasons for the errors made by the children while playing the GNomon-based games?
- Stemming from this experience, what would you change or improve about GNomon or about the games?

4.2.2 Results and Discussion

An excerpt of the discussion that the three experts (E1, E2 and E3) and the moderator (M) held during the focus group, for each question, is reported below.

1. How important is for children to play *dynamic* video games?

   E1: I think that dynamic games allow children to have a transferred experience of movement... I am thinking especially that for those kids that cannot move at all, the fact of being able to participate in a dynamic experience is something big! The possibility of accessing a dynamic video game through a PC or a tablet in which it is possible to regulate times, distances and speeds is also a good attention exercise... like a training!

2. What other types of video games do children with severe motor disabilities play in therapy?

   E2: They play with the PC or the tablet here in therapy, however not everyone is able to.
   E1: A way of playing is for example by "borrowing my finger": they see where they want to go and indicate it with their gaze and I place my finger there.
   E2: Anyway the games are always static and the most part based on scanning so they can play by themselves.
   E3: They play mainly here... although there are some parents that have the time and disposition to play with them, but often what they do, with their best intentions of course, is to guide the hands to touch the tablet so the children are not independent in the game.

3. What about non-digital games? Do children play them? Do these games have *dynamic* components?

   E1: Sometimes, but the all the games have to be adapted. The kids play these games here because at home they do not have the toys or because their parents do not have the time to support or follow them while they play.

4. For children with severe motor disabilities, what are the therapeutic benefits of playing dynamic video games?

   E2: For children with these kind of disabilities, video games are not just a pastime and playing is never time wasted. Few of the games in which they engage are only just for entertainment, fun or leisure. Playing with them is a therapeutic resource and their parents and school teachers do it always "for a reason". Pure play, with an end to itself, no. Almost never. Many parents prefer to put the kids in front of the TV to watch cartoons. That is the leisure that they have. But that is not interactive! What do you have to do in order to watch some cartoons? Nothing!
   E3: Exactly! that is what many parents want, that their children can be placed somewhere without them having to do anything.
   E2: We could not even propose some parents to let their children play a leisure game in which maybe is not that important if they are in a crooked position, but it is only important that the kid has fun.
   E3: Some parents would say! Absolutely no!
   E1: We play a lot, but always with some objective in mind, it could be rehabilitative or educational.
   E3: The children do not play at home very often
   E2: They would play... but they are not facilitated.
   E1: In school it is also different because the child with disabilities sees his classmates playing. In some way he is participating and the others may involve him too. That is also a situation of joy. In other words, in school he can enjoy play, even if he participates just a little, he is there.
   E2: At home it is different, they are more alone because they do not have their peers, and with their peers they have a relationship, they could have at least some smile as feedback. There is some kind of interaction.
   E3: For *participant P1* the moments of leisure play happen at school because he has a teacher that wraps him in a blanket, moves him and takes him out. In moments like that he finds the joy of play, of free play, not when he is at home in front of the TV.
   E2: The problem is also that these children always need the adult that helps them to play... even video games

5. Do GNomon-based game mechanics are suitable for which kind of games? Which benefits can derive from playing GNomon-based games in therapy?

   E1, E2: GNomon is good for leisure games as well as for rehabilitative and educational games!
   E2: The ingenious interface and the selection mechanism are useful for the three types of games. For the therapeutic part for sure!
   E1: They could also be educational as GNomon involves time, waiting, attention etc. And the leisure part of course as they can feel that are playing games as those played by their brothers or classmates!
   M: What benefits exactly do you think GNomon fosters?
   E2: Well it trains the children to maintain a selective attention and to hold it over time; it trains the visual scanning between various objects; it strengthen the eye-hand coordination; it supports the learning of concepts such as colors, numbers letters, depending on the game theme; it supports and develops the autonomy to play, it teaches to wait and to respect time-outs.
   E3: The benefits of the GNomon mechanisms can also be integrated with the specific characteristics of each game!

6. What do you think is the reason for the errors made by the children while playing the GNomon-based games?

   E2: I think the errors are relative to each game, not to the GNomon mechanics.
   E1: These depend on the condition of each children. For example *participant P8* had no errors at all, while *participant P1* is a kid that when is excited about something cannot control totally his movements.
   E3: The errors are not even their fault...
   E2: Exactly! Maybe for some children, when they are excited to do something new or fun, starts the dyskinesia. That is why sometimes we have to fix them to contain their involuntary movements.
   E1: The same can happen with the eyes, they have not a constant performance
   E2: Behind a simple mechanism such as "look-wait-click" there are attentive, eye-hand coordination and emotional contention difficulties... then, the dyskinesia does not help at all...
   M: But these problems are present also with scanning interfaces?
   E2: Yes, of course.
   E3: But it is true that the less of elements you have, the less of the problems. Each element can be a problem source, and maybe the scanning has less elements than GNomon, but less flexibility... at the end you have to find a

balance
E2: The errors are due to their disabilities and specific conditions, not to problems with the interface or the games. But as happens with any game, the performance improves with practice for sure! In fact it would be very interesting to make a long-term study to track this.

7. Stemming from this experience, what would you change or improve about GNomon or about the games?

   E3: There were some problems with precision during the first session and sometimes when the children activated the switch while the clock hands were far apart, a selection happened. It was corrected for the second session and now the mechanism works well.
   E2: Maybe it would be useful to explore other graphical elements rather than the clocks as interface elements because some children found difficult to wait for the clock hands to come together for activating the switch. Maybe something with colors or shapes, easier than the concept of "clock" and rotation, and angular distance.
   E1: Yes! Other possibilities could be explored, for instance an horizontal bar which maybe easier to comprehend than a circular movement.
   E2: Maybe a ball that shrinks and grows and changes color. Here, the children could wait for the ball to grow and changed to some determined color to activate the switch. This would be a simplification that would help further some children such as participant P7.
   E3: In future games, the clocks, or other landmarks such as the shrinking balls, should be integrated with the game objects. Instead of being next to the game object, they should be inside or at least they should have the same graphical style that the element to which they are associated.
   M: Do you think that other kinds of feedback different than visual would be good for these children? Maybe haptic, sound?
   E2: I think it would be worse, because the more elements you have the more confused they will be.

The results of this rehabilitative-suitability study suggest that GNomon-based games do have the potential of being used for rehabilitative purposes, answering positively the initial research question. The experts interviewed in the focus group considered that the kind of *dynamic* interaction that GNomon-based games support is "very positive" and "valuable". In fact, the speech therapists wanted to extend the use of the GNomon games from the Local Health Agency to one of the children hospitals in the city, not only for the kids fun, but for developing and improving several skills within therapy.

The research findings of this study are in line with previous findings in the field of game design for rehabilitative therapy. Moreover, the results of this study suggest that GNomon-based games could also be exploitable in speech therapy with children with cognitive impairments, or in brain injury (BI) therapy. It has found that the main rehabilitative aspects of GNomon-based games, identified in the focus group, finely address some of the main therapeutic goals of BI therapy (according to [27]), such as attention/coordination, processing speed, hand-eye coordination, sequencing and command following, visual spatial abilities, among others.

The main aspects for which GNomon-based games have the potential of being used with rehabilitative purpose to be used in therapy with children with severe motor disabilities, are summarized below:

1. *Training the maintenance of selective attention over time:* The children have to maintain their concentration in a single clock and wait for the adequate moment for making a successful selection with GNomon, ignoring distractions such as other game elements.

2. *Training the visual scanning between various objects:* The children have to move their gaze for searching the elements they want to select, instead of just waiting for the elements to be automatically highlighted (as in the case of scanning interfaces).

3. *Strengthening the eye-hand coordination:* The children have to coordinate the moment of switch activation with the what they are seeing in the screen. Moreover, they have to compensate their own latent periods and plan the motion accordingly for a successful selection.

4. *Teaching to wait and to respect time-outs:* The children cannot activate the switch any time they want if they want to successfully select an specific element. Thus, it is important that they wait (without clicking) the right moment and that they learn to do not activate the switch in the meantime.

5. *Supporting the autonomy to play:* The children can play autonomously with the GNomon-based games, they can select the game menu options by themselves and can decide to play the games outside the therapy hours. Moreover, they can feel free accessing point-and-click mechanics independently of their caregivers.

6. *Supporting the interactive learning of concepts such as colors, numbers and letters:* GNomon supports the creation of many different games, with different goals, mechanics and aesthetics. This gives the caregivers the possibility

of fully customize the games that they use in therapy, with learning or rehabilitative objectives specific to each kid, instead of adapting the children needs to the available options in the market.

Chapter 5

GNomon: Alternative Widgets

The GNomon framework had “inherited” its original and characteristic clock widget from the NOMON interaction modality, on which it is based. The design of the clocks was already adapted from its original version following the accessibility guidelines elicited with the speech therapists that work every day with children with multiple disabilities, as established before. In fact, it is possible to change widgets without changing the normal operation of GNomon.

The motivation behind designing new widgets emerges from the results of the previous studies and involves how the children with cognitive disabilities interact and understand the original NOMON widget (i.e., the clock). In fact, while a person without cognitive disabilities fixes her sight on the fixed handle and clicks whenever handles overlap, the children involved in the previous studies tend to follow the moving handle, continuously, according to the involved psychologists and the speech therapists. This causes an augmented cognitive effort and a consequent fatigue in using such an interaction modality. Thus, new widgets needed to be designed to overcome this problem. The new widgets were created in a participatory design session with a group of speech therapists for two reasons, mainly: a) they follow the development process of these children from years, with weekly meetings; and b) they are responsible of performing the cognitive evaluation of such children and monitoring their progress in the Local Health Agency where they work, in collaboration with a wider team of psychologists and physiotherapists. According to the Griffiths Mental Development Scales [49], the concepts of big/small and full/empty require fewer cognitive efforts to be understood. Consequently, the widgets were designed around these two concepts.

In order to do so, it is enough to design an object (the selector) capable of changing in form, position, scale, rotation or color, and to provide the user with an indication of the optimal moment to press the switch (the indicator). Likewise, it is important to have a different color version of the widget to highlight the elements that have a high probability to be not yet selected. In the case of the normal clock widget, the selector is a black clock hand that rotates continuously and the indicator is a red clock hand fixed at noon, which flags that the optimal moment for pressing the switch, is when the selector crosses it. The highlight version of the classic clock is the same as the normal version, but with a yellow face.

5.1 The Widgets

For the last part of this research, three widgets were considered: a clock, a bar and a ball. All of them consist of three parts: a selector, an indicator, and a third element to reinforce the optimal moment for pressing the switch (the reinforcement). The colors of the three widgets were chosen to provide maximum contrast in their normal and highlighted versions, in order to help children with vision difficulties. The chosen color palette is the following: White, Black, Red (#DC1E3E), Dark Blue (#201D5A) and Light Blue (#3EA2DA).

5.1.1 The Clock

This widget is a slightly different version of the classic GNomon clock widget. The differences are minimal and related to the colors, only: the normal clock widget did not take into account any consideration about providing the maximum contrast possible. In particular, the selector is now dark blue and turns into light blue while is crossing the indicator, as reinforcement; the highlighted version of the clock is no longer yellow, but red with a white indicator. The clock widget is illustrated in Figure 5.1.

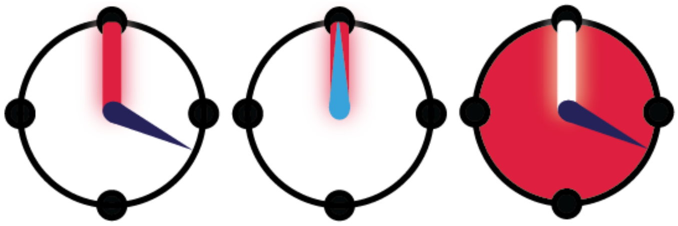

Figure 5.1. From left to right: normal clock widget, normal clock widget with reinforcement and highlighted clock widget.

5.1.2 The Bar

This widget was designed in collaboration with the group of speech therapists in order to replace the concept of rotation that is used in the clock widget, with the concepts of "full and empty", which should be cognitively easier to grasp by the target children, according to the speech therapists. The selector is a triangular bar that fills (from left to right) and empties (from right to left) a triangular frame. The indicator is a thick black line at the right end of the triangular frame, which flags that the optimal moment for pressing the switch is when the selector is filling completely the frame. As in the clock widget, the reinforcement is the color change of the selector from dark to light blue when it reaches the indicator and the highlighted version of the widget has a red selector. Figure 5.2 presents the bar widget.

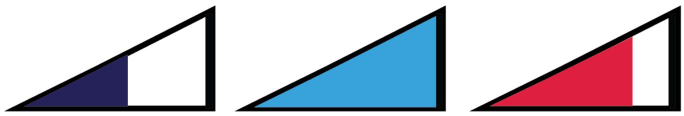

Figure 5.2. From left to right: normal bar widget, normal bar widget with reinforcement and highlighted bar widget.

5.1.3 The Ball

This widget tries to improve the usability of the interface by using the concept of "big and small", which should be cognitively easy to understand for the target children, according to the speech therapists. It uses a ball selector that expands and decreases in all directions. The indicator is a circular frame: it suggests that the optimal moment for pressing the switch is when the ball expands until it touches the frame indicator. The reinforcement is the color change from dark to light blue when the ball is at its maximum size and the highlighted version of the widget uses a red ball as the selector. The ball widget is presented in Figure 5.3.

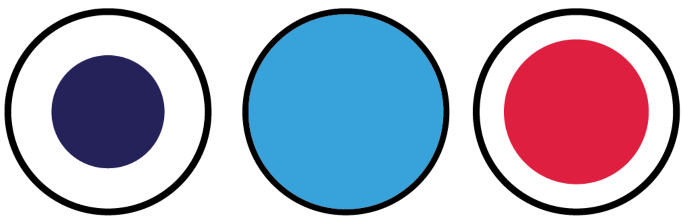

Figure 5.3. From left to right: normal ball widget, normal ball widget with reinforcement and highlighted ball widget.

5.2 Evaluation

The three widgets were evaluated through a one-session test with six children with motor and cognitive disabilities, in collaboration with one of the Local Health Agencies in Turin, Italy. The evaluation aimed at assessing the errors, the efficiency, and the satisfaction associated with each widget.

5.2.1 Participants

The participants of the study were six male children between 4 and 8 years old diagnosed with Cerebral Palsy (CP), which rely on the use of single switch interfaces to access electronic devices. Six months earlier, four of the participants took part in the playability evaluation of the first two GNomon games presented in [5], obtaining the four lowest performances. The Local Health Agency experts were in charge of recruiting the children and fixing the evaluation dates.

5.2.2 Materials and Methods

The tests were conducted in Italian at the Local Health Agency, to avoid making some children anxious about being in an unfamiliar place. A speech therapist (acting as the tester) held the sessions and kept the participants motivated along the evaluation, while two observers (one HCI researcher and a speech therapist) carefully took notes. All the tests were video recorded with the children faces hidden, with the exception of the test of P3 which was not recorded, since her parents did not give the authorization. The tests lasted between 10 and 20 minutes, depending on the speed of each child to complete the tasks. The evaluation consisted in selecting ten times the only open chest (the one with coins) from a set of four chests, during three trials, one trial for each widget (i.e., clocks, bars, and balls). Figure 5.4 shows the general interface used during the tests. The widgets under evaluation were placed in the middle of the chests to allow their selection. When the correct chest was selected, a sound indicates success and a new game round started with a new open chest. The children could take as much time as they needed to complete the task with each widget. The tester could end the test early if she noticed that they were not trying to complete the task or if they were inactive for more than 5 minutes. Between each trial with a different widget, the children could take a break to rest, if desired. The children tried the widgets in counterbalanced order, to reduce biases. For each widget, data was collected regarding the moment of selection of the chest, the number of clicks before the selection (hits and misses), and the total percentage of error. Finally, the children were asked for the easiest and the most difficult widgets.

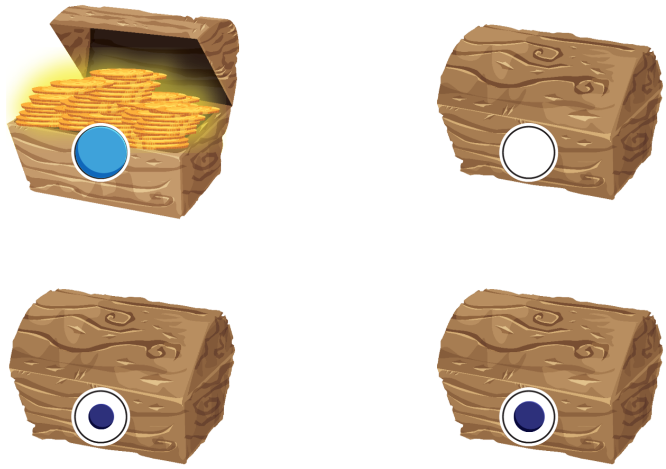

Figure 5.4. General interface of the tests.

5.3 Results and Discussion

The observer notes were used to elaborate the discussion of the obtained results and the most relevant information collected during the evaluation is summarized in Table 5.1.

All but one participant were able to complete the evaluation. The tester had to stop and invalidate the evaluation of one participant because he did not want to continue while he was doing the second widget evaluation. For this reason, we do not include her results. Participants P4 and P5, which had already participated in the playability study of three GNomon-based video games with low performances (see participants P4 and P7, respectively, in the study presented in [5]), were able to perform successfully the selection tasks with all the widgets. After six months without using any GNomon-based interface, they did not remember how to operate the clock widget. Participant P1 did not answer which was the easiest and which was the most difficult widget, but the ball widget had a "rare" effect on him, according to the observer notes taken by the speech therapist: "the balls concentrated his attention for more than 3 consecutive minutes... is the first time I see P1 that concentrated!"

The error ratios were calculated as the percentage corresponding to the ratio of misses and hits, for each widget. A miss occurs when a participant presses the switch without successfully selecting the chest with the coins or without highlighting it. On the contrary, a hit occurs when the participant presses the switch selecting or highlighting the chest with the coins. It is important to point out that consecutive events registered within less than one second are discarded. The reason is that the latent periods (i.e., the time elapsed between the movement command and the muscle movement) of these children is always, at least, a couple of seconds. The “task duration” reported in Table 1 does not include the break time between trial of different widgets. The error ratio calculated from the obtained data does not allow quantitative and final consideration about the best widget. No widget, in fact, has a significantly lower error ratio. It may be noted, however, that in most cases (3 out of 5) the ball widget has a slightly lower error ratio. Consistently, the ball widget has a lower task in 4 out of 5 cases. Data suggests that all the three widgets are almost equally efficient, being the ball widget slightly higher.

The most interesting result between qualitative data was that all the children named the ball widget as the easiest to use. They preferred the ball widget even when it did not account for the lowest error rate (as in the case of P4), or even if it was used with fatigue at the end of the test (as in the case of P3).

Participant	Age	Order	ErrorRatio (Ck—Br—Bll)	Duration (Ck—Br—Bll)	Easy—Difficult
P1	4	Ck, Br, Bll	60%—**58%**—60%	3—**3**— 4.5	-
P2	5	Br, Bll, Ck	63%—70%—**61%**	4—4—**3**	Bll—Br
P3	5	Ck, Br, Bll	59%—66%—**52%**	7—7—**5**	Bll—Ck
P4	6	Ck, Bll, Br	**30%**—38%—60%	**4.5**—6.5—4.5	Bll—Br
P5	8	Br, Ck, Bll	66%—70%—**45%**	5—6.5—**4.5**	Bll—Br

Table 5.1. Participant age, widget order during the test, error ratio, test duration (in minutes) , and easiest and most difficult widgets as emerged from the test. Best values are highlighted. The widgets are abbreviated as Ck (Clock), Br (Bar) and Bll (Ball).

Chapter 6

Conclusions and Future Directions

This chapter presents the results of a comprehensive research conducted in close collaboration with a team of speech therapists, physiotherapists, and psychologists from one of the Local Health Agencies in Turin, Italy. Two studies were carried out, aiming at demonstrating two hypotheses: that it is possible to develop dynamic one-switch video games playable by children with severe motor disabilities, and that such games are valuable as educational and rehabilitation instruments.

For tackling this complex challenge GNomon was developed, a software framework to enable the creation of dynamic one-switch video games. Then the playability of these games was evaluated by testing three GNomon-based games with a group of 8 children with severe motor disabilities. At the end of the playability evaluation a focus group was conducted with the experts of the Local Health Agency to assess the educational and rehabilitative value of the dynamic one-switch video games based on GNomon. Moreover, based on the obtained results, a third study was carried out in order to explore alternative widgets for the GNomon interface, to better support children with cognitive impairments and to be easier to understand and operate.

The results of this research are encouraging and demonstrate that, in fact, it is possible to develop dynamic one-switch games playable by children with severe motor disabilities. From a group of 8 participants, 7 of them expressed that they had fun playing the GNomon-based mini games, and all of them were able to play One Switch Demo and One Switch Ladybugs autonomously, after two sessions. Three of the participants played also One Switch Invaders and expressed that it was the game they liked the most. Moreover, two of them wanted to continue playing it after the test. Likewise, the potential of GNomon for making rehabilitative games emerges from a focus group carried out during one of the studies. All the experts agreed on the novelty of the interaction but also recognize useful principles that can be exploited to train aspects such as eye-hand coordination, the maintenance of selective attention over time and the support the autonomy to play.

Finally, one of the alternative GNomon widgets (i.e., the ball) was preferred by all the participants during the widget study, even if it was not always associated with the lowest error ratio.

How Can Others Make Use of this Work

This section presents a fascinating work in the field of accessible human computer interaction that stemmed from the research presented in the first part of this document. The goal of this section is to inspire other researchers interested in exploring the world of accessible video games for children with motor disabilities, by presenting new possible lines of work in such a fascinating field.

In fact, the various studies conducted on the topic of accessible one-switch video games, which led to the creation of the GNomon framework, constitute a valuable resource for other researchers interested in developing entertainment, educational or rehabilitative tools for children with severe disabilities. Moreover, the possibility of creating new and custom one-switch video games is within reach of any enthusiast with some programming experience in Unity, since the framework and the GNomon-games described through this thesis are publicly available at the website of the e-lite research [1].

In particular, one of the main future directions of this line of work will be the investigation of accessible *multiplayer* games based on GNomon. The objective is to foster the social inclusion of children with disabilities by allowing them to play and have fun with their normally developing peers, at the same time, with the same game. In other words, future developments of accessible games should be structured to be simultaneously *playable* by players with different levels of ability (i.e., ranging from those who can use just a single switch, to normally developing children, which are capable of using proficiently the modern gamepads). Moreover, new game mechanics have to be designed and tested, in which children differently abled can compete or collaborate with other players regardless of their input modality.

Accordingly, in the masters' thesis "Videogiochi single-switch educativi e inclusivi" [56] Mandrile presents a study that makes use of the GNomon framework, as well as the findings of this research, for designing, developing and evaluating two single switch games, playable by children with motor disabilities and their normally developing peers. The two games are "Il labirinto dei mostri" and "Palloncini" and aim at the following goals:

- The games must be playable by children with severe motor disabilities through a single switch.
- The games have to facilitate the inclusion and socialization of the disabled children with their normally developing peers.

- The games should serve as educational tools, useful to the families, educators and therapists that work with the children with disabilities.

Il Laberinto dei Mostri This multiplayer game allows two children with different levels of ability to play together collaboratively. One of the players uses a GNomon-based interface, while the other uses a regular keyboard or a gamepad. The objective of the game is to guide a pair of monsters that are trapped in a maze to the exit. For doing this, each player controls one of the monsters and takes turns to move it through the screen to its corresponding "exit" location, though the monsters cannot move freely and sometimes need to lean on each other to perform certain moves. In addition, the game requires that both monsters arrive to their exit locations for winning the level. Figure 6.1 shows a screen capture of one of the levels of the game, in which the purple monster in the bottom left corner is controlled through a GNomon-based interface while the green monster is moved by the use of the keyboard.

The mechanics of the game encourage the players to collaborate with each other to come up with a strategy that allow them to perform a sequence of moves that takes them both to their exit locations. This idea is also useful to avoid challenge and competition between the players, as the player with disabilities may be in disadvantage.

Furthermore, this game was designed in collaboration with a team of expert psychologists from the Università degli Studi di Torino to integrate educational features that develop skills such as the cognitive flexibility, the working memory, the strategic thinking, the ability to manage several information simultaneously, planning. For more detailed information refer to [56].

Palloncini Although this is a single player game, it is structured to be played equally by children with or without disabilities, using the GNomon-based one-switch interface. In this game there are several balloons on the screen, each one with an associated GNomon selection widget next to it. The objective of the game is to select the balloons following a certain sequence, which depend on the game mode that is being played. Some of the available game modes are:

- Colors: In this game mode the balloons have different colors and in the center top of the screen a color is indicated. The player has to select only the balloons of such a color.

- Numbers: The balloons in this game mode display a number inside them. The player has to select them in numeric order.

- Words: In this game mode the balloons display a letter inside them and in

Figure 6.1. The figure shows the level 56 of the game "Il laberinto dei mostri" in which the player with disabilities controls the purple monster through a GNomon-based interface (in the bottom left corner), while her normally developing playmate controls the other monster using a regular keyboard. Image adapted from [56].

the center top of the screen an image is shown. The player has to select the balloons in order to form the word of the shown image.

- Sizes: In this game mode the balloons have different sizes and the player has to select them from the smallest to the biggest (or viceversa).

Figure 6.2 illustrates the game mode *Colors* of the Palloncini game.

This educational game is suitable for children with or without disabilities and allows to set different learning goals according to the game mode selected. Therefore, the families, educators or therapists who want to use this game for specific learning goals can adapt it and personalize it according to every player. This game was also designed in collaboration with a team of expert psychologists from the Università degli Studi di Torino, and will be evaluated shortly. For more detailed information refer to [56].

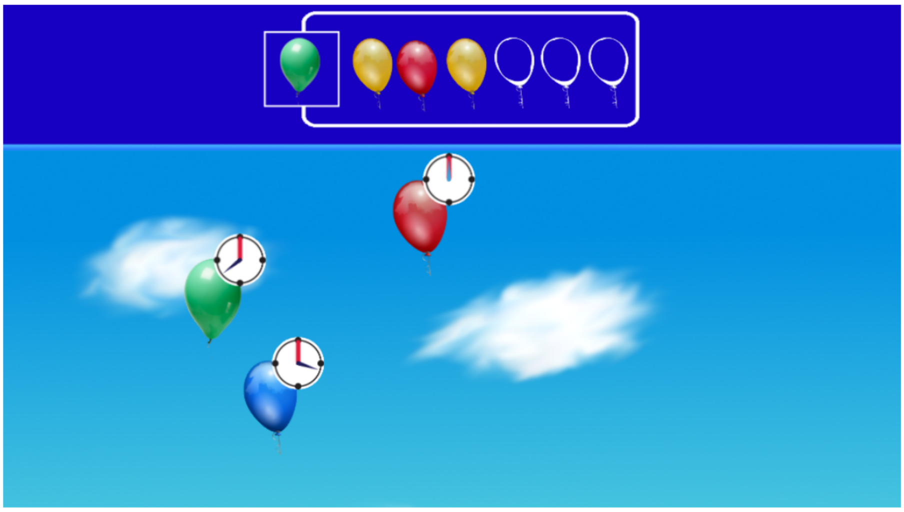

Figure 6.2. The figure shows the game mode *Colors* of the Palloncini game. The next selection of the player should be a green balloon, as indicated at the center top of the screen. Image adapted from [56].

Part II

Assisted Living for Persons with Disabilities

Chapter 7

Motivation and Background

One of the challenges that the healthcare sector has been facing in the last decade is how to ensure full coverage of professional care for those who require special attention (e.g., the elderly, people with disabilities or patients with chronic conditions), while the associated costs continue to increase. According to the recent Action Plan for the EU Health Workforce, by 2020 around 14% of these care needs will be unmet[1].

To address this challenge, ambient assisted living (AAL) systems have been researched extensively. These systems exploit intelligent environments, ubiquitous computing and mobile/wearable technologies to reduce the expenditure on healthcare by enabling people to be monitored in their own homes, rather than in hospitals, for a fraction of the cost (see the survey by Acampora et al. [7] for further details). The combination of such technologies has also proven to be suitable for creating applications that support medical staff in performing the typical tasks of highly structured environments, such as hospitals, more efficiently (as in [10] or [59]).

Research in the field has thus focused on two main objectives: how to improve the quality of life of *patients in their own houses*, and how to support *doctors and nurses within hospitals* in the specific tasks their jobs entail.

However, less research has been done about systems to support caregivers which assist persons with disabilities[2]. In 2004, persons with disabilities corresponded to about 5% of the total population of Italy (of which the major part were still living with their families rather than in ALFs), according to the 2004 ISTAT report *"Disability in Italy"* available at [46] within *assisted living facilities*[3] (ALFs) and on how

[1] The Action Plan for the EU Health Workforce is publicly available at [28]

[2] The persons with disabilities to which the authors refer to are adults between 18 and 64 years old with physical or mental (cognitive) disabilities

[3] An assisted living facility (ALF) is a housing facility for persons with disabilities. ALFs ensure health, safety, and well-being conditions for people with mental or physical disabilities by monitoring and assisting them with the activities of daily living. In these facilities, unlike in hospitals or nursing homes, there are no full-time nurses nor physicians providing medical

to design them to be effective. Although there are some studies that provide design principles for similar systems, these principles are focused on optimising assistance to the elderly, either directly (refer to design directions proposed by Morris et al. in [54]), or by supporting their caregivers (as in [20]).

The motivation for this research derives from the need of design guidelines for healthcare support systems in ALFs. In particular, the interest of this research is to address the specific requirements that caregivers within ALFs for persons with disabilities actually have, such as keeping their hands free most of the time or being alerted in case of inhabitants' necessity.

Assisted Living for People with Disabilities

Most of the healthcare support systems found in literature focuses mainly on Ambient Assisted Living (AAL), Emergency Detection, or Continuous Monitoring (according to the survey by Acampora et al. [7]). Such systems aim at enabling people with special needs, e.g., the elderly, to stay at home and to be monitored remotely by medical staff, rather than being hospitalized with the costs this entails (see the AMON [14] and the CARMA [48] systems as examples).

Therefore, many design recommendations have been elicited for systems able to address different needs of elderly living in home environments (according to Zulas et al. in [72] three main needs emerge: the support for the activities of daily living (ADL), the safety of the elderly and the delivery of data to nursing staff). Numerous of these systems have been implemented by exploiting intelligent environments (e.g., [29]) and mobile technologies (e.g., [48]). Furthermore, the combination of such technologies has already proven to be suitable for building applications in structured environments such as hospitals (as reported in [10] or in [59]) to support medical staff. Wearable technologies have also been researched as possible enabling technologies, from their first apparitions in systems such as WearNET [50] and AMON [14], to more recent tools which combine wearable and environmental sensing for long-term sleep studies, as in the work presented by Borazio et al. [22].

However, systems designed to support users different than doctors and elderly have been little researched. In particular, few systems addressing the requirements and necessities of caregivers in assisted living facilities (ALFs) have been proposed; consequently, design recommendations for these systems are very limited. This research discusses a particular type of assisted living facility (ALF) for people with disabilities, known as RAF[4] (*Residenza Assistenziale Flessibile*). RAFs are Italian health and social care facilities with the aim of providing hospitality, welfare benefits

treatments.

[4]As the RAF is a special type of ALF, both terms are used as interchangeable along this document.

and recovery to people in mental or physical conditions of dependency. They ensure adequate living conditions for the inhabitants, appropriate for their dignity, by promoting the maintenance or recovery of their residual capacities and the satisfaction of their relational and social needs.

Moreover, the few recommendations available in literature only identify the needs of persons with disabilities, not the needs of their caregivers; even if it has been shown that the quality of assistance in ALFs (and therefore the inhabitants' quality of life) is highly related to caregivers' attitudes and to their perception of their working environment (see the study of Beeber et al. in [16]). The summary of recommendations reported in [55], for instance, enumerates some practical changes in primary care practices that can enhance disability care, such as promoting positive images of disability (e.g. by hiring staff members with disabilities) and easier ways to contact the staff.

Relevant studies that have been carried out on designing systems to support the elderly or their caregivers in nursing homes[5] are reported, since the guidelines with which these systems have been designed are the most similar to those that should be used for systems in ALFs. This is the case of the design directions derived by Morris et al. in [54], from the ethnographic study of elders with cognitive decline, which include recommendations such as *to provide adaptive functionalities for offering the optimal level of assistance* and *to provide mechanisms for catalysing social relations*. Other researchers have also focused on user needs and acceptance of such systems for eliciting design recommendations: Mayora et al. [52] list the anecdotes, challenges and lessons learnt from a project involving people suffering from bipolar disorder; Altakouri et al. [12] show the results of their Wizard-of-Oz study for supporting nursing documentation, Bhadoria and Gupta [20] present a tracking and emergency alert system for the elderly, and Zulas et al. [72] assess caregivers' needs within assistive smart homes for the elderly.

[5]Nursing homes are residences for people who require continual medical care and assistance in their daily activities, usually elderly.

Chapter 8

The User Study

The goal of the research presented in this chapter was to understand the needs and concerns that caregivers of assisted living facilities have, how do they currently tackle problems and difficulties, and how technology can help or support them in their daily work. Particularly, the authors were interested in caregivers that work at RAFs, i.e., assisted living facilities for people with disabilities who cannot live alone or that require special attention.

The research questions addressed are the following:

1. How can the introduction of a healthcare support system, that might involve mobile/wearable technology, in assisted living facilities support caregivers in their daily activities?
2. What are the current needs, concerns and desires that caregivers of assisted living facilities for people with disabilities have?
3. What particular needs or issues can prevent (or foster) the adoption of any mobile/wearable device to support the caregivers through their daily activities?

To achieve this goal, three group interviews were conducted with a total of 30 participants, in the form of focus groups. Focus groups are distinguished from other techniques based on group interviews by the explicit use of group interaction as research data [47]. This technique was utilized because it draws upon participants' attitudes, feelings, beliefs, experiences and reactions to gain large amounts of information in a way in which would not be feasible using other methods such as observation or one-to-one interviewing, according to [35].

8.1 Method

Three focus groups were carried out in three assisted living facilities, managed by the Cooperativa Sociale P.G. Frassati[1] near Turin, in Italy, that have identical operative rules and procedures. In this phase, it was decided not to investigate about any technology-related issue to let the participants concentrate on the needs and concerns they have as caregivers, without worrying about the practical feasibility (or cost-related issues) of their ideas.

A single 90-minute session was conducted with each group, with an average of 10 people per group, in the same assisted living facility they work in, in order to get better understanding of the context, needs, problems, and possible tools already used. All focus groups were held in Italian and took place after lunch while the inhabitants of the RAF take their nap, since this was the only time during the day in which caregivers were able to have free time to meet visitors. The sessions were carried out in a relaxed and comfortable atmosphere, around a table with some coffee. Each session began with one of the members of the research team explaining the aim of the focus group and encouraging the participants to talk to each other, rather than to simply respond to the researcher questions.

Two researchers were present at each session: one of the researchers (moderator) conducted the interview, carefully avoiding to give personal opinions to not influence participants towards any particular position, while the second researcher constantly collected notes of the group dynamics and dialogues. In addition, all the focus groups were fully audio recorded and later entirely transcribed, and photos of particular areas of the visited assisted living facilities were taken (when allowed).

8.1.1 Procedures

Each focus group was conducted in a different assisted living facility with the participation of all the healthcare personnel of the facility. It was decided to keep the three groups separated instead of merging them into one big cluster to preserve the "naturally occurring" groups, i.e., people who already know each other through working together. The motivation behind it was that exploiting pre-existing groups allows the observation of fragments of interactions that approximate naturally occurring data, according to Kitzinger [47].

The recruitment of the participants was straightforward since the study was conducted with the cooperation of the management at Cooperativa Sociale P.G. Frassati, that helped to gather the groups and to fix the appointments for the interviews.

[1] http://www.coopfrassati.com (last visited on April 8th 2016)

The sessions lasted for 90 minutes and followed this structure: first, the researchers and the participants introduced themselves, and the researcher in the moderator role explained the dynamics of the focus group and the goal of the study. Then, an individual questionnaire was distributed among the participants to collect both general demographic data and information about their experience as healthcare assistants in assisted living facilities. Finally, a set of open questions focusing on caregivers' daily activities, related problems and desires, were posed (one by one, in Italian) to guide the session by keeping the conversation moving forward, and also to facilitate the interaction between the group members.

Finally, the list of the questions with which the researchers guided the interviews are presented below. The order of such questions was not always the same, and not all of them were posed to the three groups. Furthermore, since the moderator of the focus groups interacted as well with the participants, additional questions that rose naturally during the conversation were asked:

- Could you tell us how is your "typical day" structured?
- In your daily activities, have you developed or implemented some "workarounds" to facilitate or speed your work?
- Are there activities that risk to be forgotten? Which ones?
- What would you like to know about the RAF inhabitants when you are not with them (overnight, for example)?
- What technological tools (tablets, smartphones, etc.) have you already proposed to the RAF inhabitants or have tried yourselves? How did it go?
- For what activities would you like some kind of reminder?
- In general, do you have special requirements? for example about the tools you use? What would they be?
- May the guests request your assistance or presence? How?
- When inhabitants request assistance, what is a reasonable time to reach them?

8.1.2 Participants

From the total of 30 participants, 22 were female and 8 were male, with different years of expertise as professional caregivers in RAFs (as summarized in Table 8.1 and in Table 8.2). Regarding the technology experience, all the caregivers that participated in the study use the computer daily and own a smartphone, except for the two participants over 56 years old which use an old-fashion cellphone.

Table 8.1. Participants by age.

Age	Count (by sex)
26-35	3M, 7F
36-45	4M, 13F
46-55	1F
56+	1M, 1F

Table 8.2. Participants' expertise.

Years of Expertise	Count (by sex)
less than 1	3M, 1F
1-5	1M, 8F
6-10	5F
11-15	2M, 6F
16+	2M, 2F

All participants were healthcare assistants, working in one of three RAFs managed by Cooperativa Frassati in the area near Turin, in Italy. As reported in Table 8.3, two of the assisted living facilities (RAF1 and RAF3) accommodate people with various degrees of mental disorders, while the third one (RAF2) houses people with motor impairments. Each RAF hosts around 10 people and assistance is guaranteed 24/7: during the day, two caregivers are present within the RAF, and another one is present overnight.

Table 8.3. Details about the visited facilities.

	Caregivers	**Type of disability**	**People housed**
RAF1	7 (1M, 6F)	Cognitive	10
RAF2	10 (3M, 7F)	Physical	10
RAF3	13 (4M, 9F)	Cognitive (severe)	12

Although RAFs differ between them in various aspects such as the facility size, the spaces accessibility and their distribution, all of them generally share some characteristics such as the presence of a backyard, a fully equipped kitchen, a living room, and single or shared bedrooms for the inhabitants. In particular, RAF1 and RAF2 have backyards accessible to the inhabitants; RAF3 and RAF2 have two floors, one for the common areas such as TV/hobby room and another with the inhabitants bedrooms. All the visited RAFs have bedrooms hosting one, two or three people, a roomy kitchen, a laundry, an infirmary in which medicines are stored, a space used as office by caregivers, and spacious shared bathrooms.

In addition, the RAFs visited have several areas from which it is difficult to hear what happens in the inhabitants' bedrooms, e.g., the backyard in the case of RAF1 or, in the case of RAF2 and RAF3 (which have two floors), the rehabilitation room and the laundry, respectively. Moreover, within the three RAFs, no place allows caregivers to simultaneously see all the inhabitants bedrooms.

8.2 Observations

Some general observations made throughout the study are presented here, before discussing the data obtained from the focus groups and the elicitation of the design guidelines derived from them. In this way, some contextual information useful to understand the following sections of the paper is provided.

Common needs emerged from the caregivers across the three groups, with some minor differences due to the diverse type of disabilities present in the RAFs where the participants work in. In fact, people with motor disabilities are less autonomous and independent than people with mental disabilities who, in most cases, can leave the house and walk around the town without any assistance. Moreover, the former perform most of their activities inside the RAF, while the activities carried out by the latter often occur outside the structure. In general, although the inhabitants of RAF1 and RAF3 have to be closely monitored given that they may suffer epileptic seizures, for example, or that a few of them may try to break or escape the RAF (as some of RAF3 inhabitants have already attempted), the inhabitants of RAF2 require more assistance from their caregivers in order to perform daily activities, that they would not be able to carry out otherwise, due to the motor impairments.

During the day, two healthcare assistants are always present in the RAFs, performing various activities, from personal assistance (e.g., helping the inhabitants to brush their teeth), to drug administration, or help in housework (e.g., cooking or doing laundry). A nurse is present one hour per day, every day, while a doctor is available on request, only. During the night, one caregiver is present in the facility, performing some houseworks and running ward rounds.

Each healthcare worker brings in her pockets a cordless phone, multiple keys and, in some cases, her personal mobile phone. Caregivers express the desire to bring with them less "objects" as possible because "*it is not easy to walk around with the pockets full of stuff, and if the phone rings you have to take out many things to finally answer it!*", as said by one of the caregivers of RAF1.

Caregivers, at the end of their shift, must compile a paper form reporting relevant issues and the activities they performed. However, by the time they fill the form, they are prone to forget some events and issues to report. In some cases, they leave a post-it note to their colleagues to highlight some news (e.g., an inhabitant has the flu) and changes in some of the planned activities (e.g., the swimming pool was unexpectedly closed).

RAF inhabitants can require the assistance of a caregiver by calling them by voice or using a buzzer, inside the house. It was noticed that one buzzer is present inside each bedroom (near the bed, typically) and another is located in each bathroom, as required by the Italian law[2].

In RAF1 and RAF3, inhabitants do not own any technological tool, such as smartphones, tablets, or computers. Healthcare assistants and inhabitants' families promote this "policy", because of the possibility that such objects may be stolen, broken or traded. In fact, since some inhabitants can freely move alone around the town, they may meet ill-intentioned people or sell these objects to obtain stuff like junk food. In the past, caregivers tried to give them such tools and obtained negative results. On the other hand, inhabitants of RAF2 spend almost all of their time inside the house and they actively use smartphones and computers to communicate, play,

[2]The Italian law, with the Ministerial Decree *dei Lavori Pubblici n. 236 del 14/06/89* requires buzzers, at least in the bathroom and in the bedroom of people with disabilities.

or search the Web.

Chapter 9

Results and Guidelines

This chapter presents the most relevant information collected during the focus groups regarding caregivers' unmet needs, problems and desires, along with their qualitative analysis: the research findings and the implications derived are listed in the following. Finally, stemming from these research findings, a set of design guidelines is proposed to address the research questions stated in the user study, from a system point of view. These guidelines, numbered from DG1 to DG10, are reported in Table 9.1 and summarize the most important aspects that should be taken into account to effectively design support systems for helping caregivers in their daily activities within ALFs.

The reported guidelines do not explicitly account for privacy issues. Privacy is a very important topic to address in any healthcare support system and it is given as a pre-requisite, rather than a recommendation, for building a successful and useful system. In the case reported in this paper, privacy-related issues are strongly regulated by the rules of the ALFs, realized in agreement between ALF managers, inhabitants families and by following the Italian Privacy Law (196/2003). Moreover, all the changes that concern people in the structures (i.e., inhabitants, guests and caregivers) must be approved in advance by the ALF managers, the inhabitants and their families.

9.1 Enabling hands free operations for caregivers

9.1.1 Research Finding

One of the most common requirements across all three focus groups, constantly mentioned and discussed, was the caregivers' need of having the hands empty or free from any objects. Caregivers must have their hands empty while they are working because they should be always ready to attend any situation in which an inhabitant is involved, as fast as they can. In particular, one participant of the RAF1 group, when asked if caregivers had special requirements (like having their hands free), answered as follows:

> "*It depends on the people* (i.e., the RAF inhabitants) *you work with... but, I would say that we* (i.e., the caregivers) *need our hands empty the most of the time, because some guys could fall or suffer a seizure, and we must be ready to intervene.*"

Two other participants, one from RAF3 and another from RAF1, confirmed and explained that everything they carry around (e.g., cordless, mobile phone, etc.) has to be inside the pockets in order to avoid distracting them during their daily work. In addition, all the objects and tools used by the caregivers should be resistant to water and shocks given the fact that their attention has to be directed to the RAF inhabitants and not to devices integrity.

9.1.2 Implications

Since caregivers in assisted living facilities for people with mental disabilities, such as RAF1 and RAF3, need their hands empty for most of the time, they should not use or carry around objects such as smartphones or tablets, and definitely, they cannot operate them for long periods of time engaging their full attention to their operation. Caregivers do need devices that support them in their daily tasks, and it is very important to them that such devices can be easily and quickly operable, that can be resistant and sturdy enough, and that can be used everywhere inside the RAF, immediately. These implications are taken into account by the design guidelines DG1, DG2 and DG3 as presented in Table 9.1. Wearable devices might address these requirements while allowing the users to keep their hands free; this is in good agreement with the increasing number of studies in which wearable technology is being proposed as part of support systems in the healthcare domain such as [50], [14], and more recently [22].

9.2 Helping caregivers to remember non-routine tasks more easily

9.2.1 Research Finding

Daily activities in assisted living facilities follow a pretty fixed schedule to help caregivers remember more easily the routines of each inhabitant and all the tasks that need to be carried out to have the RAF functioning properly. Details that otherwise could be forgotten, such as wake up times, bathroom turns, medication and diets, among many others, are well structured in a "collective" routine that indicates the caregivers what to do, with which inhabitant and at what time. As expected, for RAF1 and RAF3 the routines are very similar due to the fact that they host people with mental disabilities with common needs. RAF2 also has a collective routine in which the order in which the inhabitants are woken up and transferred to their wheelchairs is specified.

Schedules are very useful to organize and simplify daily activities, however caregivers encounter difficulties with some tasks that are out of the routine, such as extemporaneous appointments or temporary drug administration. Three caregivers (C1, C2 and C3) from RAF1 discussed about this difficulty when the conversation was about the "typical" day and the moderator (M) asked about activities that can be forgotten:

> M: "*From these activities* (activities from the typical day), *which one worries you that could be forgotten? If there are some...*"
>
> C1: "*Those in the infirmary! Because it is very sensitive if something there is forgotten.*"
>
> M: "*Which is the risk of something going wrong?*"
>
> C1: "*If there are different schedules or if something goes out of the routine... if someone has to receive some temporary therapy, for example.*"
>
> C2: "*Right! Especially with the temporary medication... fever, the flu. Normally the activities and therapies are verified and contrasted with the inhabitants records and routines, but that is for routine activities or long-term treatments. You have to remember the other activities.*"
>
> C1: "*For example, sometimes it has happened to me with one of the inhabitants, Maria* [1] *, who sometimes forgets some things, that she takes a pill, then comes back and asks for it again... if the caregiver is the same, usually there is no problem because it is easy to remember you already gave her the medicine; but if the caregiver is not the same, the doubt could arise and there is the risk to err.*"
>
> C3: "*But it is difficult to make mistakes because they have to sign when they take their medicines!*"
>
> C1: "*Yes! They have to sign! But with medicines for short-term treatments that maybe are not taken after meals, it can happen...*"

Currently, caregivers have addressed the problem of forgetting things that are out of the routine by writing post-it notes and sticking them on a board within the room that they use as office. Figure 9.1 shows the main board of RAF1. However, caregivers expressed that they are not completely satisfied with such a solution

[1] The inhabitants real names have been changed for privacy reasons.

because they need to be in the office to read the notes and they have to remember to check the board to see if there are new reminders.

Figure 9.1. Main board in the caregivers' office in RAF1.

Implications

A properly designed system for supporting caregivers in ALFs should address the problem of reminding the caregivers about tasks or events out of routine, especially if there are many inhabitants housed in the assisted living facility and keeping many things in mind becomes difficult. The design guideline DG9 presented in Table 9.1 covers this particular implication. The solution should allow to create and check reminders ubiquitously, in other words caregivers should be able to create new reminders (for themselves and their colleagues) *in situ*, and check the list of reminders while are around the facility without having to be at any specific spot. These implications could be addressed by design guidelines DG2 and DG9 (see Table 9.1).

9.3 Alerting caregivers in case of necessity to offer the optimal level of assistance

9.3.1 Research Finding

The inhabitants of a RAF need the caregivers attention countless times a day: for asking them for help in simple tasks such as opening and closing doors or reaching objects (this is the case of people living in RAF2 in particular) or for more sensitive matters such as being assisted on time in case of epileptic seizures (this is the case of some people with mental disabilities, such as RAF1 or RAF3 inhabitants).

People living in assisted living facilities, currently, can call the caregivers attention by voice or by using a buzzer located in some fixed locations inside the RAF (bedrooms and bathrooms, in this case). Figures 9.3.1 and 9.3.1 show the string operated buzzer of a bathroom in RAF2 and the panel in the caregivers office that illuminates the number of the room from which assistance is requested, respectively.

Figure 9.2. Example of assistance request mechanism within a RAF2 bathroom. Here the buzzer is operated by pulling a string.

However, there are situations in which caregivers cannot hear the inhabitants, or where the buzzer is not reachable. In fact, inhabitants may be outside the house, away from caregivers (e.g., in the backyard), or may have fallen out from the wheelchair and be unable to use the buzzer, as the following conversation between the moderator (M) and a caregiver (C1) from RAF2 illustrates:

> C1: "*The problem with the buzzer is that it is fixed in a room or within the wheelchair as a horn... it has happened that someone has fallen out from the wheelchair in the backyard in such a way that is unable to operate any buzzer, not even the horn embedded in the wheelchair.*"
> M: "*What do you do in such a situation?*"

Figure 9.3. Example of assistance request mechanism within a RAF2 bathroom. Here the panel indicates who is requesting assistance.

> C1: "*There is nothing we can do... I mean, if we realize that someone is not in the house and no one has seen him for a while, we search him.*"
>
> M: "*Don't they call for help?*"
>
> C1: "*Yes, but sometimes you don't hear... if you are in the laundry and the TV is on, there is no way of hearing someone even if he is yelling.*"

These missed calls constitute a problem that the caregivers, at the moment, feel is not addressed. Furthermore, in RAF2 the buzzer and its usage are sources of discomfort and disagreements between the caregivers. The main reasons for discord are the loud noise produced by the buzzer to be properly heard, and the way it is turned off, that allows a caregiver to deactivate the buzzer only by reaching it and directly acting on it (i.e., it does not support "remote" control).

In fact, one of the biggest debates across all focus groups took place while talking about the buzzer and the possible alternatives to replace it. The following present part of the argument between four caregivers of RAF2 (C1, C2, C3 and C4) moderated by the researcher (M), that started when the buzzer rang for the first time, in the middle of the interview:

> C1: "*Here! This is the buzzer that we talked about, it sounds all over the house and here in the office the number of the room from which the call was made, illuminates.*"
>
> M: "*It illuminates just here in the office?*"
>
> C1: "*No no, above the door of the room that calls, or above the bathroom door... then we go there and turn it off.*"

M: "*And what if you could turn off the buzzer from another place that wasn't the room form which the call was made?* "

Caregivers: "*Eh! (laughs) That would be nice!*"

M: "*Where would it be?*"

C1: "*From inside the pocket!*"

C2: "*Absolutely no! Absolutely no! No, no...*"

C3: "*Maybe something that indicates the number of the room...*"

C2: "*...No, absolutely no! Because, what do you do? You turn it off, and then, for sure, you forget to go. No, absolutely no, I think no.*"

C3: "*Ah! You do not forget! Maybe you can turn it off while you are going...*"

C2: "*No no no, within the room, within the room.*"

M: "*So, if there was the possibility of turning it off from the pocket, you...*"

C2: "*At least, the light above the room door must remain on. Otherwise, no, no and no. Absolutely no. You have to turn the light off from the room because like this you assist the people effectively.*"

C3: "*So, a solution that leaves the lights on, is OK.*"

C2: "*Mmm but not even like this, because you would have to look up continuously...I think it is not a good idea. And what if the lights turn on, and you don't see them because you are elsewhere? No, I think no.*"

C4: "*It could be something that allows you to turn the buzzer off from the distance, and that shows you in a display the room number*" (from which the call comes).

C2: "*Yes, but after a while, if no one has gone to assist the person that called, it* (the buzzer) *must start playing again, because you have to go to assist the person!*"

C1: "*I agree, you have to go, off course. But there are situations in which it would be very useful to have something to turn the buzzer off from the distance...for example, if you are with Daniele* (a large inhabitant that cannot move his body.) *and the buzzer sounds very hard, and is annoying everyone, you are busy and cannot attend immediately, it is enough that the buzzer makes noise for 1 minute and then goes off!* "

C2: "*Yes, yes. In that case, yes.*"

Although there are many inconveniences produced by the loud noise of the buzzer and the sometimes impractical usage associated with it, caregivers fear that the implementation of new systems that may relieve them from these nuisances, could negatively impact the quality and efficiency of the assistance that they provide to the RAF inhabitants. In particular, as expressed strongly by caregiver C2 in the dialogue reported previously, there is a fear of increasing the number of missed calls by having the possibility of turning the buzzer off remotely because it could lead the caregivers to more easily forget the call requests from the inhabitants.

By contrast, in the case of RAF inhabitants suffering from epilepsy (a condition shared by some people with mental disabilities housed on RAF1 and RAF3), it is not possible to call for assistance in the middle of a seizure. In other words, in such cases the caregivers have to draw their attention to the RAF inhabitants without any explicit request. Therefore, caregivers need to constantly run ward rounds to check the inhabitants, especially overnight when they are out of sight. Nevertheless, it was found that running ward rounds is not enough to ensure an optimal level of assistance during a seizure, because inhabitants could suffer seizures between rounds and in such a case they could not be assisted on time. This finding is consistent with other studies that state that running ward rounds could be greatly improved, e.g., with the adoption of a wearable support system, as the one shown in [25].

Even if this remains an open problem, some workarounds have been adopted by the caregivers of RAF3: a baby monitor can be used to try to look after the inhabitants with higher risk of seizure. If they hear something "suspicious" they go and check. In general, they prefer a false alarm than missing a potentially hazardous situation.

The discussion between four caregivers (C1, C2, C3 and C4) of RAF3 and the researcher (M) about how to draw the caregiver attention without an explicit call, as in the case of an overnight epileptic seizure is described below:

> C1: "*Maybe a night video surveillance system in the people* (the inhabitants of RAF3) *rooms, could be useful!*"
>
> C2, C3: "*No, no. It is not possible... for privacy issues.*"
>
> C1: "*But it is for monitoring the seizures!*"
>
> (General discussion)
>
> C1: "*It is intended just for internal use... because there are some people that can suffer an epileptic seizure and we* (the caregivers) *don't realize it because we are elsewhere... so we need something that supports us!*"
>
> M: "*But you run ward rounds, like in the hospitals, to check them?*"
>
> C2: "*Yes, but we are not always watching, also because there are some of them that close the door.*"
>
> C3: "*Something that indicates us that they* (the inhabitants of the RAF) *are getting off the bed, would be useful. Then you go and check and maybe everything is OK, but at least you have gone and checked.*"
>
> C4: "*But it is not enough... there are some that have had seizures on the bed and not even the baby monitor is good then.*"
>
> C2: "*It is true, sometimes with the baby monitor you hear nothing... if everything is very quiet you also go and check!*"

> C3: "*We need a system that knows when someone is having a seizure and send us an SMS or some kind of signal for us to go and check what is happening.*"
>
> C4: "*Yes, but the seizures are not all the same.*"
>
> C1: "*But it only has to indicate us to go and check, it doesn't have to assess the seizures.*"

It can be argued that caregivers do not mind to respond to false alarms produced by a healthcare support system if such a system supports them in the difficult task of monitoring the RAF inhabitants while they are out of sight. This means that caregivers would prefer to have a system with false positives that points their attention to "suspicious" situations in which something may be happening, rather than having no support at all.

9.3.2 Implications

The implications of the findings reported above are straightforward and are summarized by design guidelines DG4 to DG6 in Table 9.1; nevertheless they are at the same time very significant. First, caregivers do need a healthcare support system that helps them to monitor the RAF inhabitants when they are out of sight. Such a system should be able to recognize when some hazardous situation is taking place and then notify the caregivers. It is important to point out that the accuracy of the system is not crucial and that the caregivers would accept to check on false alarms as they are used to do now with the solutions that have implemented, e.g., the baby monitor. This point also emerged as one of the needs (the need of *Alerts* under the *Delivery of Data* theme) in elder care assistive homes in the study [72] conducted by Zulas et al.

Regarding the RAF2 buzzer and the possible solutions on how to call the caregivers attention effectively, the alternative of having something that allows the inhabitants to call the caregivers personally, i.e., to call them directly without making any noise for other people in the facility, was welcomed by all caregivers. This is in good match with the third recommendation emerging from the focus groups reported in [55], that refers to the development of easy ways to contact the staff for ensuring the quality of care.

However, the way to turn the request off, once it has been received, has to be further explored. For now, it is clear that the turning off mechanism must ensure that the inhabitant that calls, gets attended. This means that a healthcare support system must verify whether caregivers attend the person who is calling after they turn a call off, in such a way the request call persists until proper assistance is provided.

9.4 Relieve caregiver loneliness in hazardous situations

9.4.1 Research Finding

Caregivers work in pairs during the day, but overnight only one caregiver is present in the assisted living facility. The reason for this is that during the day there are more activities to be carried out and the inhabitants require more attention than during the night, while they are asleep.

However, caregivers fear that something bad could happen to them and no one could help them while they are alone (without a colleague nearby). Caregivers worry for themselves but also for the RAF inhabitants, because if a hazardous situation occurs, the inhabitants could suddenly remain without anyone to assist them.

When the caregivers of RAF1 where asked directly (by the moderator M) about what would happen if a caregiver that is alone has some problems, a group of them (C1, C2, C3) answered like this:

> M: "*What happens if a caregiver is alone and suddenly is not OK? What do you do?*"
> C1: "*We must always carry around the cordless phone in the pocket, and if it is the case one of the inhabitants can call for help.* "
> C2: "*It has never happened... but I think I would call a colleague.*"
> C3: "*The problem is if you drop dead in the middle of the night!*"
> C1: "*In any case we have a private security and surveillance company that watches the house, if something happens, the guard will notice it... I hope!* "

In addition to this, another fear arose when caregivers of RAF3 were asked the same question. A caregiver from RAF3 put it like this:

> "*It is not only the fact that the people* (the RAF inhabitants) *remain without anyone to assist them, for our case it is also the fact that they remain with no one to watch them! The problem is that some of them may escape.*"

Caregivers do not like to think or talk about these possible situations, thus the conversation about the topic was quite short. Nevertheless, it was long enough for the researchers to find out that caregivers will feel safer with some kind of support in such situations, that could occur if something goes wrong and an inhabitant calls for help. The implications that follow from these research findings were used to elicit the DG7 presented in Table 9.1.

9.4.2 Implications

In the same way that caregivers expressed their desire to have "something" to allow the inhabitants to call them effectively in case of need, a healthcare support system for assisted living facilities has to provide some mechanisms to support caregivers when they are alone.

At least, a healthcare support system for caregivers has to provide with a convenient way to ask for help in case of need. Even better, it should be able to detect the hazardous situations where is not even possible for a caregiver to call for help, and should call by itself. Design guidelines to address the ALF inhabitants safety match other recommendations about the same topic in similar scenarios (elder care assistive homes) as in the results found in [72].

9.5 Controlling the environment

9.5.1 Research Finding

A common topic across the three focus groups that was discussed when the researcher asked about "special requirements" was the need of better ways to control and operate the RAF building. This topic is summarized in the design guideline DG10 in Table 9.1. Caregivers pointed out that it is very difficult to control the temperature of the RAF in such a way that everyone is happy. A caregiver from RAF2 said:

> "*It is impossible to have the right temperature for everyone. For people in wheelchairs it is always too cold, but if we rise the temperature you die of heat.*"

From RAF1, a caregiver said that it was not easy to constantly change the temperature because of the mechanism to do it *"is old, difficult to operate and impossible to calibrate in the exact point you desire"*.

Another issue related with the operation of the RAF building is opening and closing doors. In general, all doors are kept locked in RAF1 and RAF3: the kitchen door is locked to avoid that some inhabitants steal food from others (especially, in RAF1 where some inhabitants steal sweets and candies), the infirmary door is locked to keep the inhabitants away from medicines, and the main door is locked to prevent the inhabitants from escaping (this is a very sensitive matter in RAF3, where some of the inhabitants with severe mental disabilities have already tried to escape more than once).

This situation bothers the caregivers that have to carry around a big bundle of keys that is not comfortable, but has become a big problem with regard to the main door. The main door, that gives access to the house, should be closed to prevent the inhabitants to escape, though cannot be locked for safety reasons. For now, the problem has been addressed with some bells that ring when the door is opened and one of the caregivers needs to check who is opening the door.

9.5.2 Implications

Smart Home technology has already been used in contexts similar to the ALFs with success. For example, see the framework described in [29] that assesses cognitive health using Smart Home technology. Nevertheless, there is still room for systems that integrate Smart Home capabilities with the solutions to the other problems encountered and presented in this work. In other words, the smart home capabilities should be one part of a holistic solution capable of meeting all other requirements of assisted living facilities.

To conclude, Table 9.1 summarizes the research findings and its implications in the form of 10 design guidelines for developing healthcare support systems in ALFs for people with disabilities.

Number	Design guideline	Description
DG1	*Interfaces for operating in the periphery of caregivers' attention*	A healthcare support system should exploit devices and interfaces that can be operated hands-free and without engaging caregivers' full attention in a stressful manner.
DG2	*System ubiquity*	A healthcare support system should support caregivers through their daily activities, regardless of their location inside the assisted living facility.
DG3	*Portability of devices*	The devices used as part of healthcare support systems should be easily taken around the assisted living facility by the caregivers, without representing a source of discomfort.
DG4	*Unobtrusiveness of the assistance request mechanism*	A healthcare support system should offer to the inhabitants a mechanism for requesting caregivers assistance that does not disturb other people within the assisted living facility.
DG5	*Verification of assistance provision*	A healthcare support system should verify that for each request received from inhabitants of the ALF, the proper assistance is actually provided.
DG6	*Self-direct caregivers' attention to potentially hazardous situations*	A healthcare support system should be able to indicate to the caregivers potentially hazardous situations in which the inhabitants may be involved without any explicit request.
DG7	*Emergency call option for caregivers*	A healthcare support system should allow the caregivers an immediate way to call for help in case of necessity, either manually or automatically.
DG8	*In situ form filling*	A healthcare support system should allow caregivers to fill notes and forms digitally around the facility, even if not at the end of the shift and in the office, to prevent them from forgetting the information to write in.
DG9	*Effective management of reminders*	A healthcare support system should manage the caregivers' routines and remind them effectively about special events or off plan tasks.
DG10	*Basic smart home capabilities*	A healthcare support system for assisted living facilities should provide the caregivers with home automation capabilities to facilitate the management and operation of the facility building.

Table 9.1. Design guidelines for systems to support caregivers in ALFs for persons with disabilities.

Chapter 10

Prototype Design

A prototype healthcare support system was designed, following the guidelines elicited and presented before. Such a design describes an unobtrusive and ubiquitous IoT system with wearable, for effectively tackling the most relevant and frequent problems of caregivers within ALFs, without compromising the privacy or dignity of the ALF inhabitants. The system focused on two important issues that emerged during the focus groups: the modalities to provide and require assistance and how to monitor the inhabitants while they are alone in order to timely assist them, in case of need.

The overall system requirements, elicited from the analysis of the focus groups results, are reported below. Some of them can be also found, in similar formulations, in other related works such as [54].

1. *Detection and notification of potentially hazardous situations.* Caregivers should be alerted when an inhabitant is involved in a potentially hazardous situation, without the need of constantly running ward rounds or using privacy invasive methods (e.g., video recording).

2. *Supporting smart assistance.* Provide the inhabitants with a smart way of requiring the caregivers assistance, without using noisy buzzers. Confirm that the assistance requests are addressed properly by at least one caregiver.

3. *Determining inhabitants presence in sensitive areas.* Some places of the ALF may not be suitable for the inhabitants, so caregivers want to know where they are located.

4. *Unobtrusiveness.* Caregivers do not want more "objects" to carry around or strange "gadgets" to use, even if they give useful functionalities. Therefore, the system must fade in the background of the daily life in an unobtrusive way.

5. *Hands-free operations.* Caregivers require to have their hands free, for being ready to assist inhabitants as soon as possible, without concerning about the "health" of the device (i.e., they must be resistant to water and shocks).

10.1 The System Architecture

Following the system requirements reported above, a system was designed to monitor ALF inhabitants by measuring and interpreting some of their body signals and notifying the caregivers whether and where their assistance is needed. Moreover, in case of need, it is also possible to easily call for assistance form everywhere in the ALF. In general, the system first collects data from all the different sources and process it to obtain an overview of the ALF situation. Then, by interpreting such information, it determines if an inhabitant needs assistance. In the case she does, the system is also in charge of notifying it to the caregivers, for her to be assisted. The caregiver that first reaches the inhabitant, has to turn the notification off to prevent his colleagues to come in vain. Figure 10.1 illustrates the general system architecture.

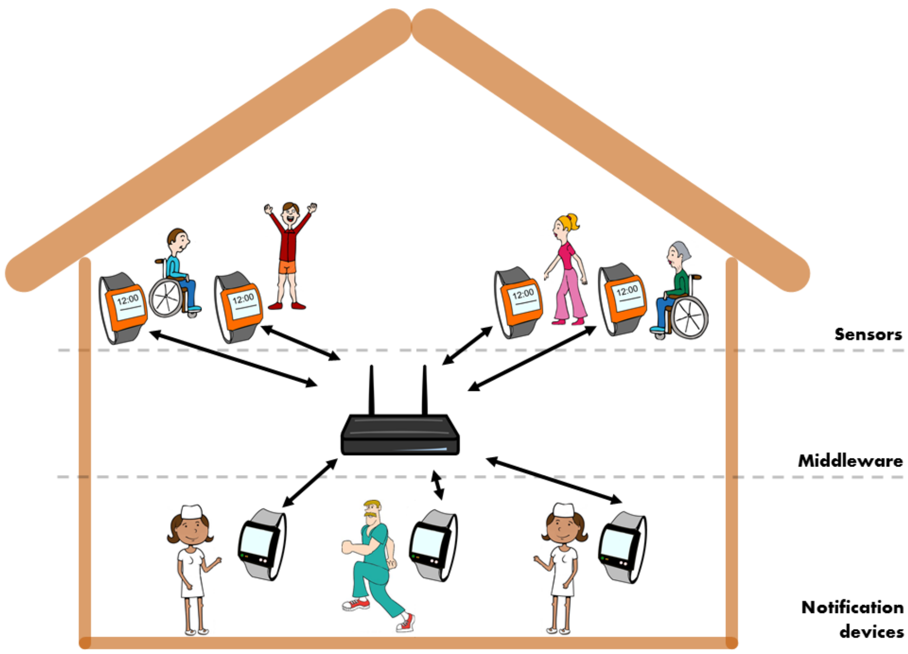

Figure 10.1. General system architecture. Each caregiver and ALF inhabitant wear a sensor/notification device that communicates with the middleware.

10.1.1 Sensors

Wearable sensors are used for measuring some body signals of its inhabitants. Wearable technology is used because it allows to meet the unobtrusiveness requirement (req. 4). It was chosen to adopt the wristwatch form factor since watches are ideally located for body sensors [51] and wearable displays. The wearable sensors collect acceleration data that can be processed and analysed for detecting epileptic seizures and falls, which is one of the most important system requirements (req. 1). The wearable devices worn by the inhabitants with adequate cognitive capabilities, have a "call function" that can be used for consciously requesting caregivers' assistance.

10.1.2 Middleware

The middleware is in charge of managing the overall system. It receives the body measures from the sensors, interprets them and determines if a situation that requires the presence of a caregiver is taking place. The middleware does not aim at assessing exactly what is happening with each ALF inhabitant, but its scope is to *point the caregivers attention* to "suspicious situations" that *might* require their presence. This means that the middleware is not designed to try to accurately detect potentially hazardous situations, such as epileptic seizures, where the consequences of missing one are very serious and are out of the scope of this kind of support. Caregivers required this type of notification since they are already used to this kind of dynamics in ALFs, given that ward rounds work like this, i.e., by checking on someone even if it is not strictly required. Once the middleware determines that the presence of a caregiver is required somewhere, it sends a proper notification to all the caregivers in the ALF.

10.1.3 Notification Devices

The devices in which caregivers receive the notifications sent by the middleware could be wearable or mobile. Wearable technology is the most suitable for meeting most of the previous requirements. One of those requirements (req. 5) is that caregivers need to have the hands free the most of the time, therefore a smartphone or a tablet are not appropriate for them. As in the case of the inhabitant sensors, the notification devices use a wristwatch form factor that is preferred by the caregivers that do not want "*another gadget to think about*". Notification devices should have sound and vibration alerts capable to draw the attention of the caregiver even in noisy environments.

10.2 The Prototype

The designed system was realized as an early prototype with reduced functionalities by extending the Dog gateway[1] [21] capabilities to realize the described middleware and some Texas Instruments eZ430-Chronos watches as both wearable sensors and notification devices.

The *middleware*, i.e., the component in charge of managing the overall system, was realized exploiting the Dog gateway and adding some new features, like notification management and some specific data elaborations. Dog is an open source gateway for home and building automation, based on the OSGi framework. It has been designed to provide intelligent environment capabilities to environments equipped with off-the-shelf home and building automation systems. Dog acts as a bridge between low-level specific protocols and high-level requirements coming from applications, like the one addressed in this paper. In other words, by explicitly modeling the wearable devices used as the inhabitants sensors and the caregiver wristwatches as Dog devices, it was possible to focus on high-level features of the system, the interactions between the parties, and the fulfillment of given requirements. Dog, in this way, takes care of low-level details and related complexities such as the data exchange between physical devices by using the proper protocols. The algorithms used to automatically determine if the caregivers presence is required, considering only the environmental and body sensors data, were not implemented for this early prototype.

For this initial implementation, the Texas Instruments eZ430-Chronos wristwatch was selected as the *wearable device* for notifying caregivers and sensing inhabitants. It was chosen because it is cost-effective and completely re-programmable, both desirable characteristics in this rapid prototyping phase of developing. The eZ430-Chronos integrates a 96 segment LCD display, a 3-axis accelerometer, sensors of temperature, pressure and a battery voltage, into an affordable device. The only functionality not supported by the eZ430-Chronos is the haptic feedback, so at this stage vibration alerts are not implemented yet. A custom firmware extension[2] similar to the one described by De Russis et al. [30] was used, because of the additional functionalities it offers: handling different types of messages and the "quick access command" capability.

The capability of the custom eZ430-Chronos firmware for managing different type of messages is useful to provide notifications to caregivers. Such notifications can be silent messages, loud messages or messages that require an explicit reply (e.g., yes or no). By using the "quick access command" functionality, each inhabitant's watch has two associated tap codes. The first one consists in three taps on the

[1] `http://dog-gateway.github.io`

[2] `http://github.com/poelzi/OpenChronos`

watch surface and serves to ask for help. The second one, that can be chosen by the healthcare assistants, serves to set the request off since the assistance has been provided and the "emergency" has been solved. To realize the same functionality, healthcare assistants can also use one of the four buttons present on the watch, according to the specific situation.

The interaction between the wearable devices (eZ430-Chronos) and the middleware (Dog) adopts a client-server paradigm. Their communication starts automatically once per minute, or manually when an inhabitant requests the caregiver presence, or when a caregiver asks the server for updates. Each eZ430-Chronos has a unique identifier that is read and stored by the control system to determine with which device is communicating (i.e., who asks for assistance).

10.3 In-Lab Validation and User Acceptance

The validation of this prototype was twofold: on one hand, the technical feasability of the system was confirmed by in-lab testing. On the other hand, it was assesses the user acceptance and perceived usefulness by distributing a series of questionaries to a group of healthcare assistants.

The test carried out in the lab consisted in the deployment of a scaled down version of the overall system, where two volunteers act like a caregiver and a RAF inhabitant equipped with one eZ430-Chronos wristwatch each. The goal was to verify the correct operation of the notification subsystem either when the assistance is requested from the inhabitants or when it is requested automatically by interpreting sensor data. Two use cases were successfully tried out:

- *Assistance request from the inhabitant.* In this case the volunteer acting as the inhabitant requests the caregiver assistance by tapping three times on her wristwatch. Dog notifies the caregiver in less than one minute providing the name of the inhabitant that asked for his help. Then, the volunteer acting as the caregiver reaches the inhabitant and turns off the request by tapping his own code on the inhabitant's watch.

- *Notification of potentially hazardous situation.* In this case the volunteer acting as the inhabitant moves her arm in such a way that the middleware interprets that something may be wrong. For such a test, there were defined fixed acceleration intervals that trigger the notification to be sent to the caregiver. This happens in less than one minute, and as before, the caregiver turns the request off by reaching the inhabitant and tapping his personal code on the inhabitant's watch.

Figure 10.2 shows the notification received and displayed on the caregiver wearable device while running the first test.

Figure 10.2. Successfully received notification.

For measuring qualitatively the user acceptance of the system, a questionnaire of 12 questions was distributed to a group of healthcare assistants. This group was composed of 8 participants, all female, with different years of expertise (as reported in Table 10.1 and in Table 10.2) that work in one RAF for people with physical disabilities managed by the municipality of Turin. The questions were about two hypothetical scenarios that describe the two aforementioned use cases.

Age	**Count**
36-45	1
46-55	6
56+	1
height	

Table 10.1. Participants by age

Years of Expertise	**Count**
5-10	1
15+	7
height	

Table 10.2. Participants' expertise

The first scenario takes place in a ALF for people with *mental* disabilities, where the system proposed in this paper has been implemented and is fully functional. First, the scenario describes how the system works. Then, it presents a use case of a caregiver that is able to assist in time one of the RAF inhabitants thanks to a notification sent by the system after detecting automatically a hazardous situation. The participants were asked to rate how useful they thought the system was, from 1 ("Not useful at all") to 5 ("Very useful"). The average rating for the system usefulness was 4.8 with many positive comments.

The second scenario takes place in a nursing home for people with *physical* disabilities, where the system has also been implemented and is fully functional. First, the scenario describes how the system works. Then, it presents a use case of a caregiver that reaches an inhabitant that have requested assistance through a wearable device and presents what happens when multiple alerts are issued. Again, the participants were asked to rate how useful they thought the system was, with the same scale adopted before. This time, the average rating was only 3.5. The general comments were quite positive, while two volunteers suggested that requesting assistance through a device could be "less personal" than doing it by voice.

When asked about the acceptance of such a system, according to the described scenarios and their own experience, the eight healthcare assistants expressed very positive comments, especially about the choice of a wearable device like a wristwatch instead of smartphone or similar.

Chapter 11

Conclusions and Future Directions

This part of the thesis presents ten guidelines that could enhance the design and implementation of healthcare support systems to aid caregivers in their daily activities, particularly within assisted living facilities for persons with disabilities. These design guidelines were elicited after a comprehensive qualitative analysis of research data collected from three focus groups, conducted with 30 caregivers of ALFs in Northern Italy. The proposed guidelines are presented in Table 9.1.

Moreover, the design of a prototype healthcare support system, based on the elicited guidelines, is described. The design monitors ALF inhabitants by measuring and interpreting some of their body signals to notify the caregivers whether and where their assistance is needed. In particular, the system allows caregivers to be automatically alerted of potentially hazardous situations that happen to the inhabitants while these are alone. In order to do so, an architecture consisting of sensors, a middleware and wearable notification devices, was proposed. Although this early prototype was not evaluated in-field, its technical feasibility was tested in-lab and its acceptance was qualitatively measured through a questionnaire of 12 questions distributed to a group of 8 healthcare assistants.

How Can Others Make Use of this Work

As in the first part of this thesis, the objective of this section is to briefly suggest to other researchers how they can make use of the work presented in previous chapters. For this purpose, a superlative masters' thesis named *"Migliorare l'assistenza in strutture per disabili: una soluzione IoT"*, which stems from the study about supporting caregivers in assisted living facilities (ALFs), is presented in these last paragraphs. Such a thesis aims at implementing and evaluating *in-field* a healthcare support system for caregivers within ALFs, as reported in [33]. In particular, the system developed by Monge in [11] was designed to meet some of the guidelines reported in Table 9.1 of Section ??, which are the following:

- Design guideline DG2: System ubiquity.
- Design guideline DG3: Portability of devices.
- Design guideline DG5: Verification of assistance provision.
- Design guideline DG6: Self-direct caregivers' attention to potentially hazardous situations.

Hence, his system was capable of recognizing when an ALF inhabitant is suffering a seizure, when she falls and when she requests for assistance. The system featured a Pebble[1]smartwatch and an Android smartphone per user (i.e., caregivers and ALF inhabitants), as well as a central server with a Java EE application runing a RESTful service for coordinating the communication between devices. The general structure of the system is described in figure 11.1, as it was illustrated in [11].

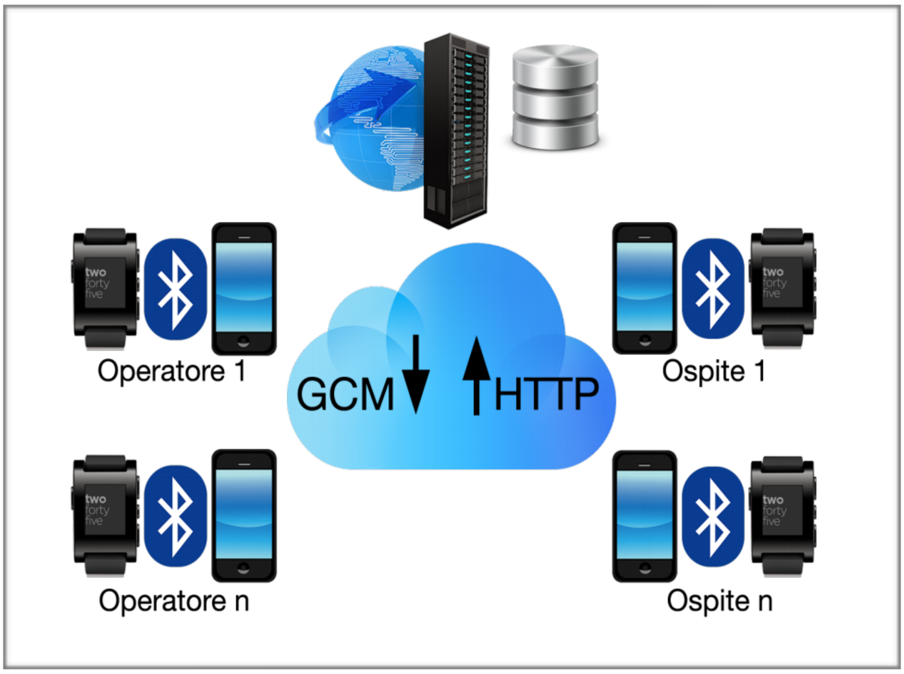

Figure 11.1. General structure of a system capable of satisfying 4 of the 10 resulting design guidelines for systems to support caregivers in ALFs for persons with disabilities. Image adapted from [11].

[1]http://pebble.com

The system was refined and it was evaluated in-field in two phases. First, it was performed a functional test with two professional caregivers to verify the user acceptance and the perceived usefulness. Second, the system was deployed in an ALF for 36 hours, and the opinions of the involved caregivers and inhabitants were collected. The results of this evaluation are presented in [33].

Similarly to this research, other researchers willing to explore IoT solutions for the implementation of healthcare support systems in the context of ALFs may use the design guidelines presented in previous chapters as their starting point and source of requirements. In this way, they can be sure that their designed solutions address concrete needs and solve real problems encountered by their final users, in real-life situations. Moreover, it would be interesting to research whether the design guidelines obtained in the context of ALFs for people with disabilities are valid or useful for the implementation of support systems in hospitals, nurse homes and similar structures that take are of persons in dependency conditions for reasons other than disability, such as disease or age.

Conclusion

This thesis is the resulting document of a three-year research on the field of Accessible Human Computer Interaction, which was carried out during the PhD program in computer and control engineering at the Politecnico di Torino within the e-lite research group. Such a research achieved several concrete contributions to the fascinating realm that exists at the intersection between the Human Computer Interaction world and the assistive technology field. In particular, this document contributes to the state of the art of two branches of academic interest to the Accessible Human Computer Interaction community: accessible video games for children with severe motor disabilities and assisted living for people with disabilities. While the former is still mostly unexplored, the latter has been calling the attention of both academy and industry during the last years.

The presented research accomplished the initial goal of using different technologies (e.g., novel one-switch interfaces, wearable devices and intelligent environments) for helping persons with disabilities in different moments of their lives: during childhood, when they need to play and share playful experiences with others, as well as in an adult age, when they need more independence and privacy without sacrificing safety and prompt support. The two main challenges that motivated this work were successfully addressed:

- First, the problem that children with motor disabilities face as they cannot access dynamic video games as their normally developing peers do, leading them to reduced participation at leisure and playful educational activities, and finally to a potential social exclusion. For tackling this problem the software framework GNomon that enables to create *dynamic* one-switch video games was designed, developed, implemented and then evaluated with a group of 8 children with severe motor disabilities.

  As stated before, the results of this research are very encouraging and demonstrate that, in fact, it is possible to develop dynamic one-switch games playable by children with severe motor disabilities. In particular, 7 out of 8 children that participated in the study expressed that they had fun playing the GNomon-based games. Moreover, once the study was already completed, two of the children and their families asked the research group for the games, as they wanted to continue playing.

- The second challenge, faced by professional caregivers that work with disabled adults within assisted living facilities, consisted in the need of the former to effectively monitor and be alerted of potentially hazardous situations that happen to the latter. To deal with this question, a series of in-field focus groups were conducted with 30 caregivers of assisted living facilities in Northern Italy. Then, 10 guidelines were elicited stemming from a comprehensive qualitative analysis of the research data collected during the structured interviews. Finally, a prototype healthcare support system was designed based on the proposed guidelines for its future implementation in an ALF located in northern Italy.

The last conclusion of this research is not deduced from the results of this work, but it emerged from the process and methodologies that I followed during the development of the studies discussed in this thesis: technology should be a means to carry out noble projects, and the nobility of a project is not given by the money or the prestige derived from its completion; its nobleness is determined by the benefits that its realization brings to the life of a community. Therefore, it is compulsory to "*go out* the lab" and talk to the people, listen to them and learn about their needs and desires. Moreover, it is essential to put our technical experience and know-how at the service of humanities and social welfare for improving the quality of life of the persons in need. In this manner, research is ennobled and transcends the ink and the *paper*.

Public Demonstrations of GNomon and the GNomon-based Games

The impact of the research about dynamic one-switch video games for children with severe motor disabilities transcended the academia and was very well received by the general public during the several public demonstrations in which the GNomon framework and the GNomon-based games were presented. The following figures document part of the success that this study had outside the accessible human computer interaction community:

- **Bimbi al Poli con Mamma e Papà 2015.** The GNomon-based games One-Switch Ladybugs and One-Switch Invaders were presented at the 21st edition of this event, which is carried out at the Politecnico di Torino and is sponsored by the newpapers Corriere della Sera/Corriere Economia and La Stampa. In this occasion the sons and daughters of the employees of the Politecnico had the opoortunity to play the GNomon-based games with a single switch (such as the one used by children with severe motor disabilities) and with the Makey Makey invention kit, which allowed them to "high five" for selecting the game objects on the screen. Figures 2 and 3.

- **La Notte dei Ricercatori 2015.** The researchers of the e-lite research group of the POlitecnico di Torino were presenting the research about Accessible video games and demonstrating the GNomon-based games during this initiative promoted by the European Comission. Figures 4 and 5.

- **Abilitando 2015.** GNomon was presented during this event that gathers people interested in the world of assistive technologies in a two-days appointment full of workshps, conferences and laboratories. Figure 6.

- **Turin Jam Today 2015.** GNomon was used to create the game "El GNomo Loco" a drive-and-shoot multiplayer game for children with severe motor disabilities and normally developing ones. The game won a special mention during

Figure 2. Bimbi al Poli con Mamma e Papà 2015 (1)

Figure 3. Bimbi al Poli con Mamma e Papà 2015 (2)

this event by a jury of experts of the video game developing sector. Figure 7.

Figure 4. La Notte dei Ricercatori 2015 (1)

- **Article at La Stampa newspaper.** One of the main newspaper of Turin, dedicated a column to GNomon and the playability study that was being carried out with one of the Local Health Agencies of the city. Figure 8.

Figure 5. La Notte dei Ricercatori 2015 (2)

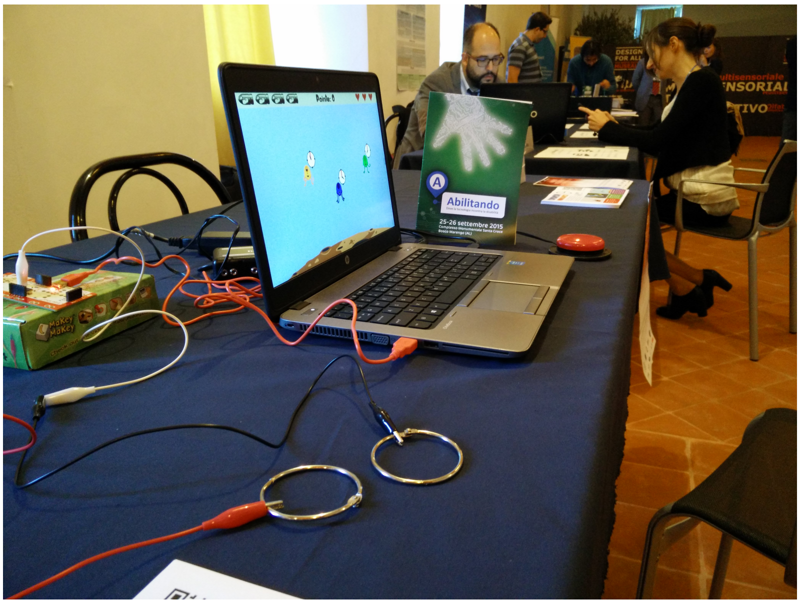

Figure 6. Abilitando 2015

Figure 7. Secial Mention for the creators of "El GNomo Loco" during the Turin Jam Today 2015

T1 CV PR T2

LA STAMPA DOMENICA 25 OTTOBRE 2015 | Cronaca di Torino | 51

L'innovazione

Bimbi disabili il Poli realizza un videogame

NOEMI PENNA

Un videogioco a misura di disabilità. Anzi, tre. È l'impresa compiuta dal professor Fulvio Corno del Politecnico di Torino, specializzato in Sistemi di elaborazione delle informazioni, e dalle logopediste Elisabetta Cane e Sara Scotto dell'Asl To1, che tutti i giorni lavorano con bambini con disabilità neuromotorie e paralisi celebrali. Per realizzarlo hanno deciso di bypassare la burocrazia e investire il loro tempo «creando uno strumento utile, educativo e interattivo, in grado di stimolare le abilità dei bambini che ogni giorno affrontano il dramma della disabilità», dice la dottoressa Cane. Hanno quindi pensato di realizzare «un videogioco graficamente accattivante e divertente, che perfettamente si adatta al "pulsantone": un unico comando che riescono a usare anche i bambini con paralisi», spiega il professor Corno. A contribuire alla programmazione dei giochi della serie Gnomon (due con le coccinelle da far saltare al momento giusto, uno con gli alieni in stile «Space invaders») sono stati il dottorando Sebastián Aced López e il postdoc Luigi De Russis. «Non si tratta di un progetto di ricerca – continua Corno – ma vorremmo farlo diventare. Ci piacerebbe continuare la produzione e ampliare il catalogo, visti anche i successi ottenuti». Sono stati infatti sperimentati con una decina di bambini disabili del centro riabilitativo di via Spalato «con risultati più che positivi e che ci hanno fatto capire che è la strada giusta», rivela Cane. «Ma per continuare ci servirebbe un finanziamento: ogni videogioco costa quasi 5 mila euro. I tre già prodotti sono scaricabili gratuitamente da internet e stiamo studiando anche nuove modalità d'interazione e socializzazione con i normodotati – conclude Corno –. Abbiamo trovato un controller a circuito che per funzionare ha bisogno del contatto umano: una stretta di mano, darsi il cinque, in modo da far interagire i giocatori fra loro».

Figure 8. Secial Mention for the creators of "El GNomo Loco" during the Turin Jam Today 2015

List of Pubblications

- Aced López Sebastián, Bonino Dario, Corno Fulvio. 2014. **Template-based ontology population for Smart Environments configuration.** In Service-Oriented Computing ICSOC 2013 Workshops. Springer International Publishing, 2014, 8377, 271-278.

- Aced López Sebastián, Corno Fulvio, De Russis Luigi. 2015. **Supporting Caregivers in Assisted Living Facilities for Persons with Disabilities: a User Study.**In Universal Access in the Information Society . Springer Berlin Heidelberg, vol. 14 n. 1, pp. 133-144.

- Aced López Sebastián, Corno Fulvio, De Russis Luigi. 2015. **IoT Meets Caregivers: A Healthcare Support System in Assisted Living Facilities.**. In Internet of Things. User-Centric IoT. Springer International Publishing, 2015, 150, 172-177.

- Aced López Sebastián, Corno Fulvio, De Russis Luigi. 2015. **GNomon: Enabling Dynamic One-Switch Games for Children with Severe Motor Disabilities.** In Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '15). ACM, 995-1000.

- Aced López Sebastián, Corno Fulvio, De Russis Luigi. 2015. **Playable One-Switch Video Games for Children with Severe Motor Disabilities.**In: the 7th International Conference on Intelligent Technologies for Interactive Entertainment (INTETAIN). IEEE, 176-185.

- Aced López Sebastián, Corno Fulvio, De Russis Luigi. 2015. **Can We Make Dynamic, Accessible and Fun One-Switch Video Games?** In: the 17th International ACM SIGACCESS Conference on Computers and Accessibility - Posters and Demos (ASSETS 2015). ACM, 421-422.

- Aced López Sebastián, Corno Fulvio, De Russis Luigi. **Clocks, Bars and Balls: Design and Evaluation of Alternative GNomon Widgets for**

Children with Disabilities. In Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (CHI '16). (In Press).

- Aced López Sebastián, Corno Fulvio, De Russis Luigi. 2016. **Design and Development of One-Switch Video Games for Children with Severe Motor Disabilities.** In ACM Transactions on Accessible Computing. (Submitted).

Bibliography

[1] Gnomon games by the e-lite research group. (last visited on April 8, 2016).

[2] International game developers association (igda). (last visited on April 8, 2016).

[3] Making video games accessible: Business justifications and design considerations. (last visited on April 8, 2016).

[4] Nomon original implementation. (last visited on April 8, 2016).

[5] World report on disability. Technical report, UN World Health Organization (WHO), 2011.

[6] Includification: A practical guide to game accessibility. Technical report, The ableGamers foundation, 2012.

[7] G. Acampora, D.J. Cook, P. Rashidi, and A.V. Vasilakos. A survey on ambient intelligence in healthcare. *Proceedings of the IEEE*, 101(12):2470–2494, 2013.

[8] Sebastián Aced López, Fulvio Corno, and Luigi De Russis. Gnomon: Enabling dynamic one-switch games for children with severe motor disabilities. In *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, CHI EA '15, pages 995–1000, New York, NY, USA, 2015. ACM.

[9] Sebastián Aced López, Fulvio Corno, and Luigi De Russis. Playable one-switch video games for children with severe motor disabilities based on gnomon. In *Proceedings of the 7th International Conference on Intelligent Technologies for Interactive Entertainment.*, pages 176–185, 2015.

[10] Kurt Adamer, David Bannach, Tobias Klug, Paul Lukowicz, MarcoLuca Sbodio, Mimi Tresman, Andreas Zinnen, and Thomas Ziegert. Developing a wearable assistant for hospital ward rounds: An experience report. In *The Internet of Things*, volume 4952 of *Lecture Notes in Computer Science*, pages 289–307. Springer Berlin Heidelberg, 2008.

[11] Monge Roffarello Alberto. Migliorare l'assistenza in strutture per disabili: una soluzione iot. Technical report, Politecnico di Torino, 2015.

[12] B. Altakouri, G. Kortuem, A. Grunerbl, K. Kunze, and P. Lukowicz. The benefit of activity recognition for mobile phone based nursing documentation: A wizard-of-oz study. In *Wearable Computers (ISWC), 2010 International Symposium on*, pages 1–4, 2010.

[13] Jennifer Angelo. Comparison of three computer scanning modes as an interface method for persons with cerebral palsy. *American Journal of Occupational Therapy*, 46(3):217–222, 1992.

[14] Urs Anliker, Jamie A Ward, Paul Lukowicz, Gerhard Troster, Francois Dolveck, Michel Baer, Fatou Keita, Eran B Schenker, Fabrizio Catarsi, Luca Coluccini, et al. Amon: a wearable multiparameter medical monitoring and alert system. *Information Technology in Biomedicine, IEEE Transactions on*, 8(4):415–427, 2004.

[15] Daphne Bavelier, C Shawn Green, Alexandre Pouget, and Paul Schrater. Brain plasticity through the life span: learning to learn and action video games. *Neuroscience*, 35:391–416, 2012.

[16] Anna S Beeber, Lauren W Cohen, Sheryl Zimmerman, Lisa P Gwyther, Tiffany Washington, John G Cagle, and David Reed. Differences in assisted living staff perceptions, experiences, and attitudes. *Journal of gerontological nursing*, 40(1):41–49, 2014.

[17] Eric Bergman and Earl Johnson. Towards accessible human-computer interaction. *Advances in human-computer interaction*, 5(1):87–114, 1995.

[18] M. Betke, J. Gips, and P. Fleming. The camera mouse: visual tracking of body features to provide computer access for people with severe disabilities. *Neural Systems and Rehabilitation Engineering, IEEE Transactions on*, 10(1):1–10, March 2002.

[19] David R. Beukelman and Pat Mirenda. *Augmentative and alternative communication supporting children and adults with complex communication needs*. Paul H. Brookes Pub, 2013.

[20] Sanjay S Bhadoria and Hitesh Gupta. A wearable personal healthcare and emergency information based on mobile application. *International Journal of Scientific Research in Computer Science and Engineering*, 1(4):24–30, 2013.

[21] D. Bonino, E. Castellina, and F. Corno. The DOG gateway: enabling ontology-based intelligent domotic environments. *Consumer Electronics, IEEE Transactions on*, 54(4):1656–1664, November 2008.

[22] Marko Borazio and Kristof Van Laerhoven. Combining wearable and environmental sensing into an unobtrusive tool for long-term sleep studies. In *Proceedings of the 2Nd ACM SIGHIT International Health Informatics Symposium*, IHI '12, pages 71–80, 2012.

[23] Bas Brederode, Panos Markopoulos, Mathieu Gielen, Arnold Vermeeren, and Huib de Ridder. powerball: The design of a novel mixed-reality game for children with mixed abilities. In *Proceedings of the 2005 Conference on Interaction Design and Children*, IDC '05, pages 32–39. ACM, 2005.

[24] Tamara Broderick and David JC MacKay. Fast and flexible selection with a single switch. *PloS one*, 4(10):e7481, 2009.

[25] Victoria Carlsson, Tobias Klug, Thomas Ziegert, and Andreas Zinnen. Wearable computers in clinical ward rounds. In *Applied Wearable Computing (IFAWC), 2006 3rd International Forum on*, pages 1–9, 2006.

[26] T. Chatfield. *Fun Inc: Why Games are the Twenty-first Century's Most Serious Business*. Virgin Books, 2011.

[27] Jinghui Cheng, Cynthia Putnam, and Doris C. Rusch. Towards efficacy-centered game design patterns for brain injury rehabilitation: A data-driven approach. In Yeliz Yesilada and Jeffrey P. Bigham, editors, *Proceedings of the 17th International ACM SIGACCESS Conference on Computers and Accessibility*, pages 291–299. ACM, 2015.

[28] European Comission. The action plan for the eu health workforce. (last visited on April 30, 2015).

[29] Prafulla N Dawadi, Diane J Cook, Maureen Schmitter-Edgecombe, and Carolyn Parsey. Automated assessment of cognitive health using smart home technologies. *Technology Health Care*, 2013.

[30] Luigi De Russis, Dario Bonino, and Fulvio Corno. The smart home controller on your wrist. In *Proceedings of the 2013 ACM Conference on Pervasive and Ubiquitous Computing Adjunct Publication*, UbiComp '13 Adjunct, pages 785–792. ACM, 2013.

[31] Constantine Stephanidis Dimitris Grammenos, Anthony Savidis. Universal accessibility in hci: Process-oriented design guidelines and tool requirements. In *Universal Access in HCI: Exploring New Interaction Environments-Proc. 11th Int. Conf. on Human-Computer Interaction (HCI International 2005)*, pages 19–21, 2005.

[32] Barrie Ellis. Oneswitch.org.uk, 2015. (last visited on April 8, 2016).

[33] Corno Fulvio, Monge Roffarello Alberto, and De Russis Luigi. A healthcare support system for assisted living facilities: an iot solution. In *Computer Software and Applications Conference (COMPSAC), 2016 IEEE 40th Annual*, In Press.

[34] Krzysztof Z. Gajos, Jacob O. Wobbrock, and Daniel S. Weld. Improving the performance of motor-impaired users with automatically-generated, ability-based interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '08, pages 1257–1266, 2008.

[35] Anita Gibbs. Focus groups: Social research update. *Retrieved June*, 8:2007, 1997.

[36] Jose Luis González Sánchez, Natalia Padilla Zea, and Francisco L. Gutiérrez. From usability to playability: Introduction to player-centred video game development process. In *Proceedings of the 1st International Conference on Human Centered Design: Held As Part of HCI International 2009*, pages 65–74, 2009.

[37] Dimitris Grammenos, Anthony Savidis, and Constantine Stephanidis. Designing universally accessible games. *Comput. Entertain.*, 7(1):8:1–8:29, 2009.

[38] Isabela Granic, Adam Lobel, and Rutger C. M. E. Engels. The benefits of playing video games. *American Psychologist*, 69(1):66–78, 2014.

[39] C. S. Green and D Bavelier. Learning, attentional control, and action video games. *Current Biology*, 22(6):R197–R206, 2012.

[40] Susumu Harada, Jacob O. Wobbrock, Jonathan Malkin, Jeff A. Bilmes, and James A. Landay. Longitudinal study of people learning to use continuous voice-based cursor control. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '09, pages 347–356, 2009.

[41] Hamilton A. Hernandez, Mallory Ketcheson, Adrian Schneider, Zi Ye, Darcy Fehlings, Lauren Switzer, Virginia Wright, Shelly K. Bursick, Chad Richards, and T.C. Nicholas Graham. Design and evaluation of a networked game to supportsocial connection of youth with cerebral palsy. In *Proceedings of the 16th International ACM SIGACCESS Conference on Computers & Accessibility*, ASSETS '14, pages 161–168. ACM, 2014.

[42] Hamilton A. Hernandez, Zi Ye, T.C. Nicholas Graham, Darcy Fehlings, and Lauren Switzer. Designing action-based exergames for children with cerebral palsy. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '13, pages 1261–1270. ACM, 2013.

[43] Honeyslug. Poto and Cabenga, 2010. (last visited on July 30, 2015).

[44] Anthony J. Hornof and Anna Cavender. Eyedraw: Enabling children with severe motor impairments to draw with their eyes. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '05, pages 161–170, 2005.

[45] Ipsos Media CT. Videogames in Europe: Consumer Study. Technical report, ISFE, 2012.

[46] ISTAT. Disability in italy, 2004. (last visited on April 8th, 2016).

[47] Jenny Kitzinger. Qualitative research: Introducing focus groups. *BMJ*, 311(7000):299–302, 1995.

[48] Sian Lun Lau, I. KoÌnig, K. David, B. Parandian, C. Carius-DuÌssel, and M. Schultz. Supporting patient monitoring using activity recognition with a smartphone. In *Wireless Communication Systems (ISWCS), 2010 7th International Symposium on*, pages 810–814, 2010.

[49] D. Luiz, B. Faragher, A. Barnard, N. Knosen, N. Kotras, L.E. Burns, and D. Challis. Griffiths mental development scales - extended revised, two to eight years. Oxford: Association for research in infant and Child Development. The Test Agency. `http://www.hogrefe.co.uk/gmds-er-2-8.html`. Accessed January 11, 2016, 2014.

[50] Paul Lukowicz, H. Junker, M. Stäger, T. von Büren, and G. Tröster. Wearnet: A distributed multi-sensor system for context aware wearables. In *Proceedings of the 4th International Conference on Ubiquitous Computing*, UbiComp '02, pages 361–370, 2002.

[51] Uwe Maurer, Anthony Rowe, Asim Smailagic, and Daniel Siewiorek. *Ambient Intelligence in Everyday Life: Foreword by Emile Aarts*, chapter Location and Activity Recognition Using eWatch: A Wearable Sensor Platform, pages 86–102. Springer Berlin Heidelberg, 2006.

[52] O. Mayora, B. Arnrich, J. Bardram, C. Drager, A. Finke, M. Frost, S. Giordano, F. Gravenhorst, A. Grunerbl, C. Raring, R. Raux, P. Lukowicz, A. Muaremi, S. Mudda, S. Ohler, A. Puiatti, N. Reichwaldt, C. Scharnweber, G. Troester, L. Vedel Kessing, and G. Wurzer. Personal health systems for bipolar disorder anecdotes, challenges and lessons learnt from monarca project. In *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2013 7th International Conference on*, pages 424–429, 2013.

[53] Helen Melhuish. Crazy chicken, 2012. (last visited on July 30, 2015).

[54] Margaret Morris, Jay Lundell, Eric Dishman, and Brad Needham. New perspectives on ubiquitous computing from ethnographic study of elders with cognitive decline. In AnindK. Dey, Albrecht Schmidt, and JosephF. McCarthy, editors, *UbiComp 2003: Ubiquitous Computing*, volume 2864 of *Lecture Notes in Computer Science*, pages 227–242. Springer Berlin Heidelberg, 2003.

[55] Elizabeth H Morrison, Valerie George, and Laura Mosqueda. Primary care for adults with physical disabilities: perceptions from consumer and provider focus groups. *Family medicine*, 40(9):645–651, 2008.

[56] Mandrile Nicolò. Videogiochi single-switch educativi e inclusivi. Technical report, Politecnico di Torino, 2016.

[57] Ominous Development. Strange attractors, 2006. (last visited on April 30, 2015).

[58] Ricardo Ron-Angevin, Francisco Velasco-Álvarez, and Salvador Sancha-Ros. Brain-computer interfaces: Proposal of a paradigm to increase output commands. In *Intelligent Technologies for Interactive Entertainment*, volume 78 of *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, pages 18–27. Springer Berlin Heidelberg, 2012.

[59] D. Sanchez, M. Tentori, and J. Favela. Activity recognition for the smart hospital. *Intelligent Systems, IEEE*, 23(2):50–57, March 2008.

[60] R.C. Simpson and H.H. Koester. Adaptive one-switch row-column scanning. *Rehabilitation Engineering, IEEE Transactions on*, 7(4):464–473, 1999.

[61] C Stephanidis, D Akoumianakis, M Sfyrakis, and A Paramythis. Universal accessibility in hci: Process-oriented design guidelines and tool requirements. In *Proceedings of the 4th ERCIM Workshop on User Interfaces for all, Stockholm, Sweden*, pages 19–21, 1998.

[62] Constantine Stephanidis, editor. *The Universal Access Handbook*. 2009.

[63] Constantine E. Steriadis and Philip Constantinou. Designing human-computer interfaces for quadriplegic people. *ACM Transactions on Computer-Human*

Interaction (TOCHI), 10(2):87–118, 2003.

[64] Tarja Susi, Mikael Johannesson, and Per Backlund. Serious games: An overview. Technical report, School of Humanities and Informatics, University of Skövde, Sweden, 2007.

[65] Broderick Tamara. Nomon: Efficient communication with a single switch. Technical report, University of Cambridge, 2009.

[66] United Nations Children's Fund. The state of the worldwide children 2013: Children with disabilities. Technical report, UNICEF, 2013.

[67] Unity. Unity3d, 2015. (last visited on July 30, 2015).

[68] Jan van der Kamp and Veronica Sundstedt. Gaze and voice controlled drawing. In *Proceedings of the 1st Conference on Novel Gaze-Controlled Applications*, NGCA '11, pages 9:1–9:8, 2011.

[69] Stephen Vickers, Howell Istance, and Aulikki Hyrskykari. Performing locomotion tasks in immersive computer games with an adapted eye-tracking interface. *ACM Trans. Access. Comput.*, 5(1):2:1–2:33, 2013.

[70] David Vincent. Penalty game one switch wonder, 2011. (last visited on July 30, 2015).

[71] L. S. Vygotsky. Play and its role in the mental development of the child. *Soviet Psychology*, 5(3):6–18, 1967.

[72] A. Leah Zulas, Aaron S. Crandall, Maureen Schmitter-Edgecombe, and Diane J. Cook. Caregiver needs from elder care assistive smart homes: Nursing assessment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 56(1):125–129, 2012.