UNIVERSITÀ DEGLI STUDI DI PADOVA

MASTER THESIS IN COMPUTER ENGINEERING
Department of Information Engineering

Development and testing of an interactive environment for the enhancement of visual-motor coordination in children with severe low vision

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To my grandfather

I learned that computer science is not just about syntax and coding. We can make a difference in people's lives by developing applications. *Kyle Rector*

Abstract

In a modern society based on the ability to see, vision plays a critical role in every moment and stage of a person's life. Unfortunately, not everyone "sees" in the same way. With a multidisciplinary team including computer engineers and therapists from the Robert Hollman Foundation, a series of digital mini-games, explicitly aimed at children with visual impairment, were designed and developed with the aim of improving their cognitive and/or motor-sensory skills. This thesis analyses the design requirements of the games, which needed a careful and detailed design that took into account the characteristics and needs of the operators (therapists) and players. It also details the implementation of three games based on a large-scale interactive environment that are played by projecting the field onto the floor. Above this area a motion capture system is placed to track the position of the children. The players' movements within the field are used to make them interact with the game elements, producing appropriate visual and auditory outputs. Finally, the usability and functionality of the system are discussed through the analysis of data collected during a pilot study. Four therapists and eleven children has been involved making them use the system in a specially designed environment. The results allowed the team to improve the final product and to define a set of guidelines useful for designers, developers, and therapists.

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Introduction

Many inputs a person receives from the outside world are based on the ability to see. Unfortunately, exists an impairment that precludes some individuals from having a perfect visual experience. The term visual impairment refers to a disability that manifests in a limitation of the functions of the visual system. It leads to partial or total visual loss. Over time, evidence has accumulated that rehabilitation can be effective. Particularly positive effects have been noted if rehabilitation is tailor-made for each case and if carried out during the first years of life, when brain plasticity is at its highest level. Very often the therapy courses include activities that may be very repetitive. This leads patients to not being consistent over time and not completing them.

Digital serious games try to remedy this problem. Thanks to their playfulness, they make rehabilitation courses more fun. In this way children are more involved in their therapies, carrying them out. Serious games with rehabilitation purposes must adapt to individual patient abilities. It is very important that they respect adaptability and configurability criteria of the category of people they are aimed at. Furthermore, one of the main objectives of rehabilitation is to promote the child's body awareness and movement in the environment to support the internalisation of topological concepts and to improve the orientation and spatial organisation of movement. The See-Sound project aims to find a system to help solve these problems. With a multidisciplinary team including computer engineers and therapists from the Robert Hollman Foundation, a series of digital mini-games, explicitly focused on children with visual impairments, were designed and developed with the aim of improving their cognitive and/or motor-sensory skills.

The games are based on large-scale responsive environments, open spaces where the player's position and movements are tracked and used to create the interaction with the game, providing an audio and graphical output consistent with the actions.

This thesis analyses the path followed by the team, from the collection of game requirements to the study of the results on a sample of children. Chapter 1 summarizes the characteristics, causes and consequences of visual impairment. In Chapter 2, the rehabilitation topic is discussed, explaining the importance of working with patients in the early years of life, and how the use of serious games has been shown to help with rehabilitation. To do this, a literature review of existing serious games for rehabilitation is made. In Chapter 3 the path followed by the team for the design and development of the See-Sound project is explained in detail. In particular, the careful and detailed design followed is explained, taking into account the characteristics and needs of the operators (therapists) and players. Are also shown all the precautions followed to allow operators to customize the games adapting them to each specific case. In the second part of the chapter, the three mini games developed for the project are widely described and the implementation choices followed are explained in detail. Finally, in Chapter 4, are presented the results obtained from the pilot study carried out at the Robert Hollman Foundation, involving four therapists and eleven children with visual impairment. Results of a questionnaire on the usability and evaluation by both operators and players are shown. These results have been used to improve the system. The results obtained from the use of the game from the rehabilitation point of view are also presented. In the last part of the chapter, is shown a set of useful guidelines for designers, developers, and therapists drawn up on the basis of the collected data analysis.

Visual impairment

Vision can be considered as the individual's ability to organize and give meaning to the sensory data collected by the visual system. Humans interact and develop meaningful representations through their senses and vision is often considered the dominant one [1] as it allows to access a whole scene simultaneously and allows to integrate information from the other senses to form a coherent sense of the environment.

1.1 Visual system and visual functions

The visual system includes eyes, optic nerves, and pathways to and between different structures in the brain.

The human eye, a spherical bulb of about 24 millimeters in diameter, as we can also see from Figure 1.1, is a complex sensory organ, designed to convert light energy into electrical signals (nerve stimuli) that are processed by the brain [2].

One of the part in the posterior of the eyes is called the retina. It is a sensory membrane made up of highly differentiated elements. In it, by the action of light radiations, chemical, physical and electrical transformations take place, thanks to which the stimulus that determines the phenomenon of vision originates.

Thanks to the cornea and lens, the structures at the front of the eyes, light enters

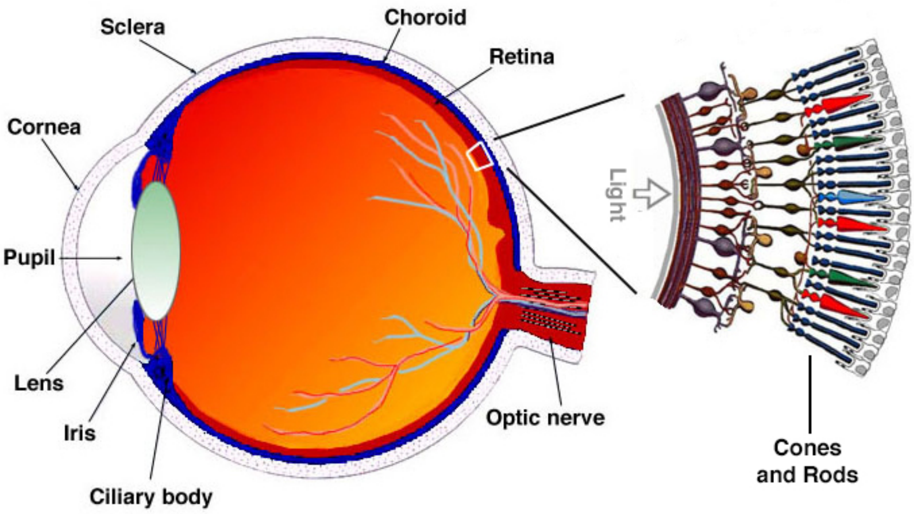


Figure 1.1: Human eye and its parts [3].

the eye, and it hits the retina. The retina triggers photoreceptors which convert light into nerve impulses (electrical signals).

There are two types of photoreceptors in the retina: rods and cones. Rods are responsible for the vision of movements, are stimulated mainly by twilight light, and respond to low levels of luminance. Cones, instead, are used to see colors and details, and respond to higher levels of luminance. They can in turn be differentiated into L (long), M (medium), and S (short). As a percentage, the human eye has an average of 60% L cones, 30% M cones and 10% S cones. Impulses generated by the photoreceptors are sent through the optic nerve and pathways to a specific part of the brain known as the visual cortex. Here is where the first stages of visual perception take place.

Due to the different response to luminance levels of the two cells, we can distinguish three types of vision:

- Scotopic: this is the type of vision that occurs when the level of illumination is very low and allows to detect differences in brightness but not differences in chromaticity (monochromatic vision due to the activity of the rods and the retina alone).

- Photopic: this is the type of vision that occurs when the level of illumination is considered “normal” (daylight) and allows to detect chromatic differences (vision due solely to the activity of the retinal cones).
- Mesopic: is the vision at intermediate levels of illumination.

The signals are then sent through the optic nerve. The nasal fibers of each eye decussate at the optic chiasm, continuing to the optic tract with the temporal fibers: right nasal fibers join the left temporal fibers (blue lines) and the left nasal fibers join the right temporal fibers (red lines). Neurons synapse at the lateral geniculate nucleus. Optic radiations connect the lateral geniculate nucleus to the primary visual cortex of the occipital lobe where visual information is processed. In Figure 1.2) a representation of the visual system and a diagram of the visual pathway can be seen.

Then, the brain sends increasingly filtered signals to many other parts of the brain where they integrate with other inputs (such as from hearing or memory) to enable a person to understand the surrounding environment and respond accordingly.

Visual functions

The visual system enables the visual functions which support a variety of activities and occupations. Following their descriptions as summarized in the World Health Organization’s report called “World report on vision” [5]:

- Visual acuity is the ability to see details clearly, regardless of the distance of the object. There are two types of visual acuity. First one is the distance visual acuity, important for many occupations and recreational activities and used in many everyday situations, such as reading a blackboard, bus numbers, or when

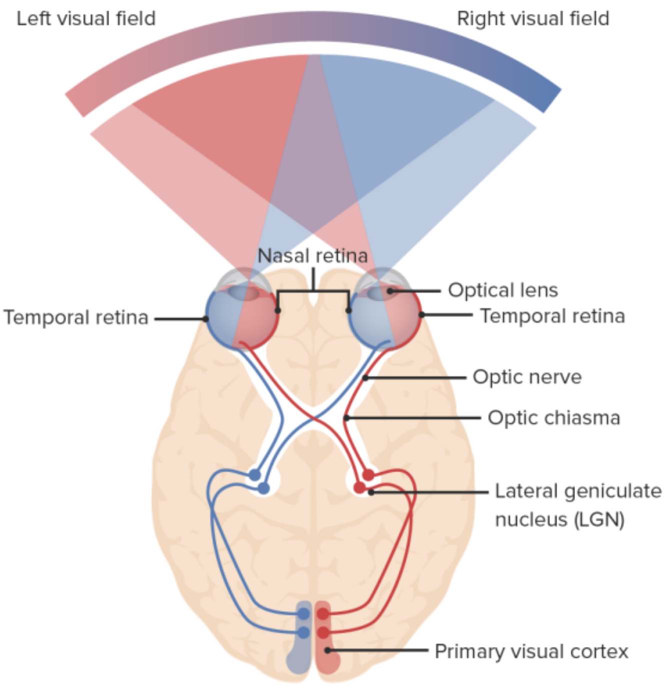


Figure 1.2: Visual system with diagram of the visual pathway and the visual fields [4].

recognizing people across a room. Second one is the near visual acuity, which is important for all near tasks, such as reading, writing, and using mobile phones and computers.

- Color vision has a very practical role, allowing differentiation of objects of a similar size and shape, and for occupations such as electrical work, aviation and fashion is very important.
- Stereopsis/binocular vision (depth perception) allows judgement of distances and the speed of approaching objects, and it is also important for many near tasks, such as threading a needle or pouring liquids into a glass.
- Contrast sensitivity refers to the ability to distinguish an object from its background, which may often involve distinguishing shades of grey and for this

reason is especially important in situations of low light, such as driving at night.

- Vision in the peripheral visual fields, as well as the central part of the visual field, assists in moving around safely, by detecting obstacles and movement in a person's side vision. It is important for safe driving and for many occupations and sports.

The brain part of the visual system is divided into two principal systems (Figure 1.3), the ventral stream, that brings about recognition, and the dorsal stream, that subconsciously appraises the entire scene and brings about visual guidance of movement [6]. Starting from the occipital lobes, responsible for the primary analysis of the image, the ventral stream runs to and through the temporal lobes until the inferior temporal cortex, where the image data of previous experiences are filed. Thanks to it, people can recognize what they see because the image match with the stored data. At the same time, if a certain image is not recognized, it is stored for future recognition. The dorsal stream, instead, runs between the occipital lobes and the posterior parietal lobes. This part of the brain functions subconsciously and immediately and appraise the whole visual scene to facilitate visual search and movement through three-dimensional space.

1.2 What visual impairment means

In a global society built on the ability to see, vision plays a critical role in every facet and stage of life. Towns and cities, economies, education systems, sports, media, and many other aspects of contemporary life are organized around sight. Vision is critical at every stage of life, from childhood to old age, passing through adolescence and adulthood, for various reason like to facilitate cognitive and social development and the growth of motor skills, coordination, and balance [7], to enable ready access to

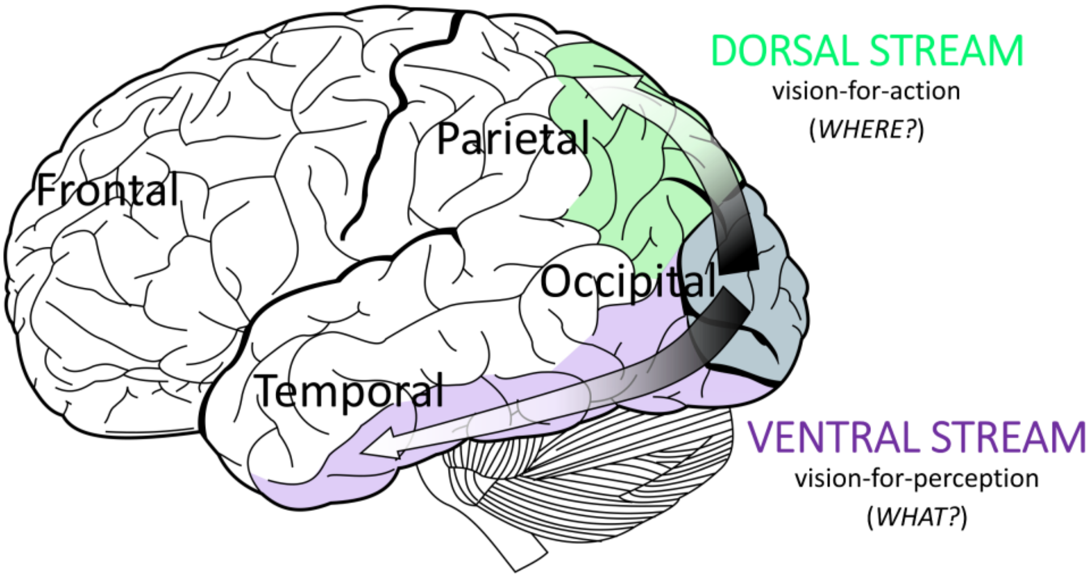


Figure 1.3: The dorsal stream (green) and ventral stream (purple).

educational materials [8] and growth of social skills like self-esteem and socialization, and to maintain social contact and independence [9].

Unfortunately, not everyone "sees" in the same way. Using the World Health Organization (WHO) International Classification of Impairment, Disabilities, and Handicaps (ICIDH) system, which, as the name suggests, is used for disorders, impairments, disabilities, and handicaps, we can start from some definitions. Impairment is defined as "any loss or abnormality in an anatomical structure or a physiological or psychological function", while a disability is "any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being" [10].

While visual perception is the ability to interpret environment through color vision and photopic, mesopic and scotopic visions (daytime, twilight and night visions, respectively) using light in the visible spectrum reflected by the objects, visual impairment, instead, is defined as a limitation of actions and functions of the eyes or visual system [11]. The term indicates a particular type of disability in which the deficit consists in any kind of vision loss, whether it is partial or total (in the second case often referred to as blindness).

Since a word definition is fixed by its usage, visual impairment has been so widely used that it cannot be restricted to a sharply defined impairment to vision [12]. Most popular definitions of visual impairment implies that someone's vision problems make it hard to do everyday activities and cannot be corrected by standard glasses, contact lenses, medication, or surgery, and affect their ability to perform certain everyday activities. Others, instead, argue that visual impairment occurs when an eye or a cerebral condition affects the visual system and one or more of its visual functions. So, also people who wears spectacles or contact lenses to compensate for their visual impairment, still has a visual impairment. Visual impairment can manifests as reduced visual acuity (objects are not seen as clearly as usual) or contrast sensitivity, visual field loss (loss of central vision or peripheral vision, eye cannot see as wide an area as usual without moving the eyes or turning the head), photophobia (light sensitivity), diplopia (double vision, see two images of the same thing), visual distortion (blurred vision or generalized haze), visual perceptual (brain's ability to make sense of what the eyes see) difficulties, or any combination of the above [11]. According to the World Health Organization (WHO), at least 2.2 billion people in the world have a visual impairment and at least half of them have a visual impairment that could have been prevented or has yet to be addressed. At the same time, population-based surveys used to measure visual impairment are typically based on visual acuity in the better eye of a person as presented in examination. The main problem is that if the examinee wears glasses or contact lenses, for example to compensate for visual impairment caused by a refractive error, visual acuity is measured with the person wearing them and they will be categorized as not having any visual impairment. For this reason, there is not a real global estimation of the total number of people with visual impairment [5].

1.2.1 Visual acuity test

Vision impairment is generally determined by measuring the best-corrected visual acuity of the better-seeing eye. To better understand the visual impairments classification, here is explained how a visual acuity test works and what those data means.

Visual acuity is usually measured using *Snellen eye charts* [13], developed by Dutch Ophthalmologist Dr. Hermann Snellen in 1862, which can measure how well the patient can see at a certain distance. As we can see in Figure 1.4), the chart is composed by a set or rows with letters. In the top of the chart there is a bold *E* which is followed by smaller letters on the further down rows.

There are other types of tests as well, like the *Monoyer* or *decimal scale* chart, developed by French Ophthalmologist Ferdinand Monoyer, which uses the same logic as the Snellen one, but is read in reverse (biggest letters in the lowest row). Another example is the *Tumbling E* chart, used for young children or people who don't know the alphabet, as it is structured like the Snellen, but only uses a bold capital letter E that rotates in all four directions. In this test, patients are instructed to tell the doctor where the three fingers of the *E* are pointing by using their own three fingers. The *Landolt C* test is very similar to the *Tumbling E* one but uses *C* instead of *E*. The *Jaeger* eye chart, instead, is a handheld chart used to test near vision. During the exam, the ophthalmologist place the chart 20 feet (or 6 meters) away from where the patient is sat. In case of doctor's office size issues, mirrors can be used to reflect the chart and simulate the 20 feet distance. Then, they ask to the patient to read the letters on a certain row of the chart and, based on the row that they can correctly read, the visual acuity evaluated. Results are then expressed as a fraction, with the patient's distance on top and the average person's distance on

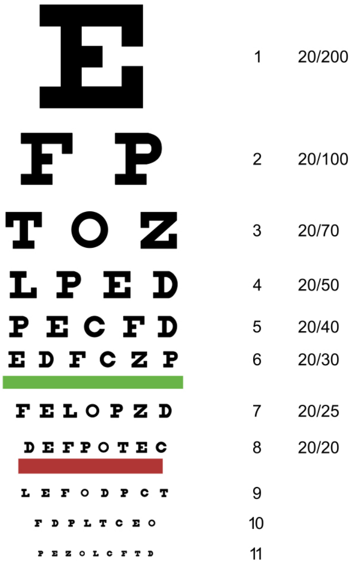


Figure 1.4: Snellen eye chart.

the bottom (e.g., 20/20 or 6/6). A common misconception is that the eyesight is perfect when the patient score 20/20 on an eye test. Instead, 20/20 (or 6/6) is a term to indicate "normal" visual acuity, i.e., the patient can read at 20 feet what most people should be able to read at that distance. For this reason, a person eyesight's test result should be 20/15 (6/4) vision, which means that they can read at 20 feet (6 meters) what the average person can only read when 15 feet (4 meters) away. In contrast, 20/40 (or 6/12) vision means that a patient who is 20 feet (6 meters) away from a standard eye chart can only read the same-sized letters that someone with 20/20 vision can read from further away (i.e., 40 feet or 12 meters away from the eye chart). In other words, 20/40 vision means the patient cannot see as well as someone with 20/20 vision.

1.2.2 Visual impairment classification

The International Classification of Diseases 11 classifies visual impairment into two main group: distance visual impairment and near presenting visual impairment [14]. Distance visual impairment is also divided into four sub-categories, based on the measure of the subject's visual acuity:

- Mild: visual acuity worse than 6/12 to 6/18.
- Moderate: visual acuity worse than 6/18 to 6/60.
- Severe: visual acuity worse than 6/60 to 3/60.
- Blindness: visual acuity worse than 3/60.

Near visual impairment, instead, is diagnosed only if the subjects near visual acuity is worse than N6 or M.08 at 40cm.

It must be pointed out that visual acuity only refers to the sharpness of images and doesn't consider depth perception, color vision, the ability to focus on moving objects or read under different lighting conditions. People with above-average distance vision may also have presbyopia (trouble seeing close objects clearly), which is a normal condition that occurs with age. Therefore, it's possible to have 20/20 vision whilst still requiring glasses for near work.

Also, if current definitions of visual impairment and blindness are used to classify the level of visual dysfunction based on visual acuity and visual field, they do not determine the overall quality of vision required for optimal functioning. There are a lot of other visual functions findings, like color vision, stereopsis, extraocular motility, contrast sensitivity, glare sensitivity and night vision, which are also important, as what a person "sees" begins with visual processing in the eyes, but then it continues along the anterior visual pathway, lateral geniculate nucleus, retrogeniculate visual pathways, primary visual cortex, and vision association areas [15]. For this reason, we can talk about visual function tests and functional vision. On the first case, a specific visual ability such as visual acuity, extent of the visual field, or contrast sensitivity is selected and its threshold are measured, while the second term refers to how people use their visual abilities to interpret visual information and react to them, for example by guiding their body movements [16].

Visual disability can be considered relative to a particular task and profession. The previously seen categorization of the visual impairment is used by institutions to determine inclusion or exclusion of a person for various important vision services (e.g., school-based educational plans, mobility or aid with activities related to daily living) and to determine eligibility for tasks such as driving and disability benefits.

With regard to this matter, the Italian legislation, following the law L. 138/2001 "Classificazione e quantificazione delle minorazioni visive e norme in materia di accertamenti oculistici" (i.e., Classification and quantification of visual impairments and rules on eye examinations) [17], divides people with visual impairment into mild, medium-severe and severe visually impaired, and blind, partial or total, depending on the size of the visual field and visual acuity.

More precisely, the articles state that:

- Art. 2: Total blind people are defined as those who are affected by total lack of vision in both eyes; those who have the mere perception of shadow and light or motion of the hand in both eyes or in the best eye; those whose binocular perimeter residue is less than 3 percent.
- Art. 3: Partial blind people are defined as those who have a visual residue not exceeding 1/20 in both eyes or in the best eye, even with possible correction; those whose binocular perimeter residue is less than 10 percent.
- Art. 4: People with severe visual impairment are defined as those who have a visual residue not exceeding 1/10 in both eyes or in the best eye, even with

possible correction; those whose binocular perimeter residue is less than 30 percent.

- Art. 5: People with medium-severe visual impairment are defined as those who have a visual residue not exceeding 2/10 in both eyes or in the best eye, even with possible correction; those whose binocular perimeter residue is less than 50 percent.

- Art. 6: People with slightly visual impairment are defined as those who have a visual residue not exceeding 3/10 in both eyes or in the best eye, even with possible correction; those whose binocular perimeter residue is less than 60 percent.

1.3 Congenital and acquired visual impairment

In addition to differentiation based on the amount of residual vision, the different types of visual impairment can refer to the causes of onset of the deficit.

We speak of congenital blindness or visual impairment when the individual has the lack or reduction of vision since birth, while we refer to acquired blindness or visual impairment if the deficit arose in childhood or later, caused by degenerative diseases, severe trauma to the anatomical components of the visual system, or other diseases such as diabetes. It is important to know the age of onset, especially for educational and rehabilitation purposes, because congenital visual impairment differs significantly from acquired visual impairment, especially in activities related to daily life, such as mobility and personal care.

Congenital visual impairments can be categorized on site of origin, with a distinction between cerebral visual impairments (damage to the posterior optic pathway and visual cortex) and peripheral visual impairments (damage to the eye globe, retina, or anterior optic nerve). Peripheral visual impairments can be further categorized as complicated (with known brain involvement in the pediatric diagnosis, e.g., cataracts in Down Syndrome), and simple (where there is no known brain involvement in the visual diagnosis) [18]. Therefore, another important distinction is between children with profound visual impairments (PVI: no vision or light perception at best) and severe visual impairments (SVI: significantly impoverished vision, but with the ability to detect form) [19].

An impairment of the visual system present at birth, or developing shortly thereafter, can affect the course of development, making it more difficult to reach certain milestones. Visually impaired children are often developmentally delayed in the areas of gross and fine motor skills and perception. The positive aspect of this situation is that the organism builds its own psychomotor strategies directly without sight, strengthening and specializing other functions and skills, which in the normal sighted person are not fully used. For the above reasons, in children with congenital visual impairment, the early intervention and constant monitoring of developmental levels achieved is very important due to the problems that the impairment can cause to other human systems. For example, in the psychomotor development of the child with congenital visual impairment, delays can be observed in the acquisition of some motor skills (postural transitions, conscious motor skills, crawling, standing, assisted and autonomous walking), and cognitive stages of orientation (object permanence, cognitive maps, recognition and reconstruction of places, mastery and use of topological concepts) [20].

On the other hand, onset of acquired visual impairment presents a more complex picture from a psychological perspective as like with any other adverse event, individuals are faced with a new problem or situation for which they are not prepared. Given the importance of sight in daily life, its loss or reduction is for the individual a reason for upheaval especially emotional and rejection. This initial response to the traumatic event may evolve in a positive way towards acceptance of the disability, or in a less desirable way towards depressive states, depending on the adaptive strategies that the individual will put in place. Visually impaired adults are concerned with securing and maintaining employment, productivity, and independence, as well as maintaining a home and fulfilling family and social obligations. Social connectedness and relationships are also highly valued and visual impairment can negatively impact relationships in the community, resulting in diminished bridging and linking capital. For these reasons, rehabilitation and psychological support are very important to improve people with visual impairment's social relationships with family, friends, and coworkers [21].

Regarding the specific case of acquired visual disability, it is important to distinguish between traumatic and degenerative onset of the deficit, as the psychological effects are very different. In the traumatic visual impairment case, the period of denial of the problem is longer, and the affected individual tends to attribute the event to a cause or a specific person, resulting in a desire for redemption and revenge. Moreover, in these cases there is a discouraged attitude towards rehabilitation and a post-traumatic stress syndrome may occur. Finally, the suddenness of the event does not allow the person to adapt their behavior in a way that is contingent on the onset of the problem. In the second case, a degenerative disease, there are other consequences, due above all to the diagnosis of the chronic nature of the illness, which, from that moment on, has a major impact on every choice the individual makes in terms of school, work, and family life.

1.4 Visual impairment causes

Functional limitations brought by visual impairment can result from congenital (e.g., prenatal, or postnatal trauma, genetic or developmental abnormalities), hereditary (e.g., retinitis pigmentosa or Stargardt's macular degeneration), or acquired conditions (e.g., ocular infection or disease, trauma, age-related changes, or systemic disease) [11].

Identified in several population-based studies, leading causes of visual impairment in the developed world [22] and a leading cause of blindness in the developing world [23] are uncorrected refractive errors. Myopia (near-sightedness) and hyperopia (far-sightedness) can generally be neutralized using spectacles, contact lenses, or refractive surgery, but vision may be lost when refractive error is corrected due to complications from refractive surgery or bacterial keratitis associated with contact lens wear. Furthermore, severe myopia may be associated with increased risk for several vision-threatening disorders, including retinal detachment, glaucoma, and cataract.

The last one is the leading age-related cause of blindness in the world [24]. Cataract is a clouding of the lens of the eye which causes light to be diffused as it enters the eye, impacting the clarity of the visual image. It usually develops quite slowly, so that people do not notice them until their vision is impacted with symptoms like blurred vision, glare or light sensitivity, poor night vision, and a need for increased light to read or perform close tasks. Cataract blindness is usually prevented by surgery, but cataract remain one of the leading causes for the visual impairment.

Glaucoma also heavily affects the count of people with visual impairments [25]. It is another age-related ill, defined as an irreversible optic neuropathy which results in unrelieved pressure inside the eye and fluid buildup causing loss of peripheral and, finally, central vision. As the vision loss occurs slowly, often people do not realize that is happening until the vision loss is quite advanced. The most common kind of glaucoma often has no apparent symptoms and no pain, but it can happen that individuals with these conditions experience increased frequency of headaches, blurred vision, and other symptoms.

Age-related macular degeneration (AMD) is another condition strongly associated with aging. Within the macula in the back of the eye is an area that contains the highest concentration of retinal cones, which produce the sharpest vision and are required to see details clearly. AMD results in damage to these cones, causing irreversible loss of central vision due to a growing dark spot seen directly in front of the eye. It can be of two types (dry or wet), but neither form causes complete blindness, leaving to the individual its peripheral vision. It is the leading cause of blindness among Europeans older than 65 years as it affects 15% of people in the ninth decade of life [26] and current laser treatments, also if they are effective in slowing progression of the condition, frequently sacrifice central vision or must be performed multiple times.

Visual impairment can also be caused by infections. For example, trachoma is a disease caused by an obligate intraocular bacteria called Chlamydia trachomatis which can lead to blindness. As trachoma infection is transmitted through contact with flies and direct contact with hands, clothes or whites and the bacterium develops where there is a lack of water, poor hygiene, and invasions of flies, trachoma is one of the leading causes of infectious visual loss in impoverished, dry areas of Southeast Asia, Middle East, Africa, and Australia [27]. Recurrent episodes of trachoma, also called chlamydial conjunctivitis, lead to a cascade of conjunctival scarring, trichiasis (in turned eyelashes, which can be treated with surgery, but it is not always successfully), infectious corneal ulcers, and corneal scarring.

Another infection is caused by the filarial nematode Onchocerca volvulus, which obtain nutrients from the human host by ingesting blood or by diffusion through their cuticle, causing on the host the so-called river blindness. This type of blindness is found principally in sub-Saharan Africa, with small foci in Central America, South America, and the Middle East. In hyperendemic areas, 50% of adults may be blind from the disease [27].

There are also nutritional and metabolic causes which bring to blindness. Night blindness, a condition making it difficult (or impossible) to see in relatively low light, for example, is the earliest sign of vitamin A deficiency and can be followed by conjunctival xerosis, Bitot spots, and irreversible melting of the cornea [28].

Another leading cause of visual impairment and blindness among adults younger than 40 years in the developed world is diabetic retinopathy, which affects more that 70% of individuals with type 1 diabetes mellitus [27]. The two main risk factors for developing retinopathy are the duration of diabetes [29] and the level of glycemic control [30], but, through screening for and treating the disease, it is possible to reduce the probability to develop bilateral blindness from proliferative retinopathy up to one in 100 cases [31].

Last important causes which can bring to visual impairment or blindness are problems in the brain (due to stroke, premature birth, or trauma) and ocular trauma. It is estimated that 500 000 blinding ocular injuries occur worldwide each year and that ocular trauma is a leading cause of monocular blindness [32]. Also acquired brain injury can bring to visual impairments. For example, on a group of patients with acquired brain injury, mean age 47 years, who were enrolled in the program, fifty-four percent of them reported visual changes, like reading difficulties, photosensitivity, blurred vision, and disorders of the visual field while another part, who did not experience visual [33]. Fields where most trauma happens are occupational injuries (mostly in the developing countries), sports (particularly when non powder firearms, like airguns, are included), and urban assaults.

In Figure 1.5 it is possible to see vision impairment caused by some of the causes described above.

Talking about congenital visual impairment instead, cerebral visual impairment (CVI) is one of the main causes of low vision of the visually impaired children.

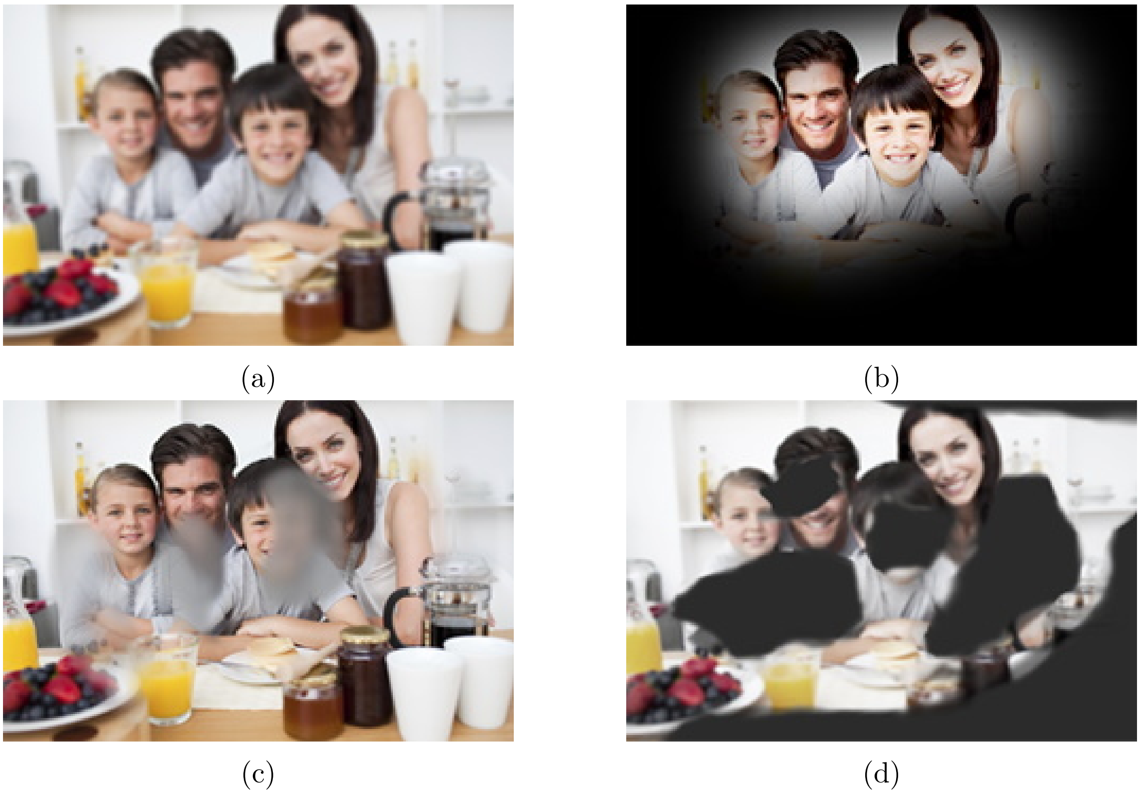

(a) (b) (c) (d)

Figure 1.5: The same image seen by a person with: (a) Cataract, (b) Glaucoma, (c) Macular Degeneration, (d) Diabetic Retinopathy.

It has been estimated that about three percent of primary school children has at least one cerebral visual impairment CVI-related vision problem [34]. In CVI, visual impairment is caused by a disorder in projection and/or interpretation of the visual input in the brain.

Brain function's disorders can be distinguished in relation to the time of occurrence of the pathological event in brain development, prenatal (before birth), perinatal (around birth) and postnatal (after birth). Such disorders may manifest as missing, incomplete, or delayed development of the functions affected. The term "early developmental disorder" subsumes all functional disorders that arise during the pre-, peri- and postnatal periods, while "brain injury" is used to subsume the wide range of conditions including cerebrovascular, hypoxic, and traumatic events that lead to disorder and/or dysfunction of cortical and subcortical structures of the visual system being affected [35].

Commonly, CVI definition includes all visual dysfunctions caused by damage to, or malfunctioning of, the retro chiasmatic pathways (i.e., the optic tracts located within the diencephalon, one of the four major components of the brain) in the absence of any major ocular disease. In a more practical way, CVI can be defined as an impairment of vision, but with normal function of the anterior visual pathways and of the ocular structures. Some of the main CVI's characteristics are impaired visual acuity (which can range from normal to blindness, in relation to the severity of the brain damage), visual field defects, and abnormal visual behavior, which consists of looking away from the target while reaching to it, looking past the target, staring into lights, and fluctuating visual performances [36]. Neuropsychological testing can be helpful to gain more insight in specific higher perceptual deficits in the individual but are only applicable to children with a developmental age above two years and nine months. In children with CVI cases, obvious ocular abnormalities has not been found.

Children with visual impairment

Different information from the environment is used by the body for orientation, movement, and regulation of behavior. The visual system of a sighted person is organized to give the highest priority to visual information. The reduction or absence of visual information therefore necessarily creates a change in the abilities and ways in which people orient themselves and move in space. The organism compensates for the lack of visual information by searching, more or less actively and consciously, for other information about space, which can enable them to orient and move.

2.1 Visual impairment and child development

Has seen in previous chapter, vision is defined as the ability of each person to organize and give meaning to sensory data collected by the visual system. It is an adaptive function as it is an ability used to perform or respond to daily activities. However, the term also includes several aspects with different onset and maturation times. For this reason, “visual function” is often used in the plural “visual functions”, referring to a set of basic and higher properties indispensable for a person’s normal daily life and closely interlinked for a global vision of reality and for guiding behavior. Some of the most important are ocular motility and accommodation, visual acuity, visual field, contrast sensitivity, stereopsis, color vision, visual attention, visuo-motor control, recognition of objects and forms, spatial and visual orientation recognition, motion perception, and numerosity judgements [37].

For the above reasons, the adult visual behavior is the result of a complex and long-term interplay of genetic and environmental influences. It starts before we born, in utero, and continues during postnatal life. At birth, for example, the visual cortex is already able to receive signals from the retina, but the visual pathways have just been developed.

Visual functions facilitate social initiative towards the surrounding world. For example, they allow adaptation, knowledge of the object, and they guide the execution of a proper action and the coding of other people actions. In this sense, vision is characterized by tonic functioning, which allows continuous monitoring of the external world and integrates the various perceptual experiences into a mental representation. They also help to organize and integrate incoming information from different senses, so without it, initial learning processes, such as those used to understand and move towards objects, can become complex and the opportunities of social learning can be very restricted and disorganized (see Figure 2.1).

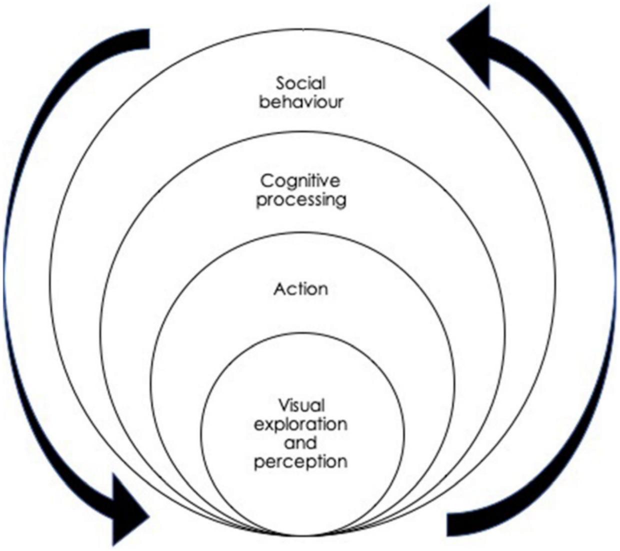


Figure 2.1: How human development is influenced by visual functions [37].

The most important moment when the development of visual functions is more stimulated by appropriate sensory experiences, called a “critical period”, is during the early stages of life, because the child’s brain plasticity (the ability to undergo functional and structural alterations in response to internal and external environmental changes) is at its highest level. It has been found that in the child’s life there are more than one critical period. They are associated with various brain functions and shorter and earlier for early sensory processing than that for higher complex functions or cognitive/executive functions [38]. In humans, for example, stereoacuity start to develop at 4-6 months, but is followed by a longer period of development that continues until school age. Visual acuity, instead, develops to adult levels during the first 5 years after birth. During these periods, on neuromotor, cognitive, and emotional development, the influence of visual functions has been found to be crucial, as they can drive the organization and maturation of human behavior. For example, during the learning of a new activity, the eye-movements first provide feedback on the motor performance, but as this is perfected, they provide feed-forward direction, seeking out the next object to be acted upon [39].

Some studies has been found that children with visual impairment, particularly those with a severe form, attain many developmental milestones at later ages than typically sighted peers [40, 41]. In addition, congenital or early-onset visual impairment may interfere with some functions and abilities like gross and fine motor functions, spatial concepts, cognitive abilities, attention and memory, communication skills and learning processes [20].

Most of the time, it seems that children with visual loss don’t have a lack of abilities, but that they follow a different developmental sequence, needing additional time, adequate circumstances, or additional experience for abilities to develop. Interestingly, there is evidence that they often employ different cognitive mechanisms than sighted subjects, suggesting that compensatory mechanisms can overcome the limitations of sight loss. This brings to the idea that the nature of perceptual input on which a person commonly rely strongly affects the organization of their mental processes. This idea is also supported by some brain imaging studies, which suggest that blindness and visual impairment lead to a reorganization of the visual cortices which are increasingly recruited to process information delivered by other sensorial channels [42].

The main problem is found on initial learning processes, such as those used to understand and move towards objects, which can become complex for them. They have difficulties understanding their positions within the physical environment in relation to objects, so also self-initiated mobility, posture, and locomotion can be delayed during early development. This can result in a lack of explorative-tactile function, which can put at risk the formation of mental images, bringing children with visual impairment to become socially withdrawn. This can turn in a limit of the connection they have between themselves and the outside world, leading to the development of autistic-like features.

For these reasons and due to the absence of visual feedback, children with visual impairment may manifest a lack of initiative. So, since visual experience may have a triggering function and may offer additional opportunities for a behavior to appear in children with normal sight, it is important to give to children with visual impairment more opportunities to demonstrate that they have acquired a certain ability.

2.1.1 Visual functions and motor development

Vision provides important feedback to the vestibular (a sensory component of the inner ear that provides the main contribution to the sense of balance and spatial orientation to coordinate movement with balance) and proprioceptive (ability to perceive and recognize the position of one's body in space and the state of contraction of one's muscles without the support of sight) systems. So, there is an important interlink between vision and motor abilities [43] and children with visual impairment can partially or completely lack a sensory experience that is essential for spatial development.

Differences on spontaneous motor patters has been found between children with visual impairment and children without it. The first subjects, for example, had “fidgety movements” widely disturbed in a specific way (exaggerated in amplitude and jerky in character), and their presence lasted longer than in sighted infants, whose movement pattern did not change in character also when they were in dark. Specialists hypothesized that exaggerated fidgety movements may indicate an effort to compensate for the lack of integration between vision and proprioceptive stimuli, that typically happens during earlier stages of life.

In another test, scientists focused on the development of manual abilities, measuring the kinematics of hand movement in infants comparing binocular condition to the condition with one eye covered [44]. The test results show that, in monocular viewing, infant’s capabilities to reach something was poorly controlled, suggesting as binocular information plays a critical role in controlling hand action into the space.

Moreover, the visual functions seem to have a crucial role also in the characteristics of walking. A study highlighted how developmental trend of independent walking in children with vision impairment, due to congenital disorders of the peripheral visual system, is analogue to the one of children with normal sight but has significant differences in the spatial gait parameters (slower walking speed, shorter stride length, prolonged duration of stance and of double support in the individuals with severe visual impairments) [45].

Another study found in young children with severe visual impairment presence of cognitive and communication difficulties, pointing out the risk of a developmental setback, often accompanied by impaired social communication, stereotypies, and behavioral disorders also if no additional disabilities at the first early neurologic evaluation were found. Probably, the presence of perception of form and motion appears to exert a protective effect on early cognitive and language development [46].

For these reasons, it is possible to think that visual-perceptual abilities guide the maturation and completion of motor control from the first periods of life and that visual impairment is often correlated to several neurodevelopment dysfunctions, probably for its key-role in early interaction with the reality. Without good visual information become difficult learn to detect, decode, process, and respond to the information coming from the surrounding environment.

Therefore, if not considered in a life-span perspective, a visual impairment during childhood can lead to cascading consequences on other functional areas and on the entire neurodevelopment, also affecting the person's future adaptive behavior and their quality of life. So, one of the best solutions is to proceed, through appropriate tools for infants and children, on an early identification of visual impairment, to evaluate the compensation's mechanisms and eventually make it possible to optimize early rehabilitation programs.

2.1.2 Diagnosis and rehabilitation

The paradigm of sensory deprivation brings to us most of the knowledge about visual system plasticity, but a recent series of experiments used environmental enrichment as a strategy to investigate the influence of sensory experience on brain development [47]. For example, it has been found that the brain development and the visual system maturation are affected by body massage. This suggests that the environment acts by modulating the level of endogenous factors which regulate brain growth and the development of visual cortex [48].

These discoveries show that the differences between visual disorders with onset at an early age and those acquired later in life are based on the high brain plasticity.

This permits the restoration of competences, but it can also be translated as an increased vulnerability during the first stages of the neurodevelopment. For these reasons early diagnosis and implementation of rehabilitation when the potential to employ the process of maturation, plasticity, and adaptation of the visual system is maximal become very important topics.

Neonatologists, pediatricians, traditional birth attendants, nurses, and ophthalmologists should be sensitive to a parent's complaints of poor vision in an infant and ensure adequate follow-up to determine the cause. The examinations can be done in the position children are most comfortable, like on their parents' shoulders, in their laps, or cribs, for fixating and following of the flashlight. The ophthalmologist should also have a quick look at the cornea, anterior chamber, lens, and pupillary reflex [49]. If required, evaluation under anesthesia should be performed, which includes fundoscopy, refraction, corneal diameter measurement, and measurement of intraocular pressure. Thanks to these examinations is possible to evaluate parameters as visual acuity or contrast sensitivity just hours after birth, confirming the results after these capabilities become more efficient in the first weeks of life.

It is important to note that is not easy to recognize if a child has visual impairment only by their acts. Behaviors exhibited by children with visual impairment may be hard to understand for sighted parents and clinicians alike, as they will serve a different function for them compared to the sighted children. For example, it is assumed that stereotyped behavior acts as a modulator to maintain an optimal state of arousal, increasing the level of stimulation or reducing tension [50].

There are also some clinical instruments used to assess visual functions in term and preterm newborns. One example is the *NAVEG* (*Neonatal Assessment Visual European Grid*) [51]. Using this tool, a detailed and complete analysis of child's visual functions is provided. The analysis is done through three main sections (ocular, motor, and perceptual visual components) and it was effective to discriminate healthy and pathological preterm infants in relationship to neurological/neuroimaging data. The discrimination was done with good results thanks to the analysis, which make it possible to highlight a profile specific for preterm infants, in particular those with brain lesions, different to the one for term infants.

These examinations and methods to evaluate visual function in the neonatal period, with particular attention to children at higher risk, are tools of maximum importance, as they may lead to early diagnosis to optimize early rehabilitation intervention programs to improve infants' visual, neuromotor and cognitive outcome.

Another important reason to monitor visual functions is to track the central nervous system maturation and is potential adaptive capacities after a brain damage, to help the discover and identification of functionally cerebral impairment in the children's early life [52]. The visual functions assessment is obviously important for rehabilitation purposes, helping professionals to formulate specific intervention programs and environmental adaptations to overcome the child's difficulties. At the same time, it plays a central role to understand if there are other neurodevelopmental disabilities, such as cerebral palsy, malformations, and syndromes associated with intellectual disability, as visual processing involves 80% of the central nervous system. In this sense, visual findings may serve as an indicator of neurological status of the subject and, therefore, the finding of a significant visual impairment can be a wake-up call for the possible presence of brain damage, and therefore a neurological disability.

Moreover, to lead to increasing diagnostic precision and better define appropriate selection of instruments for intervention and rehabilitation, it can be very helpful to review childhood neurological disease also from a neuro-ophthalmological point of view. Nonetheless, a very recent review insinuates that rehabilitation interventions for people with visual impairment are rarely adapted to children's visual capabilities and that very few studies have been conducted to assess their short-term and long-term efficacy [53]. At the same time, another study argues that "the lack of homogeneous results on rehabilitation techniques is due not only to the use of a variety of outcome measures (many of which were not specifically developed for children with visual impairment) but also to the implementation of rehabilitation programs that do not differentiate intervention activities based on the visual and developmental profile of children" [54].

For all the just seen considerations, it is easy to understand why there is so much interest in early intervention's strategies for children with visual impairment and why it is important to individuate a therapeutic approach taking into consideration the nature and the degree of the visual disability as well as the developmental profile and additional disabilities. A good way to find it is to base the model of intervention such that it could be:

- Multi-interdisciplinary, involving different professional figures.
- Multisensory, proposing activities that encourage children to integrate different perceptual information coming from the environment.
- Individualized, with activities based on the visual and developmental profile of the child.
- Multidimensional, relying re-habilitation goals on a parallel collaboration of professionals and caregivers in the different contexts of life.

The visual rehabilitation aims to minimize the adverse impact of visual disability, making children conscious of their vision in order to preserve and improve its use, facilitate the acquisition of new adaptive functions, and promote social flexibility. Is also very important that the children learn how to acquire through their other senses the knowledge that they are not able to acquire through sight. For this job, a central role is played by the sensory experience, which gives life to an approach where all the incoming sensory information are presented in a way that the child can understand and respond to it, often touching together sound and sight. The goal is to ensure that the coupled incoming information has meaning and promotes understanding of the different incoming multisensory data.

This approach aims to improve cognitive processes, to produce motor actions that progressively become more accurate, goal orientated, and meaningful. For example, a study has identified a milestone called "reach and touch on sound" as a critical developmental phase in children with visual impairment [55]. This milestone consists in the ability to reach out for and grasp an object that has been presented exclusively through the medium of sound. It seems to help the progressive cognitive development on children with visual impairment and to enhance their organization of motor experience to achieve, in the end, locomotion, becoming for this reason a necessary step for all their subsequent cognitive and motor achievements.

Another way to increase the perceptions of stimulus coming from the outside is the growth in an "enriched environment". These environments seem to influence development of visual system in animal models [47], "reactivating" the plasticity of the central nervous system changing the start and end of the critical periods for visual functions development [56]. So, it is very important to provide to the child with visual impairment this kind of environmental contexts, meaningful and enriched, which are intended to encourage the development of skills that can be used for interaction with the world.

To summarize the concepts, a fundamental part of the educational and rehabilitative action is to concretely help a child with visual impairment to be able to orient himself, to recognize places and objects, and to know how to use them. The search for the greatest possible autonomy must always be considered one of the first objectives to be pursued; it is a path to be followed in small steps, in relation to the person's abilities and dispositions. So, it is very important to use the environmental enrichment as a strategy to pursue this goal, organizing a perceptively accessible environment, equipped with environmental facilitators.

2.2 Perceptually accessible environments

Analyzing the characteristics of the orientation process of a person with visual impairment and their needs for environmental enjoyment, is the first step to be able to recognize and enhance the existing clues and to design effective environmental facilitators. It is necessary to start from the consideration that in any case information can be continuously drawn from the environment through all sensory modalities.

It is therefore possible to disseminate the environment of elements capable of providing appropriate information, even not belonging to the visual channel, in order to allow people with visual impairments to carry out equally and effectively their process of orientation.

Now are described some environmental characteristics that can be used to evaluate and improve the spaces used by people with visual impairments, from everyday living spaces to school and/or work environments, but also rooms used for educational and rehabilitation activities.

Acoustic characteristics of the space are very important. The visually impaired person uses ambient acoustic information for orientation and walking, and even when performing tasks that do not involve movement, concentration may be affected by background noise. It is difficult to concentrate in places with very high background noise, so it should be limited as much as possible. If this cannot be reduced, the room should be equipped with sound-absorbing material, i.e., material that helps to limit the spread of sound.

To facilitate orientation, the room shape should be regular and with 90° angles because a 90° rotation is more perceptible than any other and it is easier for a person to understand its own orientation with respect to the environment after having made it. In fact, it is difficult to consciously make different rotations without visual reference points. The regular shape also determines a greater memorability of the environment, an element that must always be kept in mind, also in the dislocation of the various pieces of furniture and furnishings, and in their number.

As each element that can be touched works as a reference point, the reachability characteristics of the place are very important. It is not recommended to place potentially significant elements at heights and in positions that make them not easily approachable. This is both because reachability allows the child an easy tactile exploration, and because in presence of low vision, a greater visual usability is determined by the possibility of getting very close to individual objects in order to be able to look at them closely.

In addition to increasing memorability, reducing the number of objects in the room can be a facilitating factor in the creation of mental maps. Their orderly and schematic dislocation also leads to easier visual perception.

The environment should also be characterized by the so called “visual comfort”, with a good chromatic contrast and luminance (the amount of light that is emitted from a surface in a certain direction, in relation to its extension), both for the various architectural and furnishing elements and for the objects that compose it, but above all for the elements that are significant for orientation, such as handles, switches, doors, any edges or obstacles, etc.

Motifs and backgrounds that have no functional value, do not relate to real objects, or can create visual disturbances, such as carpets, upholstery or wallpaper containing patterns or background images, should be eliminated. At the same time, also glossy or mirrored surfaces should be used as little as possible to avoid reflection and glare.

Lighting should be customizable, giving the possibility to vary their intensity to compensate for glare or poor light accommodation. Small lights should also be available to illuminate individual objects as required, taking care that direct light never falls on the child's face. Care should also be taken to ensure that natural or artificial light sources are not positioned in such a way as to cast shadows on points and objects to be observed by the child.

It is also very important to follow some measures to avoid sources of danger. Protruding materials with pronounced edges should be avoided at all costs, especially those that do not touch the ground. As they cannot be adequately intercepted, children can hit them (getting hurt) without having the possibility of noticing their presence beforehand with their limbs or stick.

Talking about stairs, handrails starting after the first step or ending before the last step should be avoided. From a visual point of view, they should be lit in such a way that, from below, the tread and riser have a marked difference in light and shade. When viewed from above, stairs should have step markings in a color that contrasts strongly with the color of the tread. A tactile sign should be placed on the floor before the edge of the first step.

Another small measure which can help children who cannot write, is the presence of specific reference points. Small symbols can be used to mark handles, doors, drawers, or any other element that must be distinguished from others. For adults, these could be useful places to put braille writing.

2.3 Routes in visual impairment

Which is the right attitude to enable the best relationship between the child and the environment is one of the most asked questions by people dealing with children with visual impairment.

There is not a totally right answer, but it is necessary to find a balance between the desire to stimulate the child and the fear of forcing them too much. On one hand it may seem correct to increase the amount of information coming from outside, filling the child's experience with many stimuli, so they can compensate, in some way, for their own shortcomings. On the other hand, however, is important to reflect on the fact that filling the person with stimuli, or worse, forcing him to absorb them, would probably lead to the opposite effect to that intended.

It therefore seems appropriate to offer the child various significant experiences, but never to make them a passive recipient of experiences. The difficult but indispensable criterion to follow is to make the child actively seek out and participant in the reality around them. It is necessary to understand that presenting an object or an environment to a child with visual impairment means first of all letting him or her know that it exists, providing them enough time to touch it comfortably. It sounds trivial, but sometimes people with visual impairments do not take notice of some things because they do not know they exist or that they are there. So, there is no point in waiting for them to be interested in, or to go towards, something when we are not even sure if they know that the object exists and is in that particular place.

For this reason, it is not possible to expect spontaneous interest in the surrounding space if the child has never been taught the existence of a certain reality. The child with visual impairment must be able to think about space in order to relate to it, as they use external perceptual information, catalogued in memories and spatial maps. To achieve this goal, the educational attitudes to be implemented in activities range from guided exploration to semi-structured exploration, to completely free exploration.

Throughout this scenario, the adult assumes the role of a mediator, who presents reality and objects, paying particular attention to those that are not directly perceptible to the child and encouraging their curiosity and knowledge. From the moment the child encounters the object, the adult should not compensate in any way for the visual deficit, because the child can perceive independently in another way.

The amount of words used by the adult during solitary exploration should be reduced to an absolute minimum, to the point of ceasing altogether in some situations. However, when the child, during an exploration, intentionally calls our attention because he is surprised, frightened, confused, uncertain or nervous, it is useful to intervene. First of all, it is useful to communicate safety and not alarm to calm the child (also with physical contact if necessary), then help them to resume exploration, or helping them towards the solution of the problem they were facing, picking up where they left off.

The adult must also respect the child's observation and manipulation time, without ever forcing them and always keeping their reactions under control. Waiting is one of the fundamental words in the helping relationship with a visually impaired person: it is very difficult sometimes not to intervene when a child seems uncertain, but, paradoxically, waiting can be very useful on some occasions. An example are the moments when the child is listening, is organizing themself, is exploring, which are all circumstances where they have a great need to not interrupt the process of knowledge, which may take longer than usual. If in those moments, when the child does not feel the need, the adult talks or intrudes, they will distract the child from his process of knowledge, reasoning and exploration.

It is very important to explain all these facts also to the child with visual impairment's parents. The cultural, social, and political changes of recent decades are threatening certain parental functions. In today's society haste prevails and parents are less able to tolerate the pace of growth and accept the gradual detachment of the child. Feelings such as apprehension, overprotection and insecurity prevail. Having a child with a disability further complicates an already delicate and complex process.

In addition to the aspects that can be found in all situations in which a child with a disability is born, there are other aspects that are specific to visual impairment. For parents of children with congenitally blindness, in particular, there is the difficulty of understanding the weak signals of their child, who is often amimic and not very expressive, and of empathizing with them in the absence of eye contact.

If parents do not receive glances, visual feedback, responses to his signals, they are much more likely to develop dysfunctional interactive modes, such as trying at all costs to fill the relational and communicative void through a continuous addition of stimulation or continuous verbal, sound, light, etc. reminders. The lack of eye contact, and all the affective communication it entails, limits reciprocal interaction and seems to generate haste and urgency to fill the gaps, silences and absences in the parents. It is an urgency to get in touch in some way with the child, to alleviate a painful perception of incompetence in one's parental role.

For this reason, it becomes fundamental, as soon as possible, to support parents in compensating for the lack of eye contact to be in tune with their child and to be able to understand and give meaning to his or her faint signals. As Fraiberg states, every child with a visual impairment will necessarily have a mother who felt rejected because her child's eyes did not return her gaze [57].

Being willing to get help is often not enough. In the beginning, the sense of loneliness can be very strong, and the prevailing feeling is not knowing who to ask for advice. It is therefore essential for parents to find out about local associations, specialized centers to contact, or parent groups with similar experiences.

The Robert Hollman Foundation is one of these, which through its courses seeks to pursue objectives such as helping the child during critical periods or filling the need for parents to become interpreters of the experience of the visually impaired child, opening new possibilities for exchange.

2.4 Robert Hollman's Foundation

The Robert Hollman Foundation, a private non-profit organization whose logo is in Figure 2.2, was set up in 1972 by the Dutch entrepreneur Robert Hollman. In 1979, the Foundation set up a pilot diagnostic and educational center in Cannero Riviera for the medical and social rehabilitation of children with visual impairment and multiple disabilities [58].

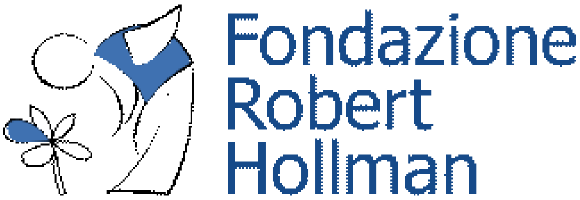


Figure 2.2: Robert Hollman Foundation's logo.

In May 1987, the Robert Hollman Foundation opened a new center in the city of Padua, which was initially considered a special section of the L. Configliachi Institute. Since 1994, the Foundation has decided to run it directly, targeting children with visual impairments and/or multiple disabilities from birth to fourteen years of age.

The Foundation provides advice and support for the development of children with severe visual impairment, with or without additional disabilities, and their families. It therefore accompanies parents and children through the various stages of growth, from birth to the end of compulsory schooling [59].

The team consists of an ophthalmologist, child neuropsychiatrist, physiatrist, psychologist, educator, pedagogue, orthoptist, visual rehabilitation therapist, physiotherapist, neuropsychomotorist, speech therapist and music therapist. All these figures together implement projects that can respond to the different dimensions of the child's experience, with multidisciplinary work. Every room in the foundation buildings, from the therapy rooms to the bathrooms, is child-friendly and designed to follow the principles of perceptually accessible environments in order to put the young patients at ease [60].

For the Foundation, every child is unique, and requires to be followed in their growth, step by step, with an intervention tailored to their potential, acting both on the preventive side and on the therapeutic/rehabilitative side. For this reason, the approach is as early as possible, also to support the parents accompanying them in the delicate and complex process of their child's growth [61].

In the Padua office, from the moment a child is referred to them, they begin a personalized analysis aimed at understanding the needs of the child and their family. Then the Foundation proposes an initial medical and functional assessment. Limits and potentialities are evaluated in order to create individualized network programs. The evaluation team is a multidisciplinary team consisting of a psychologist, an educator, a therapist (whose professional profile may be physiotherapist or developmental neuro and psychomotricity therapist) and an orthoptist. The team is also advised by ophthalmologists and child neuropsychiatrists (as external consultants). There are different types of counselling which are chosen according to the age of the child, the pathology, and the availability of the family. For example, there are counselling sessions lasting three consecutive days, early attention courses lasting one meeting per week for seven consecutive weeks, or counselling sessions lasting four meetings, also not consecutive. For the project to be effective, it is essential to integrate it with any other parties involved with the child in the various areas (school, local services, hospital, specialists, etc.).

The approach is also considered global, because the aim is not limited to treating the lacking part, but to "taking care" of the child in a global manner [62].

Speaking about educators, they are the ones who take care of the child as a whole, becoming the support that allows them to trust and rely on the people and experiences they will have both inside and outside the Foundation. They not only take care of playtime, but above all has the task of listening, accepting what the child expresses about him or herself, through words and behavior, but also through his or her own suffering and difficulties. They become those who can “give a name to things and people” and mediate the encounter with the environment.

With this in mind, activities are always carried out in structured spaces limited to the child’s range of action, with materials chosen for their shape, consistency, noise and use, which are available to the child, always in the same position. The routine and sequencing of the different activities in structured times and spaces allows the child to achieve the serenity and tranquility to tackle the activities, enabling them to anticipate what is going to do and to experience the feeling of possible predictability.

Music therapists are another important figure inside the Foundation, as sound for children with visual impairment is very important. Vibrations, even just speech, can trigger surprising reactions in them. Within the therapeutic environment, music therapy complements the care activities themselves, to help the patient find in the music therapist a person who can give an image of himself. Often, in this context, music therapy cannot directly reach therapeutic areas, but it contributes to them within the global care of the patient. The vehicle of musical communication is extremely appropriate and accessible to people with visual impairments, especially children. Both therapeutic and educational activities centered on music are therefore particularly accessible to people with a visual impairment. In the absence of gaze reciprocity, sound dialogue (both through voice and musical instruments) can be used as a possibility of encounter and mirroring.

Foundation’s covered areas

The Foundation’s proposals can cover different areas according to the specific needs of each child.

The psychological area provides support to parents through individual interviews and group experiences in the various stages of the child's growth, prognostic consultation, and psychotherapy for the treatment of psychological problems caused by developmental arrests or delays resulting from visual impairment.

The rehabilitation area offers visual, neurovisual, visuomotor, motor, psychomotor and speech therapy. Speech therapy aims to promote both verbal production and alternative modes of communication. In addition, feeding functions such as chewing, and swallowing are monitored. The center's speech therapist also looks after children with delays in learning to read and write due to a neuropsychological disorder.

Individual physiotherapy, instead, try to emerge the motor potential. It promotes neuromotor development and the acquisition of new skills, to support the child in achieving functional movement strategies. Depending on the needs of each child, this pathway may include: neuromotor rehabilitation, observation, monitoring and treatment of postural compensations related to visual impairment, sharing, and verifying the rehabilitation project with the physiatrist and, if necessary, prescribing mobility and posture aids, support for the learning of orientation and mobility prerequisites.

The educational-didactic area proposes an individualized or small group educational intervention, which uses the operator-child relationship as a working tool. The main areas of intervention in this area are play (which is often poor in children with severe visual impairments), multisensory integration (proposes helping the child, in a pleasant context, to get to know the environment and interact with it), acquisition of personal autonomy, and learning the prerequisites of Braille reading and writing.

In addition to these activities, over time has been developed both individual and group recreational-expressive proposals, aimed at promoting the child's psychophysical wellbeing, as well as, for older children, encouraging the birth of passions and the expression of talents (dance, sculpture, cooking, music). The group dimension of these proposals makes it possible to live relational experiences of meeting, sharing, and mutual help, of comparison between companions who have a visual problem in common. For very young children, these proposals are translated into contexts designed for mother-child or mother-dad-child activities, possibly together with other families.

The activities proposed are defined as experiences and not exercises, as they presuppose an evolution not only of motor skills, but also of psychological, emotional, and relational aspects. In children with visual impairment, these experiences also encourage awareness of their bodies, their boundaries, and their parts in relation to others, perception of space using the other senses, and experimentation with various movements and postures to facilitate motor skills. An example of group activities with a playful-expressive purpose are the Sherborne games, which are activities that foster children's potential by experimenting with their own movement, while at the same time establishing interpersonal relationships that are meaningful to them.

Play is the main tool through which it is possible to create a therapeutic relationship with the child, allowing them to express themselves, learn new cognitive, social, and sensory-motor skills, and become aware of their own potential. Furthermore, by playing, children gradually improve and mature their proprioception, their body awareness, and their spatial orientation. To promote fun, motivation, and a proactive motor and social initiative, and to support and favor the emergence of new competencies, the creation of facilitating environments and proposals is fundamental.

2.5 Digital games and visual impairment

Talking about people with visual impairment or blindness, assistive technologies for them are showing a fast growth, providing useful tools to support daily activities and to improve social inclusion.

Most of these technologies are mainly focused on helping people with severe visual impairment to navigate and avoid obstacles or on providing them assistance to recognize their surrounding objects. One example is a prototype showed in a study which offers the capabilities to move autonomously and recognize multiple objects in public indoor environments, only using a reasonably-sized integrated device, placed on the chest, that incorporates lightweight hardware component like camera, IMU, and laser sensors and making the interaction between the user and the system possible through speech recognition and synthesis modules [63].

Another example is the *Canetroller*, a haptic cane controller that simulates white cane interactions. Providing physical resistance that physically impeding the controller when the virtual cane comes in contact with a virtual object, vibrotactile feedback that simulates the vibrations when a cane hits an object or touches and drags across various surfaces, and spatial 3D auditory feedback simulating the sound of real-world cane interactions, it enables people with visual impairments to navigate a virtual reality environment by transferring their cane skills into the virtual world [64].

Unfortunately, as can also be seen from the examples, most of these technologies are designed for adults with already developed cognitive and spatial motor skills. Therefore, the need is to create something for young children, which allows them to develop certain skills and helps educators in their task.

A relatively recent technology used for learning and rehabilitation in a playful environment is digital games. Despite the growth of the video game industry in the last period, audio development in games often does not receive the same attention as visual design, leading to insufficient sound feedback to indicate all essential information for understanding a scenario, orientation in an environment or navigation in a game menu. Moreover, even if supported by assistive technologies, players with visual impairments experience a general incompatibility of screen readers with games, as the latter do not always fully support them.

There are, however, some text adventure games that allow screen readers to narrate in a way that the player can understand, or some “audio games” that consist only of audio without any graphics. Unfortunately, most of them are quite simple compared to electronic games in the mainstream gaming market and are not found with the same variety.

There are also some Listen and Play (LEAP) games that help children with visual impairment to become familiar with computers, allowing them to learn new skills while having fun, such as the project developed by the Greek non-profit organization *SciFY*. They maintain the website *Games For The Blind* [65] from which games can be freely downloaded for Windows, Mac OS X and Linux operating systems. The organization also maintains the *Memor-i Studio project* [66], a database of video games consisting of audio files, black and white, and color images to give the possibility to play to people who are sighted, with visual impairment or with blindness. As well as allowing all games to be downloaded free of charge, the platform also allows you to clone an existing game to enrich it with additional images and sounds, or to create new games even without programming or computer skills. Their first game called Tic Tac Toe teaches children to use basic computer keys and to move in a two-dimensional sound space; in the game called Tennis, children perceive the movement and speed of sound across three dimensions and interact in it using binaural processing.

Like the last ones just described, there are many others digital games developed with other objectives than just entertainment, so that a category called “serious games” has been created.

2.6 Serious games

As the success and proliferation of video games grows, it can be noticed the arising of new audiences who weren't into most of the traditional videogames. An example is the Wii system from Nintendo, which gained a lot of popularity as it stimulated the desire to play it even in categories of people other than the most "hardcore" players, like family's components or older people.

For this reason, videogames have the potential to be more than just entertainment, just like books, movies and television. They can become more relevant, more responsible, and more important or, in other words, to get serious. Consequently, the incorporation of both pedagogical and entertaining elements will become the target of the research community and the game industry, which will move towards the development of more elaborated games.

The term serious games refer to entertaining, enjoying and fun games or applications which are developed with a main purpose that is not pure entertainment, but to engage users into an activity, that can develop skills or teach something valuable to the player. Although the entertainment component, which uses the story, art and software elements of the game, is the first one to arise, their pedagogic component is the one that makes them serious.

The idea is to use games to hide some exercises to develop particular skills of the user: in this way the user has fun, but at the same time does something useful. The serious goals of the game will be achieved because the user will continue to play the game many times since they enjoy doing it. There are a lot of different applications of serious games [67]. They have been applied in many diverse areas like corporate and military training, health, education, cultural training, and rehabilitation.

In the military field, using virtual environments, serious games are used to train soldiers, enabling them to make decisions faster and safer to situations and obstacles that may populate the real world [68]. In the educational field to increase learning abilities of children as well as to train employees, using the principle of the edutainment (education through entertainment). Serious games are can also be used in the health field, either for doctors, e.g., for their training or to simulate real-life experiences [69], and for patients, e.g., to hide rehabilitative exercises under a game, helping them to achieve goals without lack of patient interest in performing repetitive tasks, ensuring in this way that they finish the treatment program [70, 71].

Other approaches demonstrate the value of using serious games with children, for example to hide a visual acuity test under a much more interesting game. Thanks to the game, the children pay much more attention to the exercise, and so to the answer for the doctor, with the result that the diagnosis will be more accurate [72].

2.6.1 Serious games for rehabilitation

Serious games are also used to help people with various kinds of disabilities, as they serve to train and monitor many aspects of the person, such as coordination, memory development, communication skills, and socialization.

It is easy to see that serious games are extremely beneficial to children since, being attracting for the small players, they allow accurately assessing of an illness and to provide rehabilitation and telerehabilitation programs that can last a long time without making patients to lose interest in exercises [73].

One of the major problems in therapy sessions, caused by the repetitive nature of exercises, is the loss of interest and motivation and it has been showed that games in general contribute to increase motivation in rehabilitation sessions. Offering a tiered mechanism, where levels are adapted to players skills, but of increasingly difficult to give them the sense of challenge in their progress, and requiring cognitive and motor activity, computer games can engage children's attention. So, it can be imagined that they can offer valuable contributions about how to develop more effective games for rehabilitation programs.

Even though they are considered an effective intervention in rehabilitation, to make the therapy work at its best, serious games must comply with adaptability and configurability criteria to adapt to the patient skills. For this reason, is important that designers must include the possibility of customizing the game based on the different needs of the patients [74].

The accessibility of the game, obviously, is another topic to be considered. In the particular case of people with visual impairment involved, designers will come up against the fact that the typical component of videogames, the visual component, must be replaced or complemented by sound and tactile ones.

The game feedback is very important to the user with visual impairment, so games must be designed thinking about three challenges: difficulty in using the interaction devices, difficulty in receiving feedback and difficulty in identifying the set of answers [75]. Main feedbacks used by some accessible games are Text-to-speech (to read interface elements), audio metaphor (intuitive audio feedbacks that helps to perceive environment-specific sounds and game events like opening a door or success/failure result of a game action) in association with 3D audio (spatial audio reproduction technique to identify the position of sound sources, to locate game elements, and to serve as orientation in the scenario), and tactile feedback to provide responses when the user interacts with interface elements (e.g., vibration when the screen is touched) and/or some game elements (e.g., vibration when the character bump into an obstacle).

Talking about serious games for people with visual impairments, there are some examples of games which uses these components trying to achieve different aims.

HelpMe! [76], for example, is a serious game with the objective to improve the rehabilitation process for children with cerebral visual impairment, using a system which can adapt the exercises to each particular child and to their improvements. The system also integrates an eye tracker system to record the child's eyes movement during the rehabilitation program to correctly measure the performances of the child and their capability to watch and touch a moving object at the same time. This helps the doctor to understand if the training process has a positive result, providing them a precise way to measure the performance of the children during all the rehabilitation programs.

Virtual stage! [77] is a musical game which uses the audio modality as main component. It stages a virtual musical band with different instruments and the player moves an avatar around the virtual stage searching for a specific instrument. To help the player to understand where the instruments are in the virtual space and guide them during interaction with the tablet, it has been developed using binaural audio techniques (three-dimensional sounds) for the instrument's sounds.

Two other applications designed around the gameplay idea of using primarily auditory cues are *Blindside* and *NightJar* [78]. First one is a role-playing horror-adventure game which make and extensive use of 3D audio for the gameplay, that consists of the navigation (using keys and mouse on PC or touch interface on tablet and smartphones) around the city of the player to a safety point by relying only on audio cues. Although Blindside is designed for entertainment purposes, it advertises itself as a serious game with strong emphasis on accessibility, with a focus for the visually impaired community. Second one is also a role-playing mobile game, but in this case, players only use spatial references given by audio feedback to navigate within a spacecraft called Night jar simulating the effects of blindness. Even for this game a very simple UI is available for the players, that respond to the game and control the avatar's by tapping on the screen's buttons. This game does not promote itself as a serious game but delivers subliminal messages that are found in edutainment. Unfortunately, to the drafting of this document, both are not available for the download anymore.

Another game similar to the previous ones and designed specifically (and fully accessible) for people with visual impairment is *A Bling Legend* [79]. It is a mobile action-adventure game which only uses 3D sounds, without any video, to guide the player inside the story's chapters. Even for this game, the smartphone's screen or keyboard are used to move the character, fight, and interact with the menu. This helps hearing stimulation and hear-hand coordination.

Eda Play [79] is a collection of applications for tablet devices designed under supervision of experts in the field of vision stimulation and early intervention for children with special needs. They are tailor-made for children with visual impairment and multiple disorders, to help them to train their vision and fine motor skills thanks to illustrations in comprehensible shapes, bold colored large size pictures with high contrast between them and the background, and tasks ranging from simple watching the action and simple touching on a screen to eye hand coordination.

BlindPAD [80] is based on a different approach as it mainly uses a tactile modality as the main mechanism of interaction between player and game. In this game a tactile pin-matrix display made of hundreds "taxels" (i.e., tactile equivalent of pixels), like the one in Figure 2.3, is used to interface the player with a set of games based on maps and geometric shapes perceived through their fingers.

During the TiM project [81], a project with the overall aim to provide young children with visual impairment multimedia computer games they can access independently (without the assistance of a sighted person), other tactile games has been developed. One was an accessible version of *Reader rabbit's Toddler*, an educational video game where player only have to roll mouse over hotspots to interact with the game. Instead of using the mouse, the children can feel tactile buttons on a tactile board and drive the game from that [82]. Another one was *FindIt* [82], a very simple audio/tactile discover and matching game for very young children or children

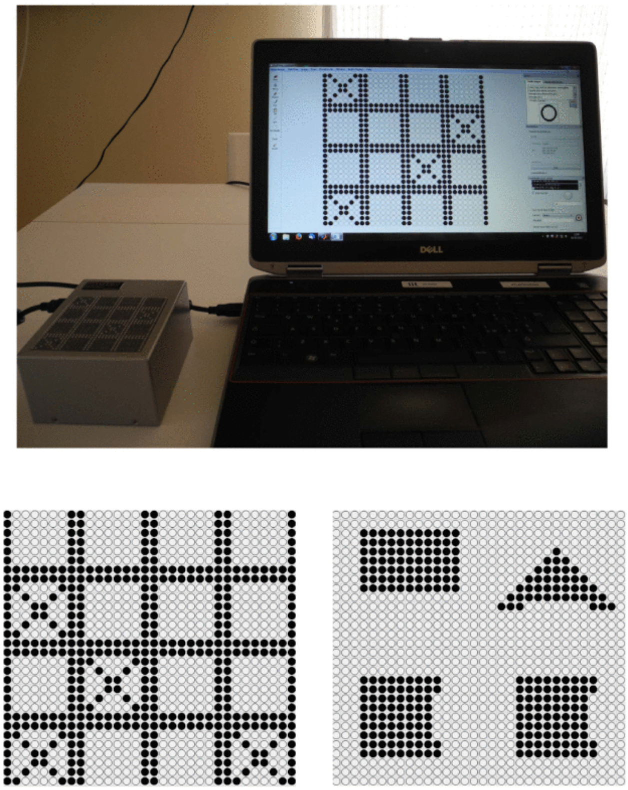


Figure 2.3: An example of how a pin-matrix display called Hyperbraille is used for the BlindPAD game [80].

with additional disabilities, where the player must connect sounds or audio clues associated to items with images on the screen or tactile information on a tactile board.

Even though good potential to address the specific needs of children with visual impairment is shown by all these games, they do not involve any aspects related to full-body movement. As shown by some pilot experiments [83, 84, 85], a full-body approach with people with visual impairment can be highly effective.

Mini games for children with visual impairment: the See-Sound project

Learning simple and complex concepts in a playful way have risen the number of applications based on large-scale responsive environment, where the player uses all their body to interact with the game. These environments are characterized by a full-body interaction that supports different learning styles and, due to their richness in emotional engagement and ease of use, particularly fit for inclusion of participants with disabilities.

3.1 Large-scale responsive environments games

The term large-scale responsive environments refers to open spaces where the presence, motion and gestures of the users can be tracked using a computer system equipped with one or more motion sensors and/or cameras and computer vision algorithms. Using the incoming data from the input visual devices, algorithms produce the coordinates of the user's position inside the field or a mathematical description of how their limbs are moving [86]. These processed data can be used to interact with the game, providing audio and graphical output coherent with the user's actions. For this reason, large-scale responsive environments games can employ full-body interaction in different ways, depending on game typology and aims, building a strong relationship between the user's position/movements and the surrounding environment. These systems are used to pursue different objectives (like pure gaming, entertainment, music production, learning, and therapy) and often with children, as they can be very surprising and engaging for this kind of public. Thanks to [84], different game typologies has been identified, as also shown in Table 3.1, basing the differentiation criteria on the application's aim.

Game Typology	**Category**	**Aim**
Experiential games	Sensory	Through an unexpected environmental reaction (images or sounds) an emotional response is solicited
	Traditional	Play a game known to learn how to interact with the environment
	Information Display	Communicate content to others and enhance social interaction
Learning games	Memory	Remember the place of some objects in the surrounding space
	Challenge	Answer a question or solve a problem
	Inquiry	Given a learning scenario, discover actions that follow some non-explicit rule, such as a law of physics or chemistry
	Play-acting	Reproducing events and situations of the physical world, trying to embody some particular aspect

Table 3.1: Summary table of games typologies divided according to their purposes.

The main division is between experiential games, which focus on the benefit users can obtain from the interactive environment experience, and learning games, which instead are focused on content learning still using the game form. The first category in turn divided into sensory, traditional and information display games. Games on first subcategory use unexpected environmental responses to activate user's emotional response and amusement. Second ones, instead, try to enhance confidence in the interaction using traditional games that the players know yet. Third kind of games are used to enhance social sharing while having fun.

The second macro category is also divided into four subcategories. Memory games exploit the spatial relationships of located items to help players to remember the place of some objects to be connected (e.g., a certain place on the space start a certain sound). Challenge games propose questions or problems of different subjects that the player must response and/or solve. Inquiry games are used to show how the proposed scenario can change based on user's interactions and movements. As the changes are not random but follow some non-explicit rule (e.g., a physics or chemistry law), the users have to discover them. Play-acting games are like last one subcategory, but instead of using a certain law, the type of interaction that changes the environment depends on the kinematic attributes of movements. These are employed to play-act events and situations of the physical world by trying to embody some particular aspect. In these games, users are the core element of the application and through they behave they render abstract concepts through body movement (e.g., spin arms in circle to increase or diminish a bike's speed).

3.1.1 Full-body responsive environments

In large-scale responsive environments, a predominant aspect of interaction design is full-body interaction. This is what differentiates them from other interactive surfaces (like smartphones, tablets, touchscreen interactive whiteboards) by allowing, due to their size, the user to walk within the interactive space itself, "transforming" the player into a living slider. The user's movements produce continuous data that can be used to change certain game parameters in live. Their positions can also interact with game landmarks producing a determined audio or visual output. Through this interaction of bodily movements, engagement, attention, and curiosity are favored, creating a deep emotional impact on users' perception.

The use of whole body also implies that many reality-based elements are involved in the interaction [84]. These reality-based themes can be divided into four groups, each one with its full-body interaction elements:

- Naive physics: movement speed, direction and physical effort.
- Body awareness and skills: proprioception, peripersonal space awareness and embodied cognition.
- Environment awareness and skills: spatial cognition, spatial learning, spatial navigation and cognitive maps.
- Social awareness and skills: local co-presence, social affordances and psychological impact of social contest on user experience.

From the above list, one of the most important elements is the proprioception, as it is the basis of controlled movement and allows players to have an idea of where they are. Spatial cognition and spatial learning are recalled when participants enter the interactive space and start to explore how it reacts to their movements. Another important feature is the socialization given by the gaming experience. Playing a game, achieving points, winning a match is not only a challenge between the user and the computer, but can bring to a great educational value as it fosters comparison, participation, and reinforcement in an informal and playful way.

These environments are also inclusive for people with disabilities. For example, they can be used for motor and cognitive impairment rehabilitation therapies, as they stimulate the players kinesthetic interaction (the ability to make meaningful movements and fit motor schemas to the design requirements). In fact, in large-scale responsive environments, a bi-univocal relationship between movement and sound is established and the user can acquire knowledges and motor skills by moving and playing. The simplicity of the interaction allows a natural involvement of children with various disabilities (including visual impairments) in the rehabilitation activities.

For example, a training system for the reduction of veering implemented as a large-scale environment application to train children with severe visual impairment or total blindness has proven to be an efficient tool [83]. The pilot study shows that the training with the application seems to reduce the amount of veering and to encourage participants to explore the surrounding space. The observed improvements on the players and the experimental data can be considered an indicator that encourage the new implementation of this type of game to employ responsive environments as real supportive tools for inclusive education, training, and rehabilitation for children with disabilities.

3.1.2 The See-Sound project

Following the above ideas, as a multidisciplinary team that involved computer engineers and a therapy team from the Robert Hollman Foundation, we created the See-Sound Project. The project purpose is to design, develop, and test a set of novel mini games explicitly aimed to improve cognitive and/or motor-sensory skills in children with visual impairments, with particular attention to the characteristics and needs of this user's category. In the See-Sound project we wanted to try to explore the potential of multimodal interaction, exploiting, in relation to audio and video, full-body movement and proprioception as complementary communication channels to access digital games and pursue specific learning and rehabilitation goals for children with visual impairment [87].

Listenig to professionals, play is the main tool through which it is possible to create a therapeutic relationship with the child, allowing them to express themselves, learn new cognitive, social, and sensory-motor skills, and become aware of their own potential. Moreover, by playing, children gradually improve and mature their proprioception, their body awareness, and their spatial orientation. With these notions we decided to create a responsive floor system as infrastructure to develop and play the games.

The term responsive floor indicates an area where it is possible to track the presence and movement of one or more users, typically employing sensorized tiles or computer vision systems. In our case, the games are played by moving within the range of a large-scale interactive environment, i.e., a floor portion placed under the range of a motion capture system which allows the tracking of one or more people. The system can run several mini games (easily adapted by the therapist to the child's needs) and link the player position and movements to audio and graphic output to produce meaningful interactions with the game. The main goal of the mini games is to help children by providing them with an exciting and educational environment, At the same time they aim to foster fun and interaction with the outside world. For these reason, a cooperative approach to design of the game from the multidisciplinary team was necessary.

3.2 Game design

As said in the previous chapters, serious games are considered an effective tool for rehabilitation. However, they must adhere to the adaptability and configurability criteria. So, designers must incorporate the option to adjust the game to the patients' specific needs following some particular design criteria [88]. Another important feature that designer must consider while working with people with visual impairment is the accessibility. In particular, the visual component (typical of videogames) must be replaced or supplemented by sound or tactile components. On account of this, the design process of the See-Sound games involved a team comprising therapists from the Robert Hollman Foundation and computer engineers from the Department of Engineering of the University of Padova and has followed a co-design approach inspired on *Design Thinking* [89]. *Design Thinking* is an iterative, non-linear design methodology that provides a solution-based approach to solving problems. It's extremely useful for situations where the overall challenge is not clear or in tackling complex problems that are ill-defined or unknown. It is based on the understanding of the human needs involved, by re-framing the problem in human-centric ways, by creating many ideas in brainstorming sessions, and by adopting a hands-on approach in prototyping and testing. There are numerous reasons to use *Design Thinking* while developing a new solution as it achieves different advantages. It is a user-centered process and, as it starts with user data, it creates design artifacts that address real and not imaginary user needs, and then tests those artifacts with real users. It also leverages collective expertise, establishes a shared language amongst the team, and encourages innovation by exploring multiple avenues for the same problem.

As shown in the Figure 3.1 the approach is based on five main steps: empathize, define, ideate, prototype, test. These stages shouldn't be seen as a group of sequential steps, (don't start in phase 1 and work through them all the way to phase 5 where conclusion is reached) but as different modes that contribute to the project with many interactions between them (the team return to earlier phases at regular intervals throughout the journey to better understand if the chosen design were right). For this reason, the design process of the project lasted a few months and required at least fifteen meetings to reach an appropriate level of development.

The first stage of *Design Thinking* is called *empathize*. This stage is meant to get a better understand of the problem and it allows designers and developers to

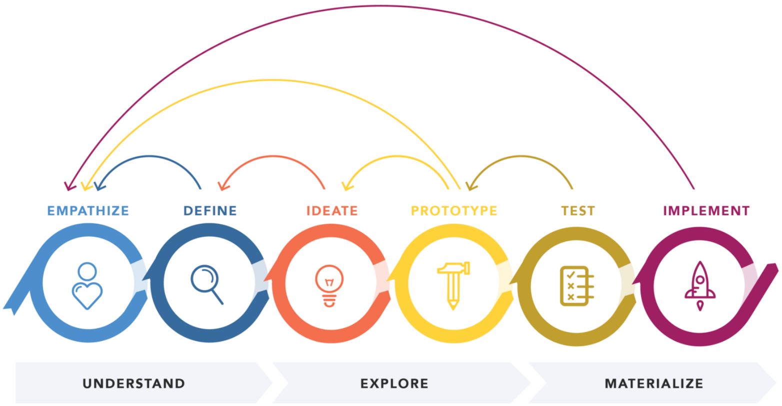


Figure 3.1: Design Thinking steps [90].

step outside their own biases to figure out exactly what the user wants. This step includes consulting experts of the matter, engaging farther into the issue to better understand the problem at hand. By liaising with people who actually deal with problems on a day-to-day basis, designers understand their motivations and experiences. A substantial amount of information is gathered during the empathize stage and is carried on to the next few stages to help define the problem and understand how to deal with it.

To foster empathising, most of team's meetings, in compliance with anti-COVID-19 regulations, were held at the rehabilitation center of the Foundation. By gaining first-hand knowledge of the physical environment, which is crucial as the games are located on the floor of a Foundation's room, and taking the opportunity to meet the end users and observe the Foundation's varied learning and rehabilitation operations, computer engineers were able to obtain a better understanding of the issues involved. Furthermore, a sensory reduction experience was given to the engineers using glasses that allowed them to imitate a reduction in vision that can be present in various visual disorders, in order to raise awareness of the difficulties faced by a child with severe visual impairment.

The second stage is the one called *define*. During this stage all the information gathered during the empathize step are put together. All the data and observations are analyzed and synthesize them in order to better concrete the core problems the team has defined to this point. This stage will help the team to gather ideas and to understand how to use them effectively to establish features, functions, and any other elements that will allow them to solve the problems.

After the first few meetings the following issue statements were developed by the team for which the designers attempted to provide a solution in the form of digital games to support rehabilitation therapy sessions.

1. "Small, moving objects, such as a ball or balloon, are difficult for children with visual impairment to perceive and interact with": the digital objects in the game will have appropriate size and dynamics.

2. "Spatial orientation is a sensitive topic for children with visual impairment, especially if the vision loss occurred early": the development of spatial orientation skills will be encouraged by the digital game through interaction with visual and/or acoustic stimuli.

3. "Low proprioceptive awareness is a characteristic that children with visual impairment sometimes have, leading them to assume incorrect postures from a musculoskeletal point of view in order to be able to use their residual visual functions": using different visual/sound feedback based on body movements, the game will help to develop player's body awareness.

4. "Children with visual impairment have different characteristics according to the type and intensity of the visual impairment, therefore the system must allow the operator to introduce, eliminate or modulate elements of the scenario to easily adapt to the needs of the individual child and create a personalized experience for them": to meet this need, the system will have some tools to

easily set various parameters, such as background color, objects color, size and speed, sounds played, etc.

5. “Rehabilitation programs for children with visual impairment are often long and demanding”: the system will have a playful component, exploiting the engagement mechanisms typical of gamification.

6. “There are few opportunities for children with visual impairment to work in groups”: trough exchange games and turn-based games, the system will aid in the improvement of basic relationship mechanisms.

Once the core problem has been better defined, it is possible to move into the third stage, the *ideate* step. During this stage, the team start to use the information from the previous stages to generate logical ideas. Is important to “think outside the box” to identify new solutions to the problem statement created, looking for alternative ways of viewing the problem. Each team component should try to gather as many ideas and solutions as possible and then share them with one another, mixing and remixing, building on others’ ideas.

In the See-Sound project case, after the statements of the previous step has been analyzed and discussed, the best idea seemed to be the design of a mini games set for a large-scale interactive environment. The idea of opting for this user interface arose from a number of considerations (many of which we have already seen in previous chapters) such as: the need for children with visual impairment of spatial orientation training, which requires full-body movements in a large environment (e.g., a room), the ability to enlarge or reduce visual objects on the floor according to the specific impairment, the improved transfer of acquired skills to the real world by completing tasks on the floor of a physical environment rather than simply using a screen, and the facilitation of creating interaction and socialization with therapists through the use of a large environment.

By the end of the previous phase, a few ideas to solve the problem have come out, giving the opportunity to move on to the next step: *prototype*. During this stage the team several scaled-down versions of the product are created which focus on solve specific features of the problem. Prototyping thoroughly can help to better address the user needs and problems identified during the earlier stages of the process.

For the See-Sound project this step has also been followed and several prototypes of the games were developed using Processing, a Java-based framework that is particularly indicated for fast prototyping. Since the operators who would use the system during the rehabilitation sessions had to be autonomous in the configuration of some parameters to make the game customized to the child's abilities, some specific meetings were held to decide which were the parameters and characteristics of the games (such as shapes, colors, speed, size and number of objects, etc.) that had to be modifiable directly from the game menus which were presented before starting a new game.

By the end of this stage, the team should start to get a better idea of the kind of constraints they may be dealing with and how they could fix the prototype to make it better for its audience. From here, the team should be ready to move on to the final step. During the *test* stage, the team will rigorously test the product using the findings and solutions that were discovered in the prototyping phase. As the *Design Thinking* process is iterative, although this is the final stage, it is important to note that this is not where it ends. Even during this step, the team can and will make alterations and refinements in order to make the product more polished for their needs, going back to previous stages to refine information and the end product to get the best outcomes from it.

For this reason, after testing several prototypes and holding meetings to improve the user experience and requirements not considered in the initial development, a final product was developed that could be presented to the foundation's therapists as a new tool which can be used during rehabilitation therapies.

Furthermore, a customized user manual was written and provided to the Foundation with the aim, together with a quick start-up course, of helping the therapists to better understand how the system works and to make them autonomous in using it.

3.3 Hardware and software architecture

The architecture of the large-scale interactive environment employed for the games, which was used both during the development of the games and for the deployment at the foundation's room, employs a PC, a motion tracking device, and a video projector and the interactions between the devices can be seen in detail in Figure 3.2.

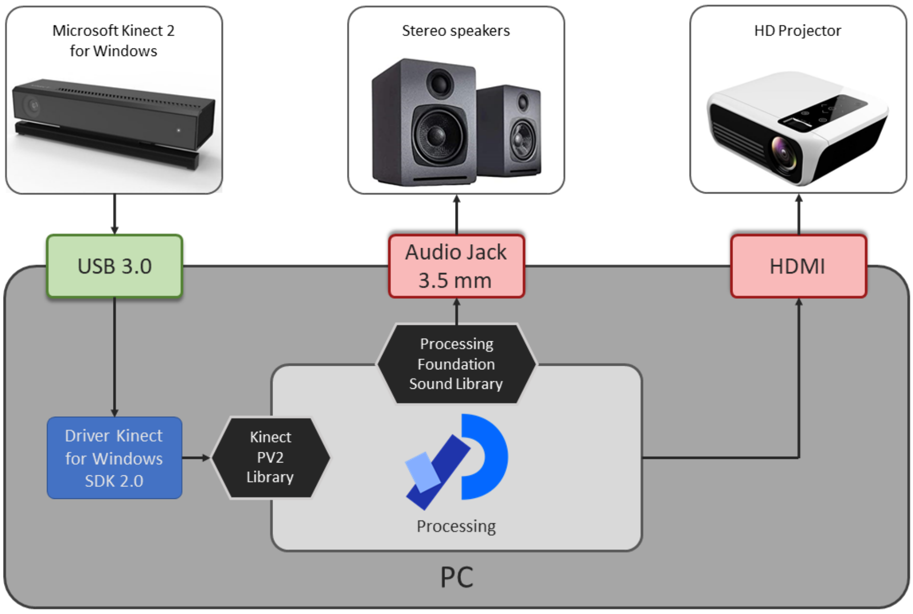


Figure 3.2: System software and hardware architecture.

The chosen tracker has been the *Microsoft Kinect v2* compatible with *Windows*.

The only requirements for the projector were a resolution of 1920 x 1080 pixels, the ability to project into the floor and a contrast ratio of at least 5000:1. The PCs were equipped with a USB port for connecting the tracker and an HDMI port for connecting the projector. Furthermore, in both cases, the operating system used was *Windows 10* and the driver *Kinect for Windows Software Development Kit (SDK) 2.0* was installed. Finally, in the game environment built in a room at the Foundation, two external speakers have been used instead of the computer's ones to achieve a cleaner, brighter sound. All the software components (like the one to track people, the menu, and the games) have been developed using Processing.

Talking about the final environment, the visual output of the game is projected on the floor in a 3.5 x 2 m game field using a single projector mounted on the ceiling. To enhance the performances of the sensor (as tracking people from a top-down perspective better results has been obtained) and to project the game field directly on the floor, both the sensor and the projector are mounted on the ceiling pointing downwards, perpendicular to the floor itself. In addition, as contrast is a very important feature that help children with visual impairment to see objects (physical or virtual) better, the floor was covered with light grey linoleum to improve projection contrast and quality, and dark, thick curtains were installed on the windows to block out almost all sunlight.

3.3.1 Processing

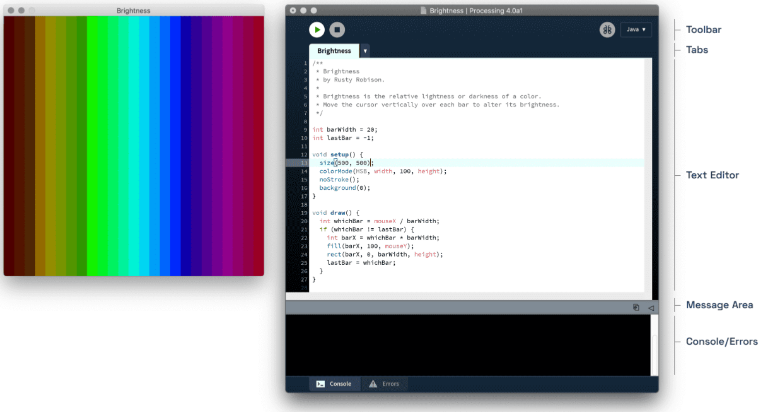
The chosen technology to develop all the software part is called Processing [91]. Processing is an open-source programming language and an integrated development environment (IDE) that enables the development of various applications such as games, images, animations, interactive content, and generative artwork. In 2001, when the convergence of software and the arts was not as well-developed as it is today, the project was initiated by Casey Reas and Ben Fry (whose started the Processing Foundation in 2012 with Daniel Shiffman) to serve as a software sketchbook and to teach fundamentals of computer programming within a visual context. It has then evolved into a tool for generating finished professional work and currently there are many students, artists, designers, researchers, and hobbyists who use it for learning, prototyping, and production.

The Processing language inherits all the syntax, commands, and object-oriented programming paradigm from the Java language, but also provides numerous high-level functions for easy handling of mathematical functions, graphics, and multimedia. It is distributed under the terms of the free GNU General Public License (GPL) and is compatible with Linux, macOS and Microsoft Windows operating systems.

The Processing language and IDE have been the precursor to other projects including Arduino, Wiring, and p5.js (a JavaScript library that reinterprets the original goal of Processing for today's web providing a full set of drawing functionalities for the entire browser page).

The *Processing Development Environment* (PDE) makes it easy to write Processing programs. As can shown in Figure 3.3, the PDE includes simple text editor for writing code, a compile, a message area, a text console, tabs for managing files, a toolbar with buttons for common actions, and a series of menus.

The text editor is used to write programs which can be compiled and executed simply by pressing the *Run* button included in the IDE. In Processing, a computer program is called a sketch. Sketches are stored in the Sketchbook, which is a folder on your computer. Every sketch is a subclass of the *PApplet* Java class (in turn a subclass of Java's built-in Applet) which implements most of the Processing language's features. All additional classes defined inside the sketch's files during the development will be treated as inner classes when the code is translated into pure Java before compiling it, so some rules must be followed (e.g., static variables and



```
/**
 * Brightness
 * by Rusty Robison.
 *
 * Brightness is the relative lightness or darkness of a color.
 * Move the cursor vertically over each bar to alter its brightness.
 */

int barWidth = 20;
int lastBar = -1;

void setup() {
  size(500, 500);
  colorMode(HSB, width, 100, height);
  noStroke();
  background(0);
}

void draw() {
  int whichBar = mouseX / barWidth;
  if (whichBar != lastBar) {
    int barX = whichBar * barWidth;
    fill(barX, 100, mouseY);
    rect(barX, 0, barWidth, height);
    lastBar = whichBar;
  }
}
```

Figure 3.3: Processing Development Environment [91].

methods cannot be used inside the classes).

Sketches can be used to draw two and three dimensional graphics (respectively P2D and P3D). While the system is set to use the P2D graphics as default render, is possible to edit the settings to use the P3D to draw three-dimensional graphics including the control of the camera, lighting, and materials. If the computer has an OpenGL compatible graphics card, both P2D and P3D renders will be accelerated.

Each sketch generally contains not only the classes that make it up, but also a *Data* folder in which the multimedia material useful for the application, such as images, fonts, and audio files, is stored. Finally, all the applications can be exported as Java applets.

Processing's capabilities are augmented by *Libraries* and *Tools*. The hundreds of libraries contributed by the Processing community can be added to the sketches to enable new features like as sound playback, computer vision, and complex 3D geometry manipulation. that aren't feasible with the Processing code core. Tools, instead, enhance the PDE by offering interfaces for activities like as color selection, making it easier to create sketches.

For the See-Sound project, for example, the following library has been used:

- *Kinect v2 for Processing*: a library used to simplify the interaction between Processing language and the Kinect sensor [92].
- *Minim*: an audio library to make integrating audio into sketches as simple as possible for people developing in the Processing environment [93].
- *OpenCV for Processing*: a library based on OpenCV's official Java bindings that provide convenient wrappers for common OpenCV functions to make them familiar to the Processing environment [94].
- *oscP5*: an OSC (acronym for Open Sound Control, a network protocol for communication among computers) implementation for the Processing PDE [95].
- *Signal Filter*: a utility library which provides a simple way to turn noisy raw data (e.g., a tracker's position) into a signal that changes smoothly over time [96].
- *ControlP5*: a graphical library which provides a set of available controllers includes Slider, Button, Toggle, TextField, etc. that can be easily added to a processing sketch [97].

To complete the package, the Processing website has a *Documentation* section, which explains extensively how to use the language, the references, the environment, the utility functions provided, and the main libraries available, and a *Learn* section, where a wide selection of tutorials, books, examples, and already developed and working sketches to learn in a practical way can be found.

Sketch structure

In Processing, when the file containing the main class is created, it must contain a `setup()` function and a `draw()` function: the first one is called only once when the application is launched to set all the application settings, while the second one is executed to generate each frame of the application (so it will be executed n times in a second according to the value of the *frames per second* setting). An example of this structure can be seen in Listing 1, where the `setup()` method is used to set application frame size, font, and framerate and the `draw()` is used to change the background color every time new frame is drawn (in this case, 60 times per second). The global variables, which can be used in every file and methods of a certain project, are declared in the first rows, outside the two methods.

Methods like `println()`, `textFont()`, `background()` and variables like `width` and `height` are all part of the Processing set of utilities that can be used to simplify the work, without the need to rewrite complex functions or import a lot of libraries.

3.3.2 Kinect

For motion capture part of the system to track the player position, the sensor used is the Microsoft Kinect v2 (also called Kinect One, as it has been developed to work with the Xbox One console).

Initially known by the codename Project Natal, Kinect is a motion-sensitive accessory developed by Microsoft for the Xbox 360 console (and later also for the Xbox One console in a more powerful and improved version) that allows the player to control the video game without the need to wear or hold anything. The original objective for which Kinect was developed was to become a motion controller peripheral for Xbox video game consoles, that stood out from those of its competitors (such as Nintendo's Wii Remote and Sony's PlayStation Move) by not requiring physical controllers. The first version was released on November 4, 2010, and the majority of games developed which included its use were casual, family-oriented titles, which helped to attract new audiences to Xbox 360, but did not result in wide adoption by the console's existing userbase.

```
// Global variables declaration
int red = 0;
int green = 0;
int blue = 0;

// setup method - only called when app starts
void setup()
{
  println(PFont.list());
  size(500, 500);
  PFont font = createFont("Arial Black", 24);
  textFont(font);
}

// draw method - called for each new frame
void draw()
{
  // change background color
  color backgroundColor = color(red, green, blue);
  background(backgroundColor);

  // change text label color
  color textColor = color(255 - red, 255 - green, 255 - blue);
  fill(textColor);
  text("New frame", width / 2, height / 2);

  red   = (red   + 1) % 255;
  green = (green + 1) % 255;
  blue  = (blue  + 1) % 255;
}
```

Listing 1: Example of a Processing project main file.

While the Kinect has failed to dominate the entire gaming landscape, it has managed to create a lot of interest in the academic and research world. Shortly after the launch of the Kinect, scientists, engineers, and hobbyists reverse-engineered the device to determine what hardware and internal software would be used, so that a driver could be created to connect and run the Kinect with Microsoft Windows and OS X via USB. For this reason, between the first and second generation of Kinect, a developer version compatible with Windows 7, 8 and 10 was created, but its production stopped shortly after the release of the Kinect One. In fact, Microsoft decided to focus on the production of the Xbox One peripheral, but, at the same time, to try to please PC users, it released a special adapter that allows the Kinect One to be used on computers. In addition, to increase compatibility, the software used for development on the Kinect One has also been made fully compatible with the version of the device for developers.

Microsoft also released its own SDK, called *Kinect for Windows SDK*, which allows developers to directly retrieve data collected from the device, allowing it to be integrated into custom, not only for gaming applications. Installing the SDKs is very simple, as all you have to do is download the *Kinect for Windows SDK* package from Microsoft's official website (version 1.8 for use with the original Kinect or version 2.0 if you want compatibility with the Kinect for Developer or One) and, after plugging the device into a USB port on the PC, run the downloaded file. With version 2.0 of the SDK for Windows, in addition to the drivers for the connection, the installation includes a software called *SDK Browser (Kinect for Windows) v2.0*, which allows to see if the connection with the Kinect is working correctly and provide a list of C# or C++ sample sketches developed by Microsoft to provide an overview of what the Kinect sensor can do.

Finally, through the use of the tools offered by the *Microsoft Speech Platform SDK*, it is possible to integrate in the applications functionalities for speech recognition (voice recognition) and for the generation of synthesized speech (speech synthesis), offering users an effective and natural way to interact with the applications, complementary to the use of mouse, keyboards, controllers and movements (very useful especially for people with visual impairment, as already mentioned in the previous chapters).

Thanks to the SDKs, which allow any developer to create new applications that take advantage of Kinect, the potential of this device was enhanced as it could be seen as an inexpensive way to add depth-sensing to existing applications, transforming human-computer interaction in multiple industries, like education, healthcare, retail, transportation, rehabilitation and beyond. For example, some interesting applications have been created to help therapists observe their patients and to add new tools to their rehabilitation pathways on patients with neurological disorders including stroke, Parkinson's, or cerebral palsy [98].

The directly successor of the Kinect devices is *Azure Kinect DK*, a developer kit and PC peripheral which employs the use of artificial intelligence sensors for computer vision and speech models, released in 2020 by Microsoft as a continuation of the Kinect technology and integrated with the Microsoft Azure cloud computing platform.

The key enabling technology is human body-language understanding: the computer must first understand what a user is doing before it can respond. This has always been an active research field in computer vision, but it has proven formidably difficult with video cameras. The Kinect sensor lets the computer directly sense the third dimension (depth) of the players and the environment, making the task much easier. It also understands when users talk, knows who they are when they walk up to it, and can interpret their movements and translate them into a format that developers can use to build new experiences.

In order for a computer to respond to a certain movement of the human body, it must first pick it up and understand it. This has always been an active area of research in computer vision but has proved particularly difficult with video cameras. The Kinect sensor, on the other hand, makes the task much easier thanks to the technology behind its motion detection algorithms: depth detection of the players and the environment.

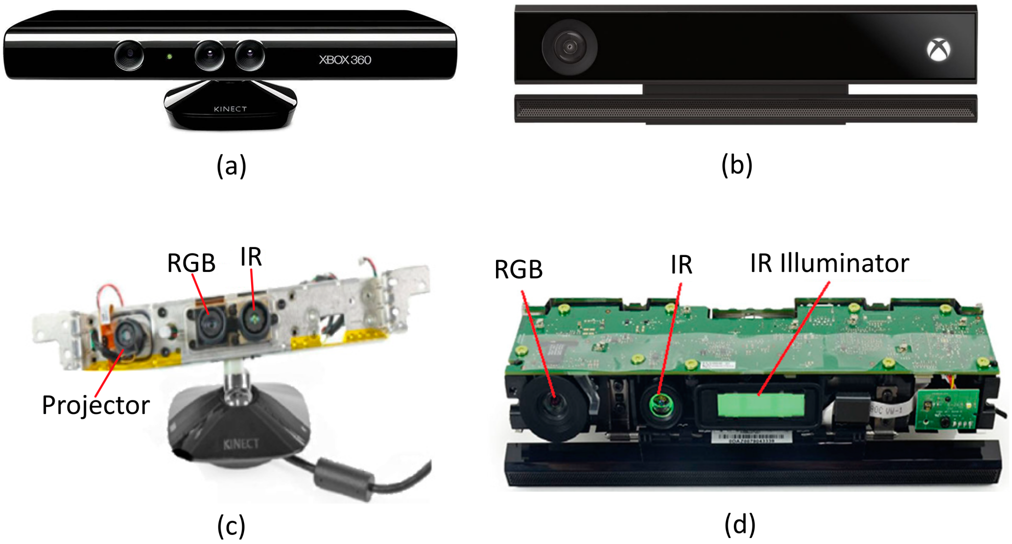


Figure 3.4: How the Kinect sensor looks like externally and disassembled in its original version (a, c) and second version (b, d) [99].

The Kinect sensor incorporates several advanced sensing hardware, as can also be seen in Figure 3.4. The first version was equipped with an RGB camera, an infrared camera, and a lower-resolution structured light 3D scanner which, in combination with infrared, was used to calculate the distance of objects. It also had an array of four microphones used by the system to process data from the environment in which you were standing, allowing echo cancellation and noise reduction via active noise control. The Kinect bar was also motorized along the vertical axis and was able to follow the players' movements, orienting itself in the best position for movement recognition. The set of sensors and a suitable software, provide the Kinect with full-body 3D motion capture, real-time gesture recognition, body skeletal detection, facial recognition, and voice recognition capabilities.

As shown the Table 3.2 , which details the characteristics of the devices, there are not many differences between the two versions of Kinect. In fact, the Kinect One

	Version 1	**Version 2**
Color camera resolution (H × V) [px]	640 × 480 @ 30 fps	1920 × 1080 @ 30 fps (15 fps with low luminance)
Color camera FOV (H × V) [°]	62 × 48.6	84.1 × 53.8
Depth camera resolution (H × V) [px]	320 × 240	512 × 424
Depth camera FOV (H × V) [°]	58.5 × 46.6	70.6 × 60
Depth range [m]	0.4 - 6.0	0.4 - 4.5
Depth technology	Structured-light	Indirect time of flight
Tilt motor	Yes	No
Joints tracked	20	25
Skeletons tracked	2 of 6 recognized	6 of 6 recognized
Hand tracking	None	States: Open, Closed, Lasso, Unknown, Not Tracked
Basic face tracking	100 points - Head yaw, pitch, roll - No expressions	5 points for eyes, nose, mouth - Eyes open, closed, looking away - Mouth open, closed, happy, neutral - Head yaw, pitch, roll
HD face tracking	None	Over 1000 points
Audio stream	4-mic. Array	4-mic. Array
USB standard	2.0	3.0
Software SDK/API	1.8	2.0

Table 3.2: Kinect first version and Kinect One technical specifications.

features technology similar to that of its predecessor but enhanced. The camera has a wider field of vision and, by exploiting an active IR sensor and a different technology for depth reading called "time of flight calculations", it allows tracking even in low light conditions or without visible light. This technology is based on the fact that infrared light that reflect off closer objects will have a shorter time of flight than those more distant. So, infrared projector on the Kinect sends out modulated infrared light, as shown in Figure 3.5, which is then captured by the sensor, that also captures how much the modulation pattern had been deformed from the time of flight, pixel-by-pixel. Time of flight measurements of depth can be more accurate and calculated in a shorter amount of time, allowing for more frames-per-second to be detected.

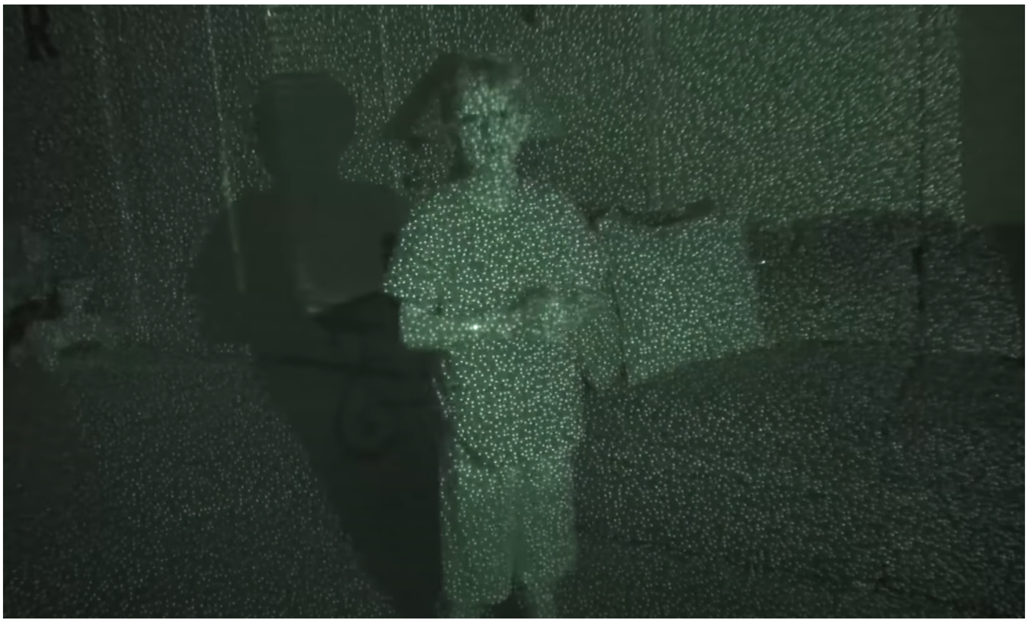


Figure 3.5: Environment irradiated by infrared rays from the Kinect sensor's projector.

Kinect's data sources

Thanks to its hardware and software, the Kinect allows the developers to use multiple data sources, as shown in Figure 3.6 directly coming from the sensor in a more raw or elaborated way. Following, a list of the sources and their main characteristics:

- *Color*: the data flow captured by the main camera. Resolutions, frame per seconds, and FOV depends on the sensor's version.
- Infrared: shows what the infrared sensor captures. The advantage of this flow (in particular in the second version of the Kinect) is that it can be used to recognize images, depth, and movements without the need for a light source to illuminate the scene.
- *Depth*: the data flow which shows the depth of the objects in the scene from the Kinect. Each pixel taken individually is presented as coordinates (X, Y, Z), where the first two values indicate where the pixel is located in the Cartesian plane while the third indicates the distance from the sensor, making it possible to understand how far each pixel is from the camera.
- *Body Index*: this data flow returns the possible presence and position of people that the Kinect recognizes as being present in the scene. The number of people recognized simultaneously in the environment analyzed by the sensor depends on the version of the latter (two for the original and six for the second version).
- *Body*: for each person detected in the scene, this data flow returns a set of values representing the bio correct skeleton joints of the people found, allowing a more accurate tracking of the person's movements (20 or 25 joints per person, depending on the sensor version). In fact, thanks to these values, it is possible to track in a much more detailed way the movements and the rotations of person's limbs, spine, shoulders, head, and hands (of which, the second

version of the sensor is able to track both the position of the thumb and the opening/closing of the whole hand).

- *Audio*: Using a microphone array, the Kinect can also capture audio from the scene it is in. The audio data is recorded at specific time intervals and associated with an "audio beam", which creates a "cone" in which the person talking is most likely to be located and which will then be analyzed further to refine the tracking (the person is more likely to have moved to an area adjacent to the cone rather than the opposite side). The cone can be directed automatically (based on the position of the sound source in the horizontal plane tracked by the sensor) or manually by the program that is using the Kinect (allowing the cone to be directed to the desired area, even if no sound is coming from that point in the horizontal plane).

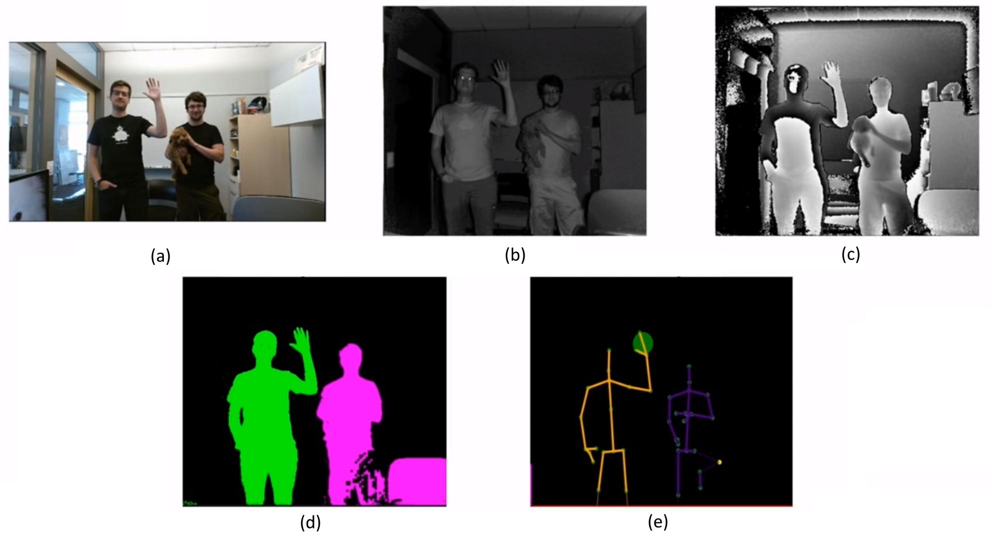


Figure 3.6: Same frame visually represented in various data sources (Kinect One): (a) color, (b) infrared, (c) depth, (d) body index, (e) body skeleton.

Different data flows were tested for the See-Sound project, but it was decided to use the *Depth*, attaching the Kinect to the ceiling and locating a set of points (blobs) closer to the sensor than the floor (more information about the tracker algorithm in the next section).

An important negative note is the fact that Microsoft ceased production of Kinect on October 25, 2017, so currently it is only possible to find it as warehouse leftover or used stocks, which makes large-scale commercialization of the system devised in the See-Sound project impossible.

3.4 The games

In the following sections, the mini games and the tracking mechanism that has been designed and implemented by the team are presented. For each one there will be a quick presentation, why it has been added to the platform, and some details about its implementation.

3.4.1 The tracker

One of the most important parts of the See-Sound mini games is the tracker that allows a person to interact with the game trough their body. The underlying idea is that the moving centroids of the people inside the field of view of the motion sensor are provided as inputs to each game to move certain game elements.

As explained in previous sections, the sensor used is the *Microsoft Kinect One* and, to simplify the interaction between the language and the physical device, the *Kinect v2 library for Processing* has been used during the development. In the See-Sound project it was not important to know the exact movements of the player, but simply to know with a good approximation in which position of the field he was in order to make some game elements interact with them. Since the field is projected on the floor, creating a luminous rectangle in which the player can move, after some tests it was decided to use the Kinect in an unconventional way. Instead of placing the sensor in front of the player, with the angle of vision parallel to the ground, it was decided to fix it to the ceiling, so that its field of vision would be as equal as possible to the field of play generated by the projector (see Figure 3.7.

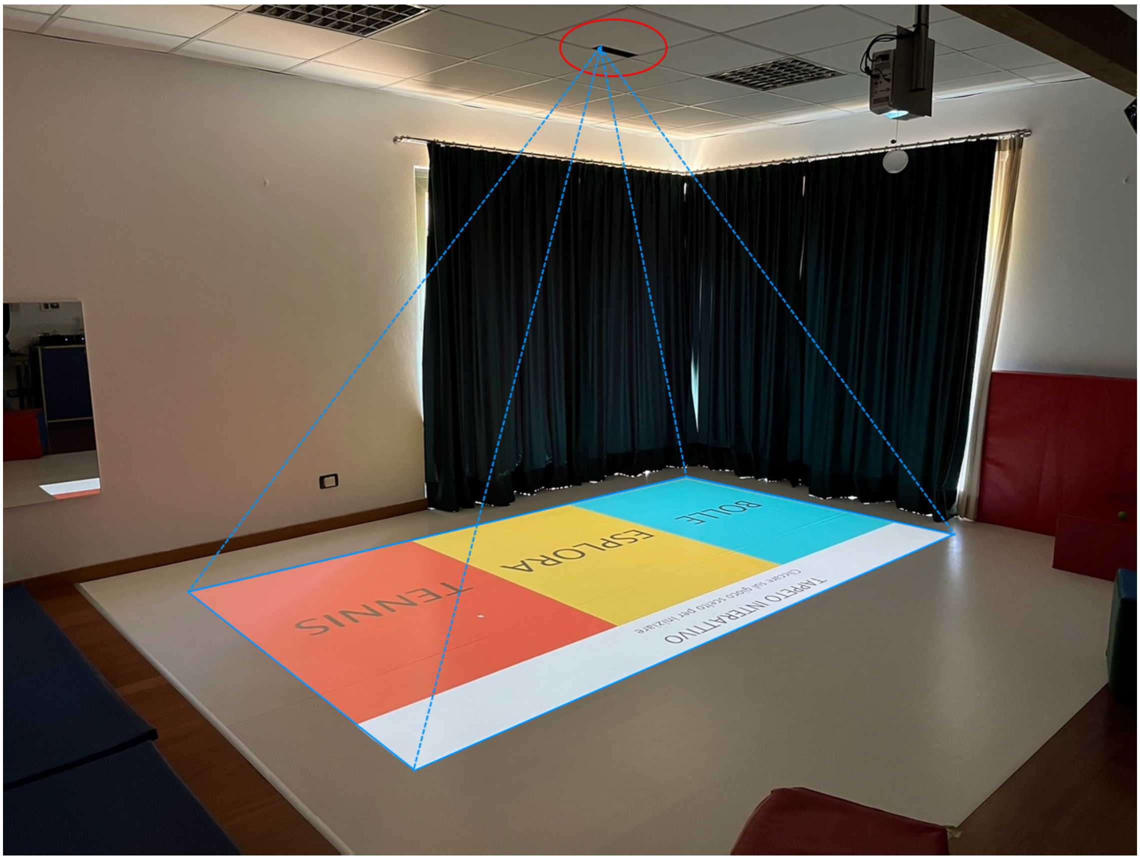


Figure 3.7: The room where the system is placed. Inside the red circle there is the Kinect. The dotted blue line indicates approximately the area in which the sensor can track players. The projector and a piece of one of the two speakers can also be seen at the top right.

In this way people are tracked from a top-down perspective and not from a frontal perspective. In order to do this, the depth data flow of the Kinect was used, where the maximum depth values referred to the floor and all the lower ones to whatever element (object or person) that is between the floor and the ceiling and inside the playing field. In particular, if we consider the set of pixels seen by the sensor as a matrix of numerical values, where each value indicates how far that pixel is from the sensor, we can intercept all the pixels that have a value within a certain range. By placing the Kinect in the ceiling and entering as a range a value between 0 (the closest point to the sensor) and the height of the Kinect (the furthest point from the sensor, the floor), any pixel with a depth value within this range indicates that there is something high enough at that point that is not the floor. The moment a set of neighboring pixels, that we will call “a blob”, returns values within the range, it means that it is not a false positive but an object cluttering a part of the scene (in our case it is the player).

The advantage of the library used is that via the function `getRawDepthData()` it returns exactly the matrix we have just talked about. The number of rows and columns in this matrix is given by the constants `WIDTHDepth` and `HEIGHTDepth`, which are also made available by the library. In order to transpose the position in the depth matrix back to the position in the real playing field (as the two rectangles being of different sizes), we have used Processing’s `map()` function, which allows us to map a value in the range *(A, B)* to a value in the range *(A’, B’)*. Moreover, a signal filter has been used to stabilize the coordinates received from the Kinect. We used a library called *Signal Filter Processing*, which provide a simple way to turn noisy raw data, such as tracker’s position, into a signal that changes smoothly over time. The library is built upon the *One Euro Filter*, that, as a lightweight alternative to common filtering algorithms, perform very well also if called very often (in the tracker implementation is called thirty times per second). The *1€ filter* (also known as the *One Euro filter*) is a simple algorithm for filtering noisy signals with great precision and responsiveness. It employs a first-order low-pass filter with a frequency cutoff that is adaptive: a low cutoff stabilizes the signal by decreasing jitter at low speeds, but as the speed rises, the cutoff is increased to eliminate lag. The method consumes relatively minimal resources and only requires two parameters to tune. In a comparison with other filters, the *1€ filter* has less lag using a reference amount of jitter reduction [100]. An example of how the code has been structured can be seen in Listing 2, while on Figure 3.8 a debug view of the final tracker result is shown. Talking about the latter, in the top left corner, there are coordinates and some debug (e.g., the grey square is the blob). In the top right corner, instead, the blue dot is the exact player position, while the red circle is the one filtered and approximated.

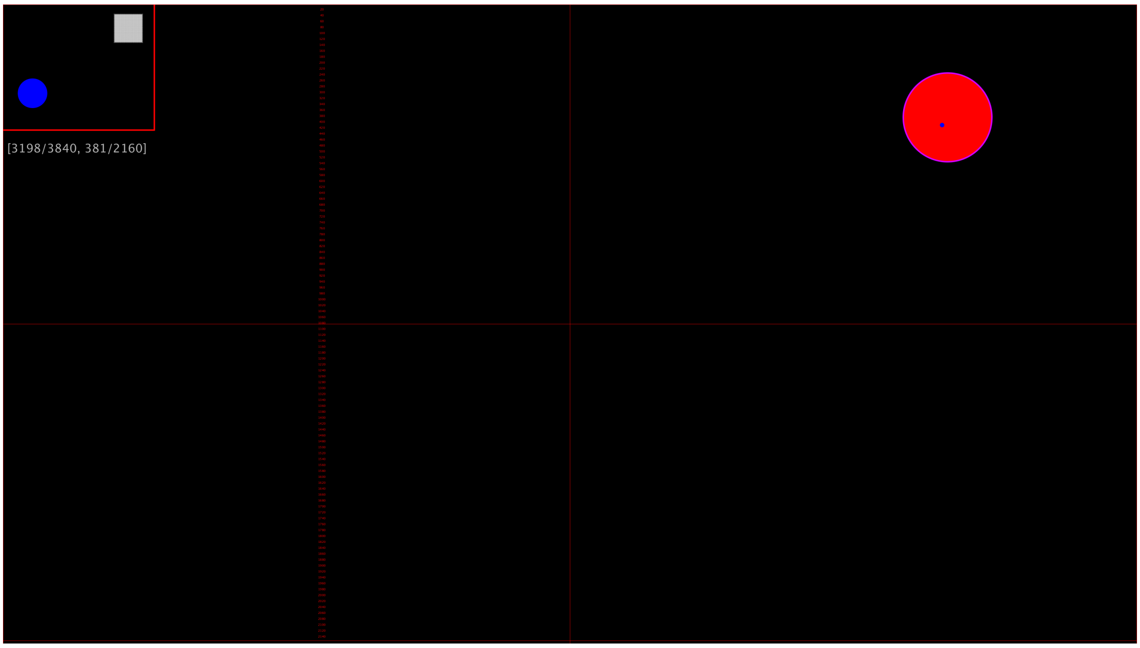


Figure 3.8: Debug view of the final tracker.

In the code in Listing 2 you can also see the mechanism used to transmit the data to the games. In order to simplify the implementation of the coordinate receiving mechanism in the games, the oscP5 library was used, thanks to which we simulated a virtual sender providing coordinates on a certain port (tracker side) and a receiver listening on the same port (game side). In this way, at each new coordinate processed by the tracker, a new packet will be sent to the game, which will use it to identify the new coordinates of the player and act accordingly.

The tracker set up in this way works in a smooth way, but, unfortunately, it

```
class Tracker {
    KinectPV2 kinect;
    int[] sourceRawData; // length kinect.WIDTHDepth * kinect.HEIGHTDepth
    SignalFilter stabFilter;

    // Constructor
    Tracker(mainClass mainClass) {
        kinect = new KinectPV2(mainClass);
        kinect.enableDepthImg(true);
        kinect.init();
        stabFilter = new SignalFilter(mainClass, 3);
        // server to send data to every app
        oscP5 = new OscP5(mainClass, myListeningPort);
        connect("127.0.0.1");
        ...
    }

    void compute() {
        // Get the Kinect matrix with depth values: single array
        sourceRawData = kinect.getRawDepthData();
        findBlobs();
        ...
        // filter coordinates of the blob
        filteredCoord = stabFilter.filterCoord2D(noiseCoord, width, height);
        ...
        // send coordinates messages
        oscP5.send("/position" + ((blobIndex > 0) ? blobIndex : ""),
        new Object[] {
            new Float(map(filteredCoord.x, 0, width, 0, 1)),
            new Float(map(filteredCoord.y, 0, height, 0, 1))
        }, myNetAddressList);
    }
}
```

Listing 2: A piece of code of the Tracker class used to found player's coordinates.

tends to give incorrect position results at the edges of the playing field, misplacing the player or not being able to intercept them anymore. The problem is due to the accuracy distribution of the Kinect depth calculation. After some research, it has been found that the accuracy of the depth value found is not the same for all points analyzed by the sensor [101]. In particular, the following measures are some of the ones that has been computed in the paper that has been used to find some interesting result.

Depth accuracy is defined as the difference between the true depth value and the average value of the measured depth values corresponding with a planar surface located in front of a Kinect One and is calculated using this equation:

$$\text{Depth Accuracy} = d - \text{mean}(M_d) \tag{3.1}$$

To illustrate how the depth accuracy differs in the space, a 3D cone is built to show the accuracy distribution, which is evaluated from both horizontal and vertical direction. Moreover, as show in figure 3.9, three colors (i.e., green, yellow, and red) has been used to show the different accuracy areas: in the green, yellow and red areas of both the horizontal and vertical plane, the average accuracy is less than 2mm, between 2mm and 4mm, and more than 4mm, respectively.

Depth resolution means the minimum detectable difference by the Kinect sensor in a certain continuous distance range and is calculated using this equation:

$$\text{Depth Resolution} = \min |M_d[i+1] - M_d[i]| \tag{3.2}$$

where $M_d[i+1]$ and $M_d[i]$ are two adjacent depth values in M_d.

The structural noise has also been calculated, which is the phenomenon that happens when planar surface is pointed perpendicular towards the depth camera and the depth values, which should be constants, distribute in ring shapes with different radius as the camera cannot capture a perfect flat surface.

Kinect One, unfortunately, has structural noise when capturing depth images. To investigate this problem, the authors of the paper [101] placed the Kinect in front of a flat wall, at 1m from it, and measured the depth values. In Figure 3.10,

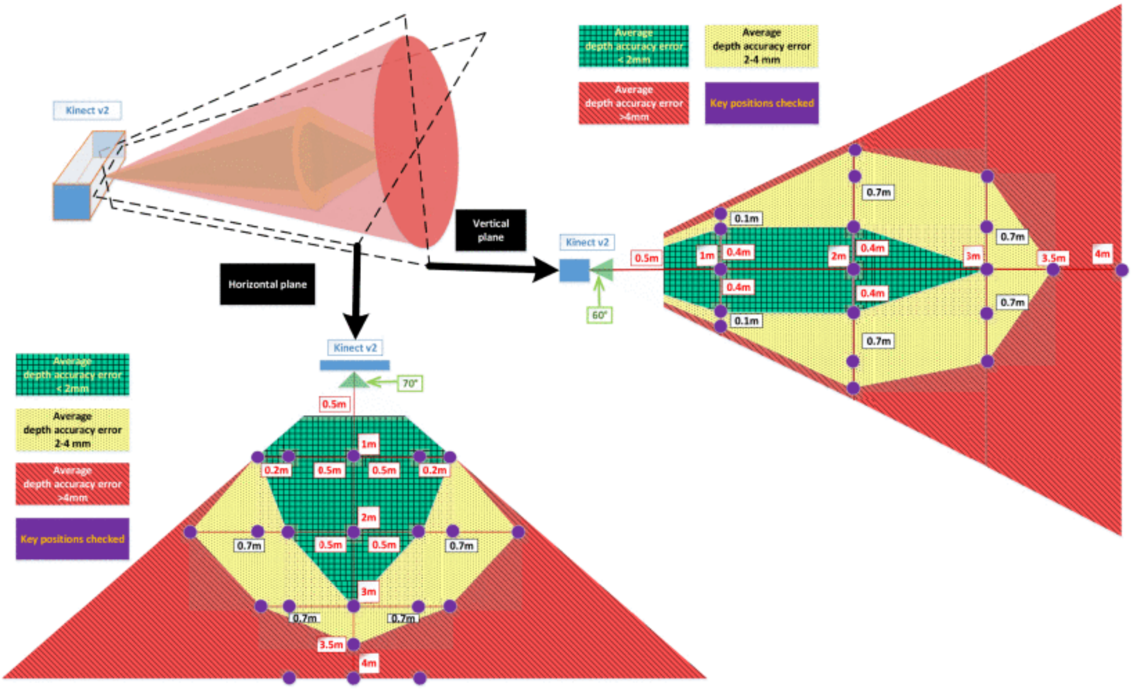


Figure 3.9: Accuracy distribution areas of Kinect One [101].

where the x and y axes represent the horizontal and vertical index of the frame respectively, it can be observed that the result of the depth values is not a uniform rectangle but more of a dome and the recorded depth values are distributed in the shape of rings. This means that the depth values of the pixels decrease when their distance from the central part increases. The reason for this ring phenomenon is difficult to understand, but it could be due to diffraction from the random variance of the depth pixels mentioned in the paper itself (called depth entropy, i.e., the fact that the value of a certain pixel can vary even by several millimeters even though sensor and object are stationary).

Based on the results obtained from the experiments, a cone model to describe the Kinect accuracy distribution has been obtain, finding that Kinect One has good accuracy if the object is positioned within the green regions (see Figure 3.9).

One approach to improve the accuracy of the data is to use more than one Kinect

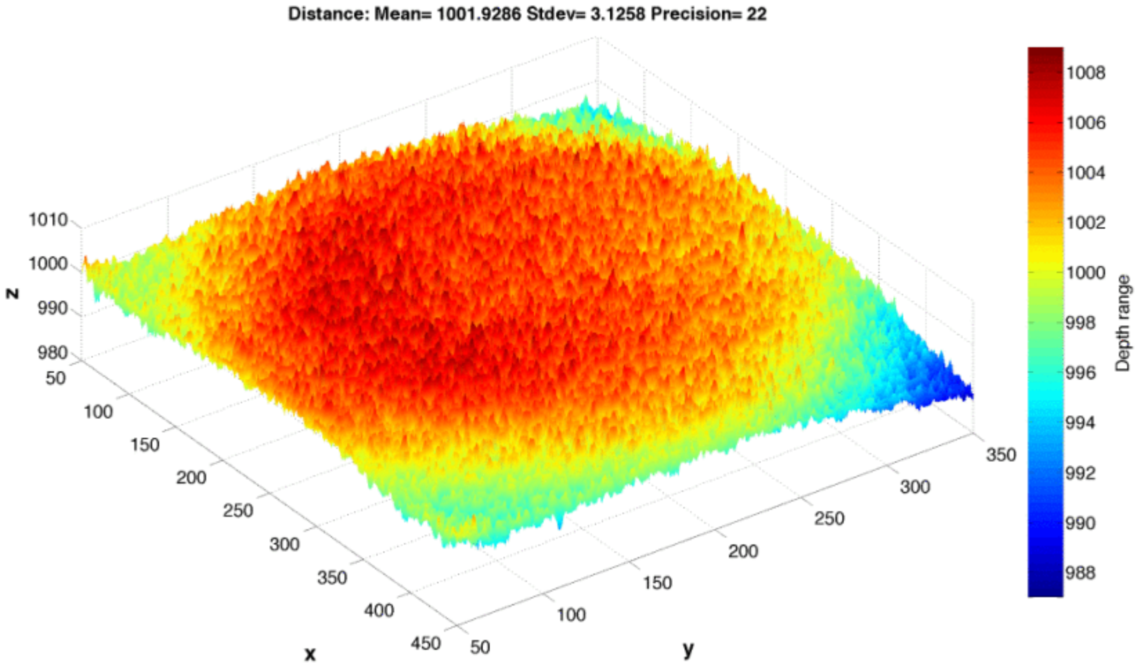


Figure 3.10: How the captured planar plane looks like when set 1m from the sensor (to notice the ring shape formed by the captured pixels) [101].

at the same time. One example is to apply the trilateration principle with multiple Kinects One to improve the overall depth accuracy and consequently also the player's position. Unfortunately, the Foundation only had one sensor and a limited budget. So, as they were hard to find for sale and not very cheap, rather than buy other Kinects, we adapted the games to avoid the edges of the playing field.

3.4.2 Game launcher

As explained above, the whole project has been designed following a *Design Thinking* approach, where the last step is testing. Extensive testing can really help to develop an even deeper understanding of the product and the end users (in our case both therapists and children using the games). So going back to other phases should not be seen as a failure.

For this reason, one of the problems encountered almost from the first weeks of test was the difficulty of not having a single place to select games. It was difficult and time-consuming for the therapists to figure out which icon to click to launch the desired game or to close and launch another application while continuing to follow the child. In addition, being able to have a comprehensible menu from which the child can choose his or her favorite game with the help of the therapist is a good way for the child to acclimatize to the new location and become familiar with the environment and a good incentive to continue therapy. Therefore, in order to overcome this problem and improve the usability of the games and the final user experience, a single launcher application was developed that contained the integrated tracker and a menu in which the desired game could be selected.

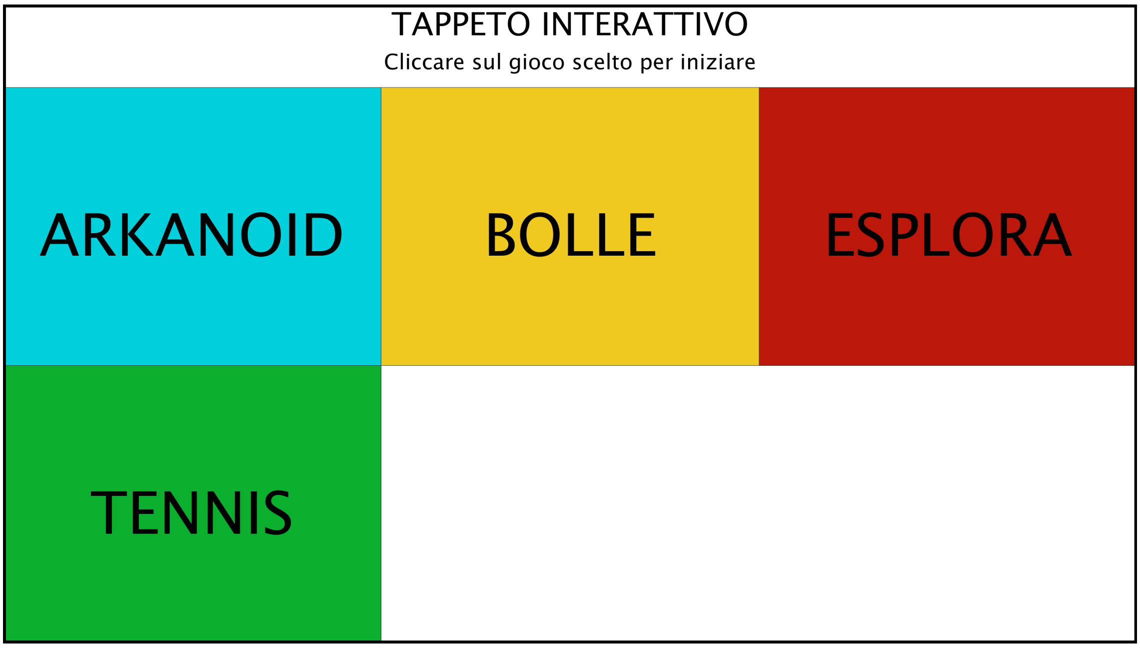


Figure 3.11: The launcher menu view.

As shown in Figure 3.11, the main menu is really simple. It only consists of a title and a set of colored rectangles, each of which represents an available game with its own name. In this way, the desired game can be easily identified and executed by simply clicking on the corresponding square. According to the therapists' instructions, the names have been written in capital letters, using a simple font and a large text format. In this way, the children themselves can read the names and click on the game of their choice or indicated by the therapist. This approach has also been followed for all the other games configuration menus.

Another feature of the menu is the total adaptability to the presence of new games. In fact, it has been designed with future scalability in mind, and every time a new game is implemented, a new colored rectangle with its name is automatically generated. In order not to limit the number of possible rectangles, their size and the size of the font of the titles are automatically adapted according to the number of games available.

3.4.3 Bubbles

The *Bubbles* game is the first mini game created for the See-Sound system. The Bubbles game design was related to the problem statements 1, 3, 4, 5 (see Section 3.2) with the objectives of being fun, train coordination, reaction time, selective attention, color recognition, and to develop in the child the ability to predict a rectilinear trajectory and to plan related movements.

The gameplay is very simple: bubbles appear on the four sides of the field surrounding the player, who must move to explode them. Each bubble bursts when the player steps on it with his body. The game goal is to burst several bubbles in the shortest possible time. The game has a rectangular monochrome playground with some borders of different color which delimit where the player must stay. Inside the field moving bubbles appear, coming in from the borders. Figure 3.12 shows the game field with some bubbles (the white/red circle is the player position, only used for debug and not in production). During the game, a horizontal bar on the top of the screen slowly decreases to mark the passage of time and it increases by a certain

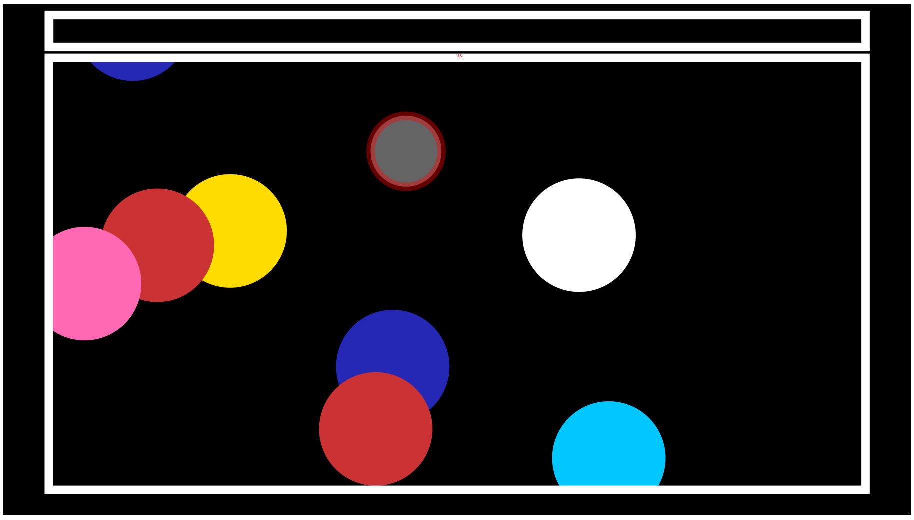


Figure 3.12: The Bubbles game field with some bubbles moving.

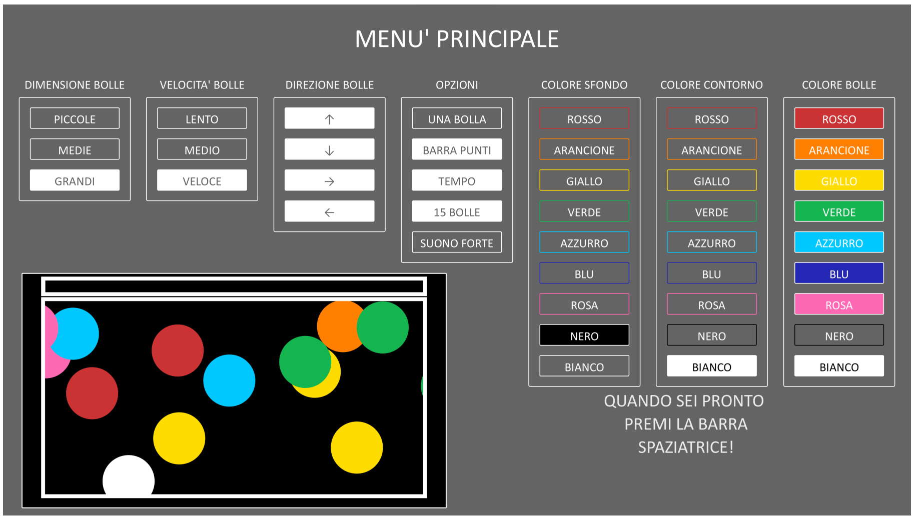
value only when a bubble is burst. The game ends when the bar is fully depleted (or the bubbles has all been exploding, depending on the game mode). This mechanism introduces a penalty for inactivity and stimulates the search of the next bubble. In addition to this, a timer reports the seconds elapsed from the start of the game to give feedback to the operator. When the game ends, music plays and a victory screen appears to let the player know that he has reached the goal of the game. In addition, the time taken to win is also present on this screen, so that the operator can see if the child is making progress.

In order to make the therapists autonomous and allow them to modify game parameters to customize the games for the child using the platform at that moment, a user-friendly configuration interface was developed, visible in Figure 3.13.

The items on the configuration page are explained below:

- *Bubble Size*: set the size that the bubbles in the field will be (small, medium, large). Higher is the size, easier it will be to burst them.

- *Bubble Speed*: set how fast the bubbles will move on the field.



QUANDO SEI PRONTO
PREMI LA BARRA
SPAZIATRICE!

Figure 3.13: The Bubbles game configuration menu.

- *Bubble Direction*: set the direction in which the bubbles will rise. Bubbles can only move in one direction within the field and not in random directions. For example, if a bubble is born on the right side of the screen, it can only move in a horizontal line towards the left side of the screen. horizontal line towards the left side of the screen. Therefore, if you select all the options, you will Therefore, selecting all options will result in bubbles originating from all four sides of the screen.

- *Background Color*: set the background color of the game (only one color can be chosen at a time).

- *Outline Color*: set the color of the borders that define the playing field (only one color can be chosen at a time).

- *Bubble Color*: set the colors of the bubbles that will appear (several colors can be chosen at the same time, each bubble will have its own color).

The central column, called *Options*, allows to select the game mode:

- *One bubble*: only one bubble is generated at a time, requiring the current bubble to be burst before the next one appears and the new bubble will appear as soon as the previous one is hit or exits the screen. Due to the low number of available bubbles, the top bar decreasing behavior has been highly reduced. This mode has been added after initial testing as it is particularly suitable for children that could be confused when a high number of bubbles surrounds them.

- *Fifteen bubbles*: the game finishes when fifteen bubbles have been burst. This is the alternative to the time bar, where no penalties are given for inactivity. This mode has also been added after initial testing modifying standard game mechanics.

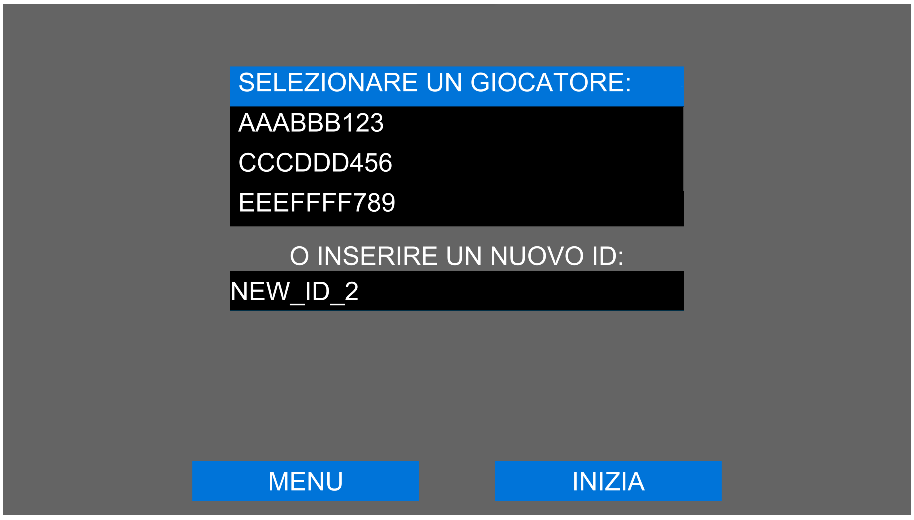
- *Points Bar*: infinite game mode. The points bar that causes the game to end is removed, so the game will only end if the operator presses the M button to return to the setup menu.

- *Time*: removes the elapsed seconds timer (by default it is a red number below the point bar).

- *Loud sound*: when a bubble explodes, instead of playing a *Pop* sound, a louder visual feedback is given (necessary for children with hearing problems).

To further ease the configuration to the therapist, a preview of the final game field is shown in this page.

This game also provides a tool that allows the operator to record, re-watch and analyze previous games. As can be seen in Figure 3.14, before starting the game it is necessary to choose the name of the player (or an identification code that represents them), which can be chosen from those who have already played previously or entered as a new player. In this way, each game started will be saved in a local archive. The


SELEZIONARE UN GIOCATORE:
AAABBB123
CCCDDD456
EEEFFFF789

O INSERIRE UN NUOVO ID:
NEW_ID_2

Figure 3.14: The screen to select the player name.

player's positions and the positions of the bubbles that appeared/exploded during the game will be saved there. For a correct save, the game must end with a win or the operator must press the *M* button to return to the menu. If the program is closed in a different way, part of the game may be lost.

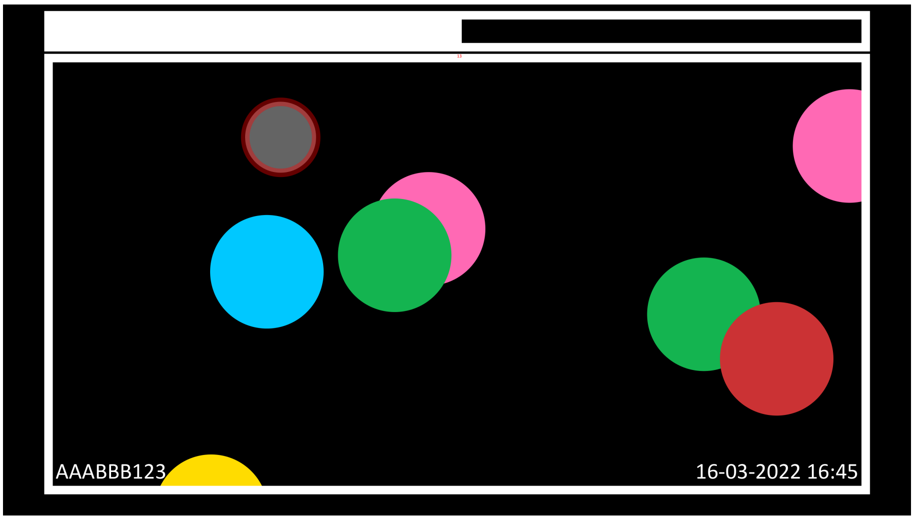


Figure 3.15: What a re-watch of a game looks like.

From the setup menu you can also access a screen where you can choose the player and a game to review from the list of all his plays. After choosing a player and a game, pressing the *Show* button the playing field visible in Figure 3.15 is seen, in which can be found a grey-red circle (the player) that will move exactly the same way the player moved during the chosen game. At the bottom can also be seen the player ID and the date and time of the saved match.

This mechanism is particularly useful for an offline analysis of the children behavior. For example, for the analysis of the data in the following chapters, an algorithm was implemented for the automatic calculation of the player's reaction time using these saved games.

3.4.4 Sound explorer

Another mini game implemented for the See-Sound system is the one called *Sound explorer*.

This game is designed to overcome problem number 2 and aims to develop and improve the ability to understand and recognize absolute spatial references.

The main objective of the Sound explorer is to search for sounds "placed" on the floor around the player, visually marked by colored rectangles (Figure 3.17). The player initially places themselves in the center of the playing field (white circle) and, according to the operator's request, have to move over one of the rectangles to listen a certain sound. When they return inside the white circle, a re-entry sound is played to give them sound feedback. Some examples of operator prompts could be "move to the red rectangle" or "move to the area where the dog sound comes from".

Considering the indications of the second type, due to the fact that players does not have to use their eyesight to locate the colored rectangles but could only rely on the sounds they hear while moving in a certain direction, a particularity of Sound Explorer is that it can also be played by people with total blindness.

The gameplay may seem meagre and lacking in real purpose, but it was decided to proceed in this way because, since spatial orientation training requires a very flexible approach, the therapists asked the team not to implement a predetermined game mechanic. Instead, they suggested a kind of sandbox to verbally propose fun activities to the child with prompts such as “find the kitten”. In this case, the reward that makes the child realize that they have achieved the goal is the pleasant sound that starts when the correct position is reached. Therefore, in order to nurture the player’s curiosity to play new games and to increase the variety of experiences offered, three different sound libraries have been implemented from which the therapist can choose.

As in Bubbles game, a user-friendly configuration interface has also been implemented to allow therapists to customize games according to the child’s needs. In this case there were only two editable options: the sound library used and the game mode (Figure 3.16).

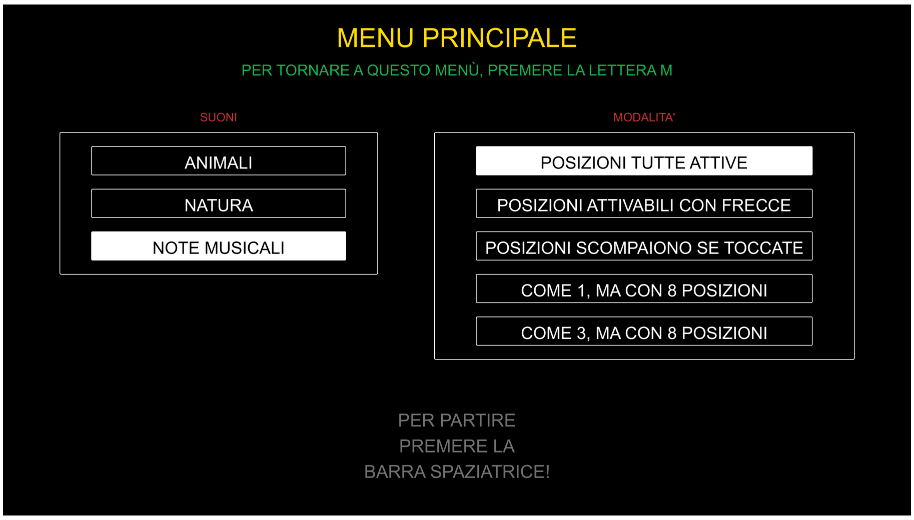


Figure 3.16: The Explore game configuration menu.

Changing the sound library used allows to choose which category of sounds is started when the player reaches one of the colored rectangles. Three sound libraries are currently available: animal noises, nature sounds and musical notes.

The section for choosing the game mode, on the other hand, offers five alternatives. In the first three modes, the playing field is the same: four colored rectangles are positioned around the center (Figure 3.17). The differences lie in the mechanism that makes the colored rectangles visible or not.

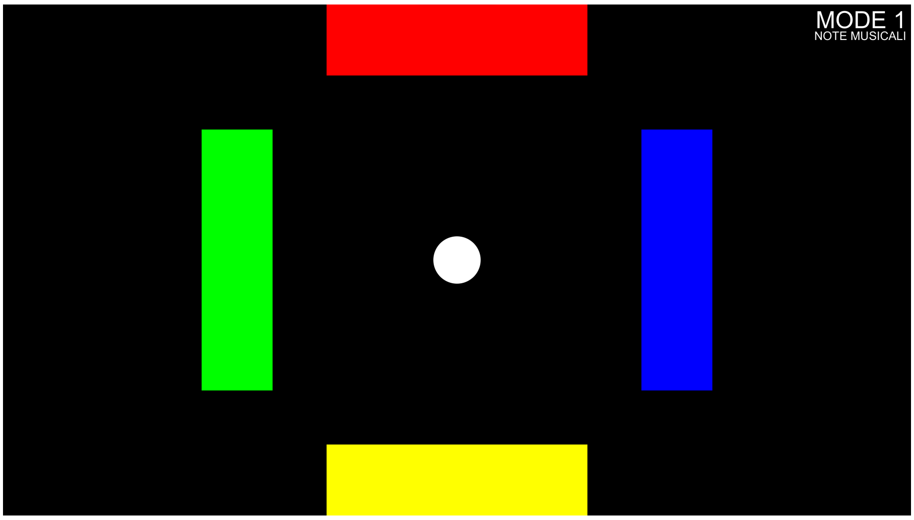


Figure 3.17: The Explore game field on game mode 1, 2, and 3.

Here explained all the game modes:

1. *Positions all active*: in this mode all the rectangles are visible and as soon as the player positions himself on one of them, the sound starts.

2. *Positions activated with arrows*: the field is initially totally black (except for the central circle). The operator can make one or more rectangles visible by pressing the directional arrows on the keyboard. Once it visible, if stepped on by the player, the rectangle plays the sound.

3. *Positions disappear if touched*: also in this mode all the rectangles are visible, but, as the name says, as soon as the player positions himself on one of them, the sound starts and the rectangle disappears.

The last two modes, however, differ from the first three because instead of four rectangles there are eight of them (Figure 3.18). Regarding the rectangle's visibility, instead, modes 4 and 5 work in the same way as modes 1 and 3, respectively.

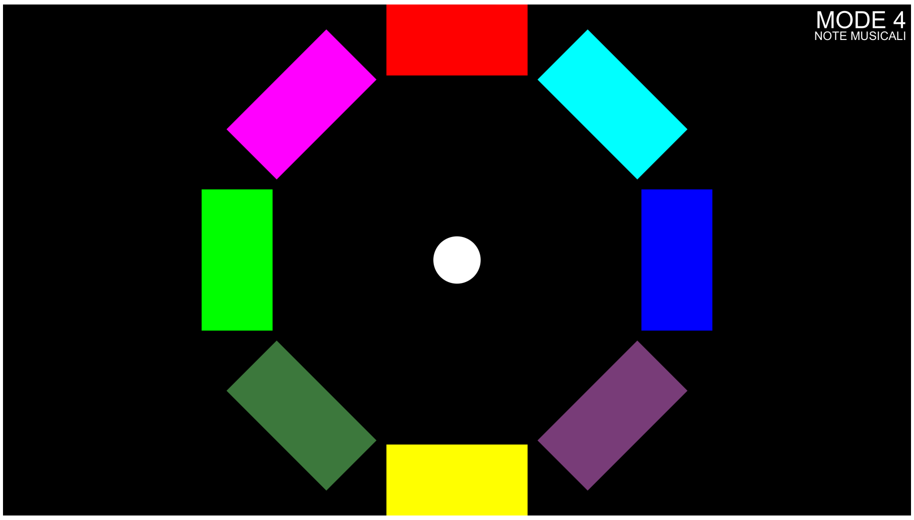


Figure 3.18: The Explore game field on game mode 4 and 5.

3.4.5 Ping Pong

The latest game implemented entirely for the See-Sound project is called *Ping Pong*.

This game was developed to respond to the therapeutic need expressed in problem 6, to play exchange games to support the relationship and the expectation of one's turn. Even in this case, the gameplay is very simple, to allow children of all ages to play, but in reality it requires good visual-motor coordination that must also be combined with the audio feedback generated when the ball hits the racket or the lines of the playing field.

Ping pong is a remake for a large-scale interactive environment of one of the first computer games ever created: *Pong*. The gameplay is very simple and similar to tennis: you play with two players, the playing field divided into two parts, in each of which there is a racket controlled by one of the two players, and a bouncing ball.

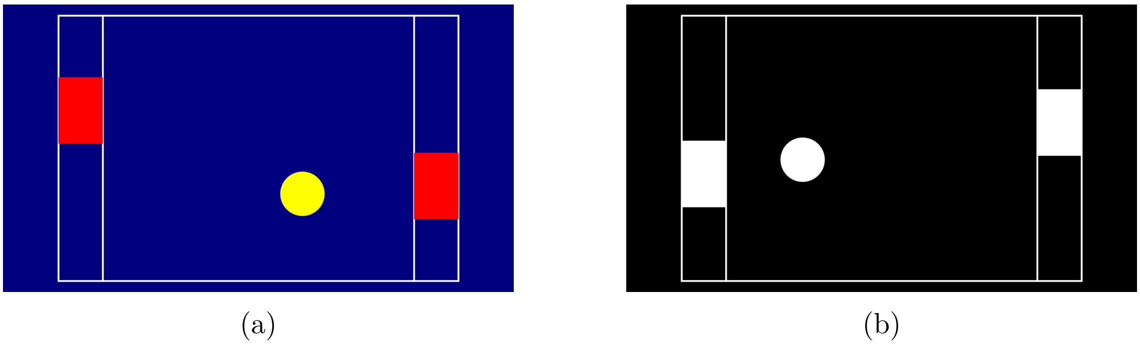

(a) (b)

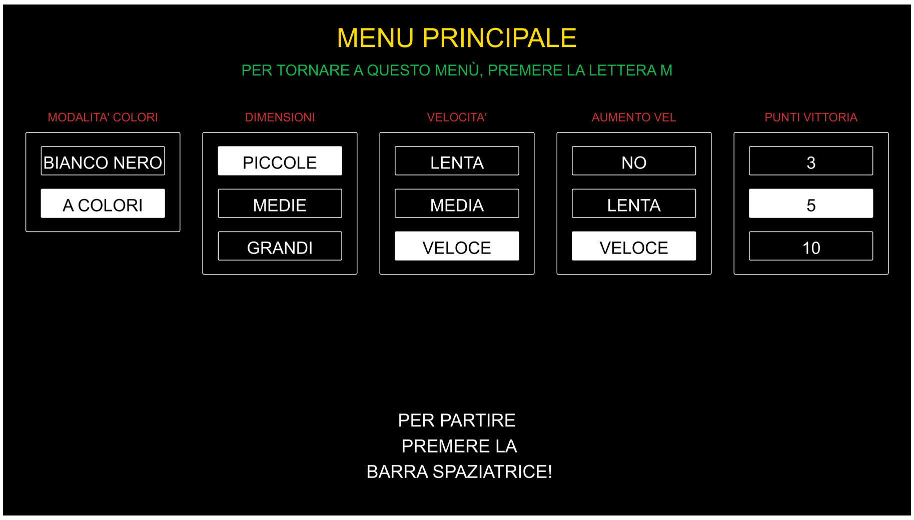
Figure 3.19: The Ping Pong game field on colors (a) and B/W (b) mode.

Each player controls the racket (the red rectangle in Figure 3.19) on their part of the court using their own body, as its position corresponds to the player's position. The ball starts from the center of the court and bounces within the boundaries of the field. The aim of the game is to intercept the trajectory of the ball with its own racket, so that it bounces off it and makes the point in the opponent's field. If the ball crosses the racket margin, the player on the opposite side gets a point. The game ends when a predetermined number of points is reached.

As with the previous games, the properties of the rackets, the ball and the gameplay can be adjusted to suit child's needs via the configuration menu (Figure 3.20).

Below is an explanation of all the properties that can be customized:

- *Colors mode*: in order to facilitate the identification of the game elements, the chosen colors for field lines, background, and game component are always of high contrast and all the lines of the playing field have a high thickness (about 10 cm, depending on the projector). This option allows to choose between two color palettes (Figure 3.19):
  - *Black White*: the field will be black, the borders and rackets white.
  - *Colors*: the field will be blue, the borders and rackets yellow.



MENU PRINCIPALE

PER TORNARE A QUESTO MENÙ, PREMERE LA LETTERA M

PER PARTIRE
PREMERE LA
BARRA SPAZIATRICE!

Figure 3.20: The Ping Pong game configuration menu.

- *Size*: allows to choose the size of the ball and rackets.
- *Speed*: allows to choose the speed at which the ball moves around the field.
- *Speed Boost*: in order to keep the game not boring and increase its durability, enabling this option allows to choose whether and how fast the ball will increase its speed after being touched by a racket and after each point: this is a entertaining feature that requires players to be faster and faster as the game goes on.
- *Victory points*: how many points a player must score before being declared the winner.

Evaluation and discussion

Helped by Robert Hollman Foundation's therapists, we assessed the system's usability and appraisal through a pilot test involving 11 children with visual impairment.

4.1 Subjects

A very important challenge in this research field is set by the fact that childhood visual impairment is relatively rare, and it is difficult to find a homogeneous sample of cases. Many studies of development in this population have small sample sizes and they frequently gather rich longitudinal data but using a very small number of infants or young children [19]. Therefore, being also a heterogeneous population, when conclusions are based on just two or three children, it is not surprising that studies produce contradictory results [102]. The high rate of children with visual impairment who have additional brain involvement and/or additional needs is another methodological challenge [103]. Thus, caution is required when comparing children with visual impairment to their sighted peers and observations need to be interpreted from the perspective of how the child with visual impairment learns and makes sense of their environment.

Taking all these statements into account, the therapists recruited study participants from among the children with visual impairments who came to the Foundation.

All participants included had age between 3 and 8 years, and confirmed diagnosis of Low Vision, while the main exclusion criteria were presence of a degenerative visual and/or physical pathology, or other associated disabilities. The research team member in charge of recruitment explained the study design to the families, who gave their consent to include their children in the study with the freedom to stop it at any time. A total of 11 children participated in the study, the characteristics of which are summarized in Table 4.1.

Age (years)	Mean	5.68
	Standard Deviation	1.77
Sex	Female	5
	Male	6
Diagnosis	Moderate low vision	8
	Severe low vision	1
	Blindness, monocular	2

(a) Children's sample summary.

#	*Sex*	*Age*	*Visus*	*Code*	*VI Type*	*Rehab. started [y]*	*Sessions Played*
1	M	5y 11m	1/10	OO	Severe	3.8	1
2	M	6y 7m	1/10	OD	Severe	5.7	3
3	M	2y 7m	1/10	OD	Severe	2.3	2
4	F	8y 4m	2/10	OO	Moderate-Severe	2.6	2
5	F	5y 10m	2/10	OO	Moderate-Severe	5.3	4
6	F	5y 10m	1/10	OO	Severe	4.6	3
7	F	7y 7m	2/10	OO	Moderate-Severe	3.8	4
8	M	5y 3m	3/10	OO	Mild	5.0	4
9	M	7y 5m	2/10	OS	Moderate-Severe	6.1	1
10	F	5y 6m	1/10	OS	Severe	5.1	2
11	M	3y 3m	2/10	OS	Moderate-Severe	2.8	2

(b) Children's sample details.

Table 4.1: Sample characteristics.

In the table, the value *OO* means that visual acuity was assessed with both eyes together. If there is measurement in only one eye (*OD* or *OS*, i.e., right and left eye respectively) it was assessed with occlusion (blindfold over the other eye). Often there is a difference in visual acuity between the two eyes and the better eye is indicated to define the classification of the severity of visual impairment according to the Law of the country.

Unfortunately, there were two major setbacks along the way: inconsistent participation and drop-out. Indeed, due to the COVID-19 pandemic and seasonal flu, participation was less consistent than expected, so that none of the children managed to attend all five sessions. Moreover, one very young child left the study in the third week because, frightened by the lights, he was unable to adapt to the new proposal.

4.2 Materials

For the duration of the test, the therapists included a period of time dedicated to the See-Sound system in the patients' rehabilitation programs. During this 15 minutes of time, the system replaced the classic therapy activities as a new stimulus for the development of visuomotor activities.

To normalize the test results, the first round of each session was on the game *Bubbles* for all participants and for the whole test period. This match was preconfigured with the following parameters: maximum bubble size, slow speed movement and in all directions, bubbles of all colors, white background, and black field's borders. The first bubble was black and always started from the center of the right side of the field. The game ended automatically after 10 bubbles had been burst. The *One bubble* mode was also activated, so as long as the bubble on the field was not burst or came out the other side, no new bubbles were generated. In each of these games it was necessary to always start the children at the same point: the center of the game field. In this way, the reaction times of the participants could be calculated later.

Subsequent games were, however, custom-structured by the therapist in relation to the child's preferences, the rehabilitation goals of the training, and the child's performance during the previous session. In order to verify that different types of stimuli could be used, the intermediate proposals could be either the game *Bubbles* with different characteristics, or the other two games (i.e., *Sound explorer* and *Ping pong*).

Children satisfaction

In order to assess the quality of the games and whether or not they were appreciated by the players, at the end of each session the therapists asked the children how much they enjoyed the activities they had just done. To assess the subjective satisfaction of each child, a visuo-tactile VAS scale was used, which was adapted to be used by children with visual impairment.

The VAS scale is an analogue psychometric survey system that allows to collect in a simplified way how an individual perceives a specific situation or experience [104]. The VAS scale used included three smileys to give the child the opportunity to vote how much fun they had. As can be guessed, the red sad face corresponded to "not at all", the yellow face to "so and so", and the green happy face to "very much".

As can be seen in Figure 4.1, two adaptations have been made to allow children with visual impairment to use the scale without problems. Firstly, the smileys have bright and contrasting colors that are easily perceived. Secondly, a tactile mouth made of different materials has been applied for each face, to allow the child to perceive the orientation of the smiley (down, straight, up) just by touching the paper to help them to understand which figure it is.

Figure 4.1: The VAS scale for satisfaction adapted for visual impairment.

To better analyze children behaviors and system utility, other useful information has been collected on each session using different tools:

- *Therapist's diary*: therapists took notes at the end of each session about the most significant and intriguing aspects of the experience, which have been analyzed to integrate the collected data with qualitative observations.
- *Game's log*: as explained in previous chapters, a mechanism has been built into the games to collect various technical information throughout the duration of a game, such as the position of the player and objects around him. These logs were processed through an algorithm to calculate the children's reaction times as a supplement and reinforcement to the analyses made on the subjective data.
- *Video recording*: two video cameras installed in the walls of the room recorded all sessions to provide an objective and detailed record of the child's progress. These videos will only be analyzed by authorized personnel to protect the confidentiality of the subjects. Analyses will be able to provide further information on reaction times, confirming the measures provided by the logs, and will allow the evaluation of the child's experience from an external, expert perspective (assessing the child's behavior and bodily reactions). Training performance

data were collected on a remote database available at the Foundation.

Usability questionnaire

The team also produced a questionnaire to investigate the usability of the system by therapists. The questionnaire, available in Italian at the link at the bottom of the page [1], is composed of nine questions (Q1-9) about the experience of using the mini games, followed by the ten standard questions (Q10.1-10) of the *Systems Usability Scale* (SUS) questionnaire. All the answers are based on a 5-point Likert scale, where 1 means *Strongly Disagree* and 5 means *Strongly Agree* with the proposed sentence. After each question in the first section and at the end of the SUS section, additional white space was provided to encourage and allow respondents to add comments.

4.3 Method

The test was carried out during the period November-December 2021, during which participants played the mini games in the Foundation's dedicated room for 5 consecutive weeks, once a week, for 15 minutes per session. The therapists involved were given a course on how the system works and on methods of proposing games to the child. Each participant had a reference therapist who, after initially introducing the proposal and choosing according to the child's preferences the game to play, remained at the child's side throughout the session. In order to leave the child as much freedom as possible, it was important that the therapist remained outside the play area as much as possible, only helping them when they was in difficulty. When necessary, a second therapist was involved in the room to manage the computer system, in order to allow the reference therapist to focus only on the child.

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[1] `http://www.dei.unipd.it/~roda/mini-games/questionnaire.pdf`

As said, the starting game of each session was *Bubbles* for all participants and for the whole period of training.

The intermediate proposal, which could be either the game *Bubbles* (with different characteristics), *Sound explorer*, or *Ping pong*, instead, was tailor-made by the therapist in relation to the preference of the child, the rehabilitative objectives of the training, and the performance of the child during the previous session. All rounds were customized using the configuration menus to adapt the games to the child's needs and to ensure that the gameplay remained within the "optimal gameplay corridor", which allows the player not to be frustrated by a game experience that is too difficult but also not to be bored by one that is too simple (Figure 4.2).

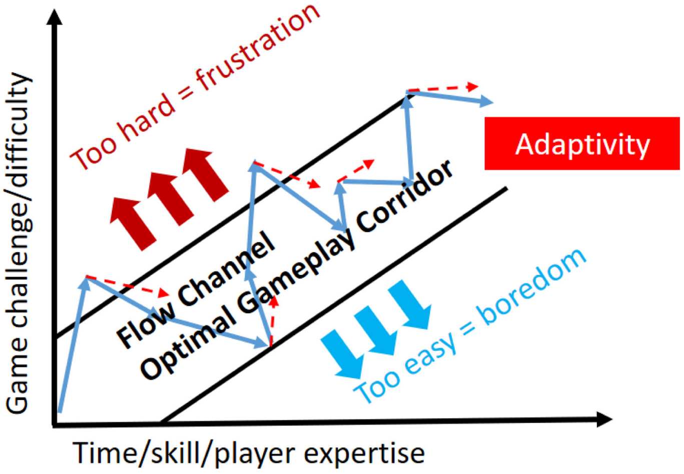


Figure 4.2: The therapists should increase/decrease the game difficulty, relying on player performance, to remain inside the optimal gameplay corridor, helping them to adapt to the game[105].

To assess game's quality and players appreciation, at the end of each session the therapists asked the children how much they enjoyed the activities they had just done. The presentation of the figure to the children was the same at every session: first, the therapists presented in front of the child them individually (Figure 4.3), giving the children time to explore each face both with the visual and the tactile modalities, and then all the three smileys together. After the presentation, the therapist asked the question “Did you enjoy playing this game?” and the child gave their answer, either pointing or touching the smiley, or verbally.

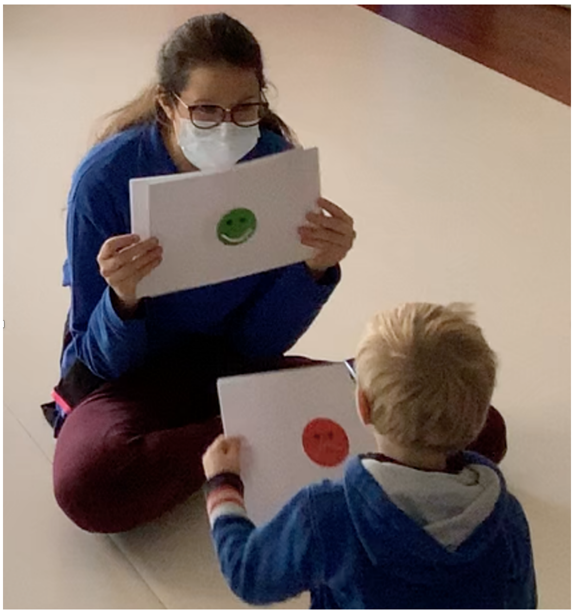


Figure 4.3: How the tactile satisfaction VAS scale has been presented to children.

After the conclusion of the training and the preliminary tests with the children, a questionnaire to investigate the usability of the system was administered to all four therapists involved in the project. These results, whose analysis is presented below in detail, were used by the team to improve the usability of the system and to simplify and automate some cumbersome steps that were spoiling the experience of both the operator and the child.

4.4 Results

In this section the results from the analysis of data collected during the project will be presented.

Regarding children’s satisfaction with the game, the system seems to have been highly appreciated. In fact, as can be seen in Table 4.2, almost all of them, using the tactile VAS scale, rated their level of enjoyment during all the sessions with the maximum score (value *3* in the table). To confirm the ratings, some phrases expressed during the game and reported by the therapists are: “It’s magic!”, “I can’t wait to burst the bubbles”, “Teacher, this is fun for me!”. Many of them expressed that they would like to continue playing even after the end of the testing period, spontaneously asking every week to play during their therapy sessions.

Although the children generally showed greater motivation in the first few sessions, interest waned by the third or fourth game for some of them, especially the older ones. Therefore, the introduction of a wider range of available games and additional levels of difficulty could ensure that interest in the system would remain high for longer.

Session	Score 1 *Not at all*	Score 2 *So and so*	Score 3 *Very much*
1st	0	1	5
2nd	0	0	5
3rd	0	0	5
4th	0	0	7
5th	0	0	5

Table 4.2: Summary of the marks given by the children for each session.

Another analysis was done using the logs of the recorded games. An algorithm has been implemented to automatically analyze the logs of the children’s positions and the bubbles during the first game of each session. The values extrapolated from the game’s logs are the reaction time of the child (after how many milliseconds it notices that a new bubble has been born in the playing field) and the time taken to reach the new bubble since its birth (called “Time to bubble” in the tables).

It is necessary to take into account the main criticism encountered during the data analysis: the low participation of children. As already explained, a big problem was the absence of the children from the therapy sessions due to health reasons.

None of them participated in all five meetings arranged for this test. Unfortunately, not having a large enough sample of participants and sessions carried out, it was not possible to make statistical analyses, but some assumptions based on the results and the segmentation of the samples.

Moreover, two children only attended one of the five sessions. This made it impossible to assess a time trend in their course. They were therefore removed from the following analysis. The participants evaluated for the analysis are therefore nine. It is possible to see the details of their times in the Table 4.3. In this was entered for each participant the average value of the times obtained during an entire game analyzed. The white boxes indicate that the participant was absent during that week's session.

	Reaction time [ms]				**Time to bubble [ms]**			
Player ID	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
2	2262	2117	2108		3054	2894	2752	
3	3753	2862			5663	4281		
4	2303	2028			3157	3663		
5	2572	2803	2088	1792	3230	4220	3387	3117
6	2340	2533	2275		3773	4160	3023	
7	2793	3100	2502	2224	3517	3900	3632	3847
8	1600	1837	2312	1606	2402	3033	3987	3160
10	2540	1844			5485	3114		
11	3080	1534			7261	3379		

Table 4.3: Average time results for each children and session.

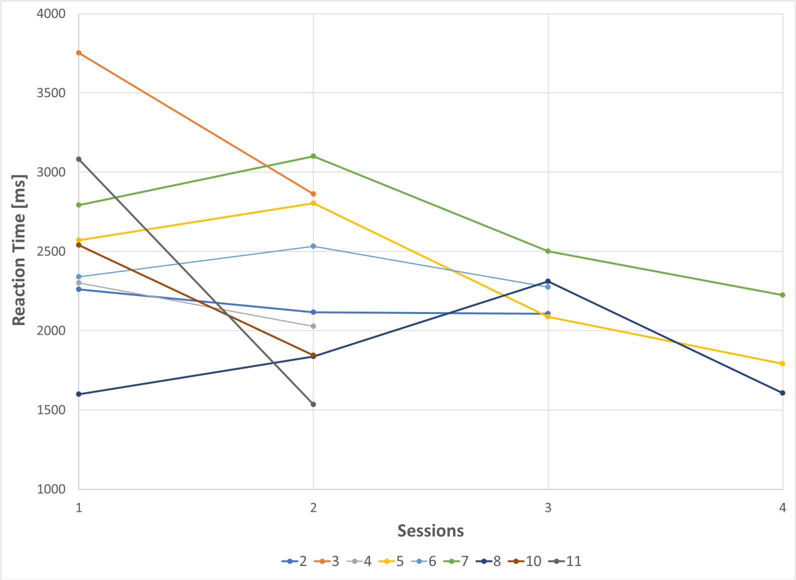
In the Figure 4.4 we can see a graphical representation of these values during the game sessions. We can clearly see that in both values, for some participants more and for others less, the trend of the graphs is downward. Unfortunately, such a low number of sessions cannot statistically prove our thesis. However, it cannot be denied that, since there was a decrease in all participants times, if the test had been continued, the theory would probably have been confirmed. This therefore suggests that the system we devised can be a valid support tool to add to a therapy rehabilitation course.

Interestingly, in some cases the downward trend leads to some upward peaks. This can be caused by many reasons. For example, the mood of the child in a day session influences a lot their involvement in the activity. Another problem is the random generation of bubbles, which sometimes arise at a point close to the player's position and take very little time to reach. The color of the bubble also has a great influence, with children seeing some colors more easily and others taking longer.

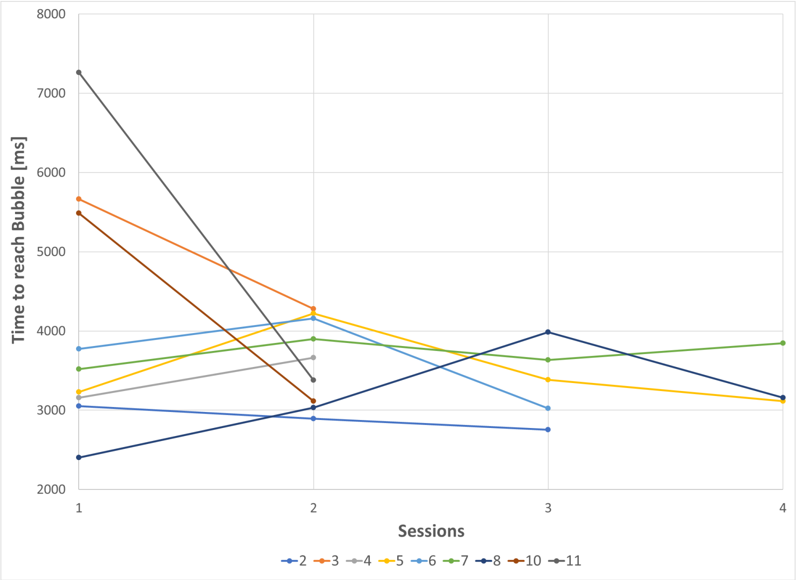
Segmentation based on "time from start of neuro-visual therapy"

With the help of the more experienced members of the team, some data analyses were prepared in order to verify the functioning of the system as a tool for therapists. A first analysis was made by dividing the participants into two groups. The criterion for the division was the number of days since the child started the rehabilitation process at the Foundation. In particular, children with more than four and a half years of therapy behind them were divided from those with less time. For each group, the time values seen in the previous section were averaged for each session. In the Table 4.4 the details of the participants and the two groups can be seen.

On the other hand, in the graphs in Figure 4.5 we can see the time trends. Again, it can easily be seen that the trend in both graphs is downward. Furthermore, children who have been participating in therapy for less time have slightly worse results. We can therefore say that children who were already used to the activities of the Foundation's courses quickly understood how the game works and were able to adapt very quickly to the new tool used. This confirms that, thanks to the careful design, the system developed is in line with the others used at the Foundation and adapts very well to the needs of the therapists, becoming to all intents and purposes a good tool to be integrated into the rehabilitation pathways.



(a)



(b)

Figure 4.4: Chart of reaction time (a) and time to reach a bubble after is born (b) for all children.

Segmentation based on "visual impairment severity"

A second segmentation of the data was also made. In this case, the division criterion was the severity of the visual impairment of the patient. In particular, the

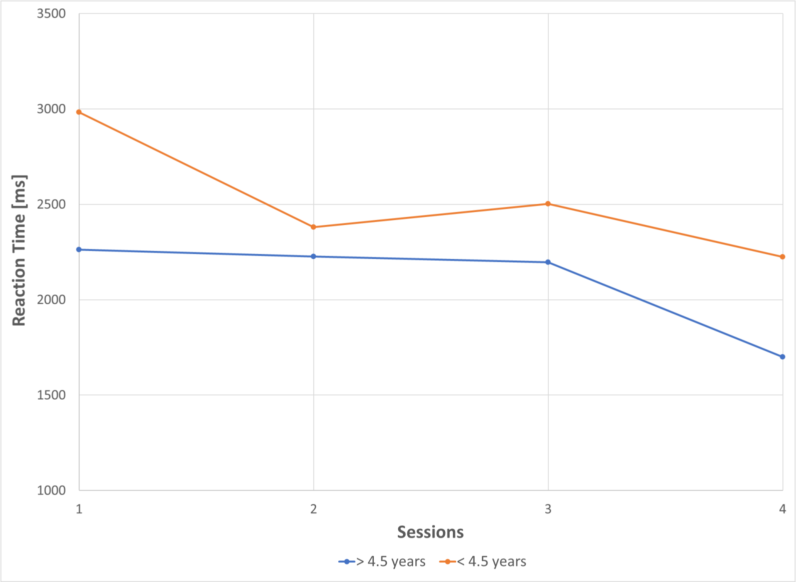
	Reaction time [ms]				**Time to bubble [ms]**			
Rehab. time	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
> 4.5 years	2263	2227	2196	1699	3589	3484	3287	3138
< 4.5 years	2982	2381	2502	2224	4899	3806	3632	3847

Table 4.4: Average time results for data segmented by time from start of neuro-visual therapy.

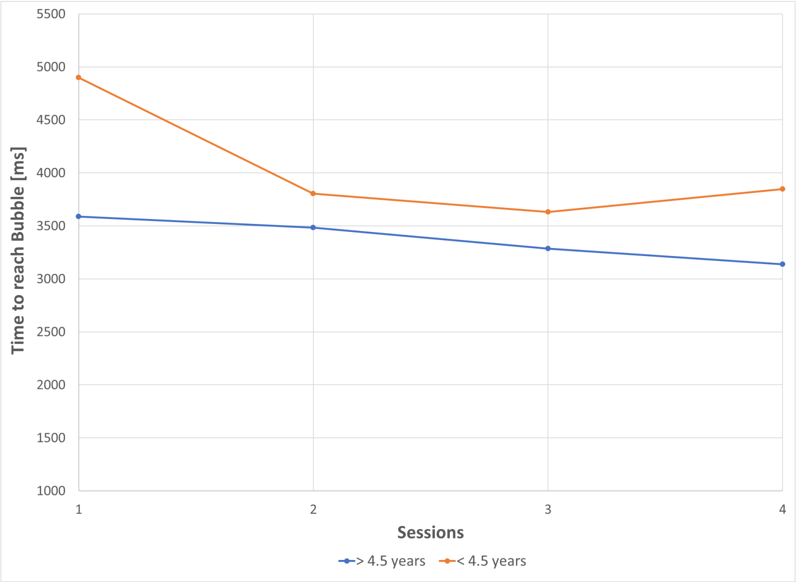
participants were divided into *Severe* (children with severe visual impairment) and *Moderate* (moderate to severe or mild visual impairment). Again, for each group, the times of the values seen in the previous section were averaged for each session. In the Table 4.5 we can see the details of the participants and the two groups.

In this analysis we encountered an important critical point. Unfortunately, most of the children in the first group did not complete more than two sessions. Therefore, as can also be seen from the graphs in Figure 4.6, the data does not totally reflect reality. In fact, while in the case of the *Moderate* group the trend is very similar to that of the graphs of the individual child, in the case of the *Severe* group we can see a very rapid descent in session 3 and a lack of data in session 4. This strangeness is explained by the problems listed above. In fact, session 3 is calculated using only the data of two participants (the only ones who participated in the third session). As a session advanced in time, the children had already adapted to the game and performed very well, lowering the average time of that session for their group. None of the children in the Severe group participated in the fourth session, making it impossible to create a valid average.

Analyzing the graphs, it is possible to notice a similarity between the two series that we did not expect. In fact, since the data is based on the game *Bubbles*, which requires the use of sight, we expected a greater gap between the two series. In particular, the line of the *Severe* group should have been higher than the other, as children with higher visual impairment would have struggled more with the game,



(a)



(b)

Figure 4.5: Chart of reaction time (a) and time to reach a bubble after is born (b) for children segmented into two group by their time from start of neuro-visual therapy.

achieving higher times. Instead, as can be seen, the two lines are very close together. From these data we can deduce that the design of the games led to a very high level of accessibility of the games. In particular, the customization of the parameters seems to have been very useful to the therapists in order to adapt the games to the children's abilities in the best possible way. For example, it was noted that the sound feedback related to the bursting of the ball and the possibility to choose its intensity, was perceived by the players as a reward that encouraged them to continue the game and helped them to better understand the position of the bubbles. On the other hand, from another point of view, the low performance of the children in the *Moderate* group could be due to a loss of involvement in the game caused by the low level of challenge (as the parameters used during the test were the same for all sessions and all participants).

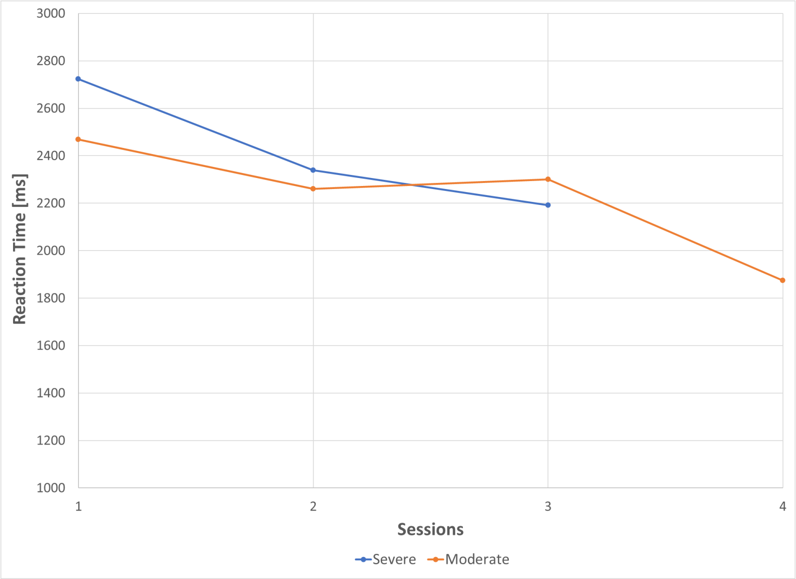
	Reaction time [ms]				**Time to bubble [ms]**			
VI severity	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
Severe	2724	2339	2191		4494	3612	2887	
Moderate	2470	2260	2301	1874	3913	3639	3669	3375

Table 4.5: Average time results for data segmented by visual impairment severity.

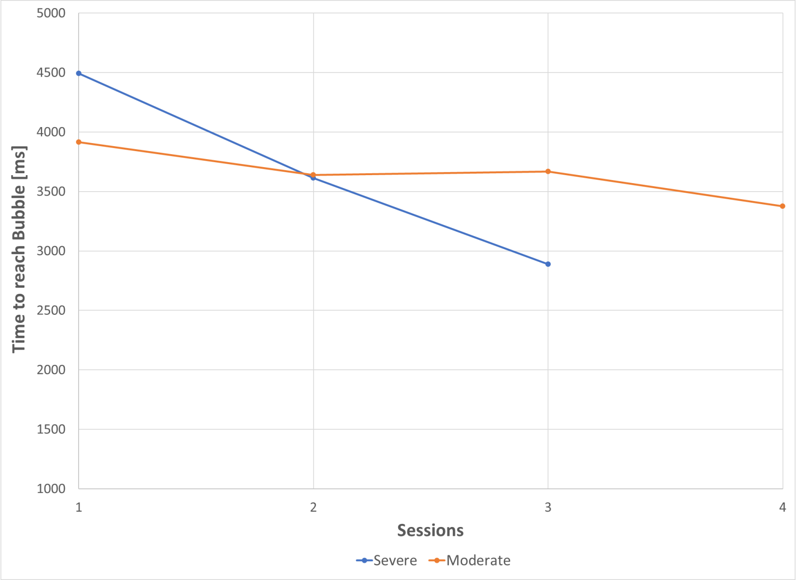
Analysis of subjects with comorbidity

A further analysis, helpful to understand the usefulness of the system, has been the one carried out on the timing and behavior of children with comorbidity. In health care, the term comorbidity refers to the coexistence of several different diseases in the same individual. Of the sample used for the test, two subjects have comorbidities.

Subject number 6, in addition to severe visual impairment, has dyspraxia. Dyspraxia is classified as a "developmental co-ordination disorder". It is a permanent congenital (or early acquired) disorder of performing an intentional action. So, it is a developmental disorder of motor coordination. The child with dyspraxia has difficulty in planning, programming, and executing motor acts with a purpose. For this reason, we analyzed this participant's times in comparison with the average times of other children without comorbidity. Using only the logs obtained from the games,



(a)



(b)

Figure 4.6: Chart of reaction time (a) and time to reach a bubble after is born (b) for children segmented into two group by their visual impairment severity.

it was found that the reaction times are above the average of the other participants, while the times to reach the bubble are comparable to the average (for one session even below the average). We also analyzed the diaries and the video recordings to verify the correctness of the data. The analysis of the former shows that in the first session the child partially recognizes the location of themselves in the space by positioning on the starting line but referring to the small test square on the right, instead of the large game area that is about to appear. In subsequent sessions they helps to prepare the room if invited to do so and recognizes their own placement in the space by positioning autonomously and correctly at the start of the game field. The participant also asked several questions of curiosity about the functioning of the interactive carpet. From the recordings, the enthusiasm generated by the activity is very evident. In fact, they move constantly and expresses it by running, jumping, throwing themselves down on the carpet, and hugging the therapist. They are very focused on the game and moves between the bubbles in a quick and agile way. From the therapists' analyses, they were rated with the highest marks for the development of directionality and orientation, precision in reaching the goal, visual exploration, reaction time, containment within the play area, and anticipation of the trajectory.

Subject number 7, on the other hand, in addition to a moderate-severe visual impairment, has Down's syndrome and a cognitive delay. Also in this case, the analysis of the logs obtained from the saved games showed that the reaction times are higher than the average of the other participants, while the times to reach the bubble are comparable to the average. On the other hand, the analysis of the diaries shows that the subject improved some skills during the sessions. In the first session, with respect to visual-motor coordination skills, they had longer reaction times and jumped over the edge of the bubble. In the following sessions, however, there was an improvement in visual-motor coordination and accuracy when jumping into the bubbles. For the duration of the test, they were unable to anticipate the trajectory of the bubbles, chasing them to burst them. From the analysis of the videos, however, we can see the subject's involvement in the game, even asking the therapist to play again. The child can even read the words “You win” on the final screen of the game, expressing elation due to the result by dancing and saying positive phrases. They received the highest rating in the categories of developing directionality and orientation, recognizing his position in the room and objects around them, and restraint within the play area. The child received lower marks in the categories of reaction time and accuracy (they were always touching with hands or jumping into the edge of the bubble, not realizing that had to go inside to explode it).

These results lead us to confirm that the main objective of the system design, i.e., accessibility and the possibility to be used also by patients with multiple disabilities, has been successfully achieved. It also confirms the functionality of the games as a useful tool for rehabilitation but at the same time playful and engaging, inviting the children to continue with their therapy activities.

Analysis of therapists' diaries and video recordings

In addition to the logs of the recorded matches that led to the previous results, the therapists' diaries and video recordings of the sessions were also analyzed. From the analyses we extrapolated the following qualitative results:

- All participants were highly engaged by the games. Many expressed their enthusiasm by actively participating in the preparation, jumping around, laughing, and happily accepting all the game suggestions. Many asked to play again and to continue after the session was over.

- Most of the participants improved their perception of space and their orientation in the room during the sessions.

- The main difficulty encountered by children during the sessions was predicting a trajectory for bursting the bubbles. Being an advanced skill, it developed more slowly than the previous ones. Most of them tended to chase the bubbles rather than predict where they would go.

- The size of the lettering and the font used proved adequate for the participants, who were able to read the game options. This made them autonomous in setting up the games according to their own preferences.

- The possibility of being able to change the game parameters proved to be very important, allowing the games to be adapted to the needs of each child.

- Almost all participants helped to prepare the room for the game. This process helped the therapists to make the children curious and to more involve them in the activity.

- Most participants were also able to manage the presence of several bubbles in the playground by blowing them in sequence (divided attention).

- All participants improved in directionality, orientation, accuracy of their trajectories, reaction time, and the ability to stay within the 'playing' field.

Analysis of the usability questionnaire for therapists

A summary of the results of the Likert scale analysis is shown in Table 4.6 where the column headings correspond to a 5-point Likert scale going from *Strongly Disagree (1)* to *Strongly Agree (5)* and the most frequently-chosen answers are highlighted in bold.

Although some technical problems emerged during the sessions, overall, the therapists rated the user experience positively.

Questions Q1 and Q6 suggest that the game instructions were easy to understand and explain to the children, although, according to an additional note, one respondent would have liked a standard explanation offered to all therapists, and clearer instructions on the possibility to intervene verbally during the game. Questions Q9 and Q4, on the other hand, tell us that all respondents felt comfortable using the

	1	*2*	*3*	*4*	*5*
Q1	**2**	**2**	0	0	0
Q2	0	0	1	**3**	0
Q3	**2**	1	1	0	0
Q4	0	1	1	**2**	0
Q5	0	0	1	**2**	1
Q6	0	0	1	**2**	1
Q7	1	**2**	1	0	0
Q8	0	0	**2**	**2**	0
Q9	0	0	0	**2**	**2**

(a) Usage experience questionnaire.

	1	*2*	*3*	*4*	*5*
Q10.1	0	1	**2**	1	0
Q10.2	**3**	1	0	0	0
Q10.3	0	1	**2**	1	0
Q10.4	**3**	1	0	0	0
Q10.5	0	**2**	**2**	0	0
Q10.6	**2**	0	**2**	0	0
Q10.7	0	0	**3**	1	0
Q10.8	**3**	0	1	0	0
Q10.9	0	0	**4**	0	0
Q10.10	**3**	1	0	0	0

(b) SUS questionnaire.

Table 4.6: Therapist's usability questionnaire results.

system on their own, but thought it might be useful to benefit from the presence of a colleague to handle the technical part. Some additional notes pointed out that this benefit would vary greatly from child to child: some children learned the system so quickly that they could even set up the games themselves, while others would be inhibited by the presence of other people to the point of not being able to engage in the proposed activities.

Talking about the relationship between therapist and child, from questions Q3 and Q8 it can also be seen that the system did not create a barrier between the therapists and the children and helped to create and strengthen their relationship. In the answers to these two questions two exceptions can be noted: a child who strictly refused to participate because of the videotaped sessions, and a child who, perhaps because of his too small age, did not want to enter the play area out of fear.

Thanks to the possibility of quickly changing the configuration of the games, all the therapists found that the mini games helped them to improve their therapeutic work and to test the skills and progress of each child (Q5). Furthermore, responses to question Q2 indicated that the mini games were also useful in helping to focus on new aspects of therapeutic work, in particular helping to strengthen the relationship with the children, and allowing therapists to observe how the children observe, explore, and interact with their surrounding space.

In an additional note, one therapist noted that some children find it difficult to observe and react to obstacles and moving objects (such as a ball, a car or another child), so presenting visual stimuli that do not pose a threat to the child can help them focus their attention on their surroundings and react accordingly. Therefore, the mini games were not considered an obstacle to therapy (Q7) but a good support tool for classic ones, even though it was suggested to develop further games and an additional level of difficulty in the existing ones.

Due to the too small sample of people interviewed and some questions not necessarily directly applicable to this project, the score calculated from the SUS questionnaire can only be partially considered. The answers scored between 50 and 62.5, with an average of 56.25, corresponding to “marginally acceptable” usability. Therefore, linking this result to the analysis of the previous answers and the additional comments, it is clear that the system has been well received and appreciated, but there are opportunities for improvement both in user interface simplification and usability, and in expanding the library of available games.

4.5 Critical points

Through the previous analyses, we also drew up a list of critical issues encountered during the test and sessions.

The first issue was ethical. It was not possible to compare the improvements given by the system with the improvements given by classic activities. In fact, when it was explained to the parents that some children would receive this experimental treatment, some of them complained saying that, if it worked better, it should be applied to everyone. Furthermore, as described above, it was not very useful to compare the results of children with visual impairment with those of children without, as the first have slower developments of some visual-motor skills. For this reason, the comparison would not have been accurate, and we would not have been able to produce adequate results. It was therefore decided to proceed by sampling all children of the Foundation which meets the above criteria and only children with visual impairment.

Another critical issue was the age of the children. Older children were bored with the large, slow bubble tests. Therefore, some results are distorted by the patient's unwillingness to play the game (an urge that returned when the game parameters, such as number of bubbles, size and speed, were adjusted to their potential). At the same time, in the first sessions the younger children were afraid of the system, being a new environment and with an activity they had never seen before. A mistake, which was solved in the following sessions, was to present the child the environment already dark and without lights, with the system ready to be used. This made it impossible for the children to understand where they were, which frightened them. In fact, the results show that this category of children has long reaction time compared to the others, as they often returned to the therapist's arms (frightened by the sound of the exploding bubble or by the movements of the bubbles on the ground).

The last critical point is the frequency of participation. Since most of the patients began to adapt to the system from the second meeting, those who only participated in one session had no obvious results. The latter, since they could not give valid results, were removed from the previous analyses, further reducing the already small sample of participants.

4.6 Discussion of results

This section summarizes the main results of the team's discussion after the end of the test. The main topics are some strengths of the system, the skills most developed by the children during the experience, some useful indications for therapists and some useful guidelines for the development of future systems along the lines of this project.

4.6.1 Game adaptation

One of the features most appreciated by the therapists was the presence of an intuitive interface through which the characteristics of the game can be selected. This allowed them to create a proposal adapted to that specific moment in the growth of each child, to the objectives of their rehabilitation path, to their desires, and to their level of tiredness/activity. The use of high contrast colors and simple shapes of adequate size allowed all the children, including those with the lowest residual vision, to play and express themselves in the best conditions, creating a decisive factor in sustaining their motivation in adhering to the proposal.

The presence of the configuration interface was also appreciated by the children. In fact, thanks to the large capital letters, they were able to read the game commands (e.g., color, size, speed, etc.) directly on the projection on the floor in order to choose the options they preferred so that they could be directly involved in customizing the games. The co-design of the training program contributed greatly to increasing the children's motivation, intent, and active involvement in the game and, at the same time, made the game as suitable and accessible as possible to their needs.

An initial adaptation phase was important in order to familiarize the children with the game. The novelty of the game initially made some children fearful, even if they appeared curious. After an initial moment of caution, when most of them asked for the easiest options, all the children, except one, expressed great satisfaction, opting for an increase in difficulty and completing the whole test program.

The possibility of adapting the games to the child's needs also allowed the therapists to stop and understand in more detail how children perceive the reality around them when placed in the most facilitating and suitable conditions.

The following skills were the ones most observed in the children during this experience:

- Ability to adapt to novelty, and time needed to feel at ease.
- Use of vision to explore the surrounding space (i.e., neglected area, reaction time, perception and localization of target etc.).
- Use of oculomotor skills (i.e., fixation, saccadic movements, smooth pursuit) in order to orientate themselves and navigate in space.
- Ability to maintain, shift, and share attention (i.e., reaction time, visual crowding, etc.).
- Online visual monitoring of movement (i.e., quality of visual-motor coordination, movement accuracy, etc.).
- Ability to orientate in space (i.e., internalization of topological concepts, etc.).
- Motion perception.
- Color recognition.
- Compliance with waiting turns and social rules.

The analysis of these observations and the possibility of increasing the level of difficulty made it possible both to identify certain critical areas in the child's

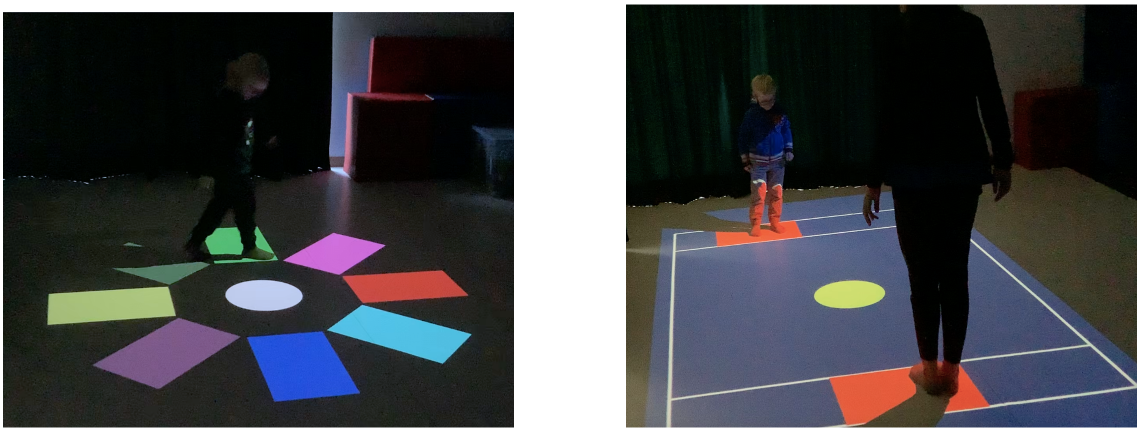

(a) (b)

Figure 4.7: Two game of different complexity: one with only stationary objects (a) and another that requires the ability to respond to other player's actions (b).

development and abilities and which conditions favour the child's best performance (see Figure 4.7).

These observations served to create a basis for the definition of the rehabilitation objectives, defined by the professionals during the first session and gradually revised in relation to the modification of the parameters of the children's games and behaviour. The advantage of knowing the child's strengths and weaknesses makes it possible to intervene with a rehabilitation program that is personalised and tailored to the child's abilities and supports the transfer of skills to the real world.

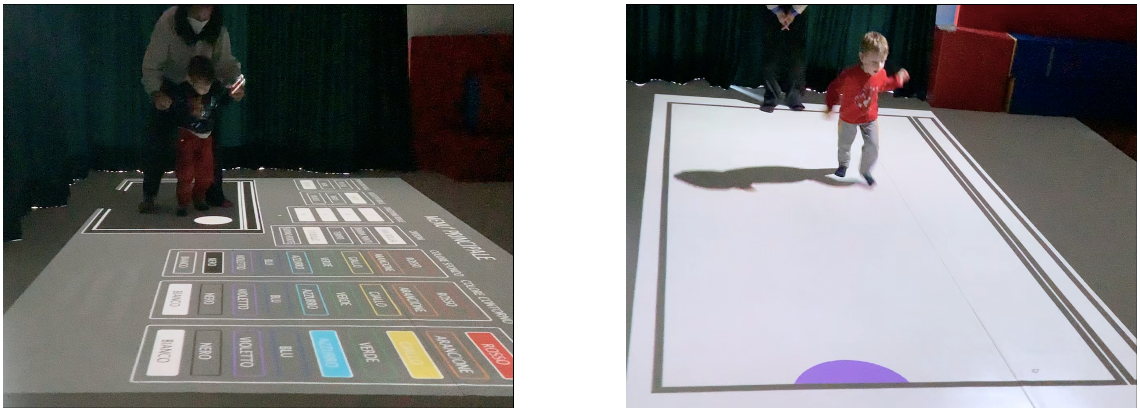
4.6.2 Children preparation and non-technical customization

Although the adaptability of the play parameters is a great point in favor of this project, through this experience it was confirmed that it is not sufficient when working with children with visual impairment who, because of this condition, do not have full awareness of their surroundings.

Indeed, particularly in those with a lower visual residual, a certain hesitation and fright was noted in the children during the first session of play. Analyzing the matter, it was realized that these emotions were greater when the children had never been in the room and/or entered directly into a prearranged environment (i.e., dark room and projector on). In order to overcome this problem, it was decided to spend some time before the beginning of each session during which the children were guided to explore the room under normal conditions (light on and curtains open) and then gradually create together the ideal environment for the use of the interactive floor (i.e., pulling the curtains, turning on the projector and PC, turning off the lights in the room). It is also very important that, before the start of the game, the caregiver verbally explains its characteristics to the children to help them to prepare for the new session, allowing them some time to ask questions or clarify doubts about the game, its characteristics, and the functioning of the system.

In this way, the children were not only more involved and encouraged to participate in the activity, but intrigued by the actions they took, they often asked why certain actions were taken and how the system worked (e.g., “Why do you have to turn off the light?” “Where do you turn on the game?” “Where does the light come from?”) and felt gratified to be operating the technological part of the system themselves. An amusing and at the same time revealing phrase is “The magic wand makes everything more magical”, said by a child while switching on the projector with the remote control.

A further method found to involve the children even more was to pause on the configuration interface for as long as necessary and to guide the children verbally or physically so that they understand how the game works and feel more confident with the proposal. In fact, most of them wanted to choose their own settings (e.g., size and speed of the bubbles) before playing, feeling that they were part of the creation of a game tailored to them. Turning off the projector and turning on the room lights were two other important actions to do together with the child to return to the initial environmental condition at the end of each session, allowing them to mentally conclude the play session.



(a) (b)

Figure 4.8: (a) Child during first session, want to play with the therapist. (b) Same child in the second session, playing independently.

Another feature that helped the children to adapt to the play environment (some more quickly, some less so), mostly in the first phases of the experience, was the presence of a known reference figure nearby. During play, the therapist should stand in a stable position and give verbal and/or physical mediation when necessary during the matches (e.g., to show their presence if required, to verbally anticipate sudden noises helping the child to feel more secure, to help with orientation during play, or to play games for two players). Two young children, for example, asked to play in the therapist's arms in their first session, but in the following sessions they adapted to the environment and they wanted to play alone (Figure 4.8).

In the end, this test experience has shown that not only should adaptable and technically functional games be created, but it is equally important to plan how to prepare and accompany the children in the game, creating a context that makes them feel comfortable in order to help them better express their skills.

4.6.3 Guidelines from results

At the end of the testing period, the multidisciplinary team met again to draw conclusions from the work done. Discussions on the topic and data analysis resulted in this list of guidelines mainly addressed to designers interested in developing children's games with visual impairment using large-scale interactive environments.

- The background should be as uniform as possible to easily identify objects in the foreground.
- The color of the background should be configurable to ensure an optimized contrast in relation to the visual ability of the child with visual impairment.
- Foreground objects should, at least initially, be simple shapes. More complex and detailed shapes can be introduced in a second phase, for children who show better abilities to recognize objects.
- Due to personal differences in color perception, it is important that the color of objects is configurable for each user.
- The size of the objects that make up the game should be configurable in relation to the child's needs. If this is not possible, the smallest object should be at least 10 cm in size.
- The maximum speed of a moving object should be 1 m/s and should be configurable in relation to the child's visual-motor capacity.
- The lines delimiting the playing field must be at least 5 cm thick.

Conclusions

The design and development of the mini games was an exciting but challenging experience.

The fact that they were based on a large-scale interactive environment meant that they had to overcome obstacles that are not present in normal games, such as the choice of games to be developed, the language for development and the sensor to be used, looking for the one with the best price/quality ratio, the best way to position it, and its compatibility with the software used. Another big challenge was the dual audience that would use this system. Firstly, children with visual impairment, who, as seen above, need special attention to many aspects that are not normally considered. Secondly, the therapists, who, because their technical knowledge was not advanced, required the development of a system that was simple and intuitive to use. The need for a user-friendly system was also due to the fact that the system should not waste their time during the rehabilitation sessions but should instead become a useful tool to increase the child's desire to continue the therapy.

In terms of successfully overcoming these challenges, having followed an approach based on design thinking certainly played a good role. Thanks to this approach, the team was able to retrace its steps whenever the choices made were not fully compatible with the production environment, giving them the opportunity to design and implement a system that was as close as possible to the needs of the end users.

The fact of working in a multidisciplinary team was also very helpful and allowed us to define some guidelines both for the design and development of games in such a context and to help therapists and educators who accompany children to make the best use of digital games in order to include them in their rehabilitation paths. This experience has shown how important it is not only that the games have suitable characteristics, but also that the way they are proposed is tailored to individual peculiarities.

Finally, the pilot study, which directly involved the children with visual impairment and the Foundation's professionals, allowed us to assess the usability and the appraisal of the system, enabling us to improve it and adapt it as much as possible to the needs of the end users. This led to the result of having a system that is highly appreciated by both the operators and the children who use the games, as can be seen from the excellent results obtained in the questionnaires given to both.

The experience with the children also made it possible to better understand how they perceive the reality that surrounds them if placed in the most facilitating conditions to express themselves. In addition, it emerged that the interactive environment can be a useful tool to support the children's commitment and motivation, and to help them achieve their rehabilitation goals.

5.1 Future works

Despite the general appreciation, some weaknesses of the system were highlighted during the discussions.

First of all, the sensitivity of the tracking sensor, which, due to some hardware limitations pointed out above, did not detect the child correctly when the child was at the edge of the playing field or arrived later than the player's position when the player was moving too fast. Unfortunately, although mitigated as we tried to optimise the tracking algorithm as much as possible, these issues remained present throughout the tests. Also, since the Kinect One is no longer being manufactured, it would be impossible to recreate the system on a large scale without encountering the problem of lack of supplies. Therefore, as a future implementation, it was thought to replace the used tracker device with a more modern one that can be purchased more easily, such as *Azure Kinect DK*, an advanced version of the old Kinect that includes sophisticated computer vision and speech models, advanced AI sensors, and a range of powerful SDKs that can be connected to Azure cognitive services, or another depth only camera, as it is the main piece of data from the system that is currently used by the tracking algorithm. Another future option would be to use a simple video camera integrating computer vision and machine learning algorithms to track the position of the person within the field, but the development work required would probably lose the cost advantage of the hardware (which being limited would create several problems in terms of design and implementation).

Another problem encountered was the low longevity of the games because, as already pointed out, being games with a very simplified gameplay, despite arousing much curiosity and appreciation in the first sessions, they tended not to entice older players to replay them. Since the system was designed with a view to future scalability, it will not be difficult to overcome this problem, as it will be enough to organize with the therapists to see what other games can be developed. By developing games with a more complex gameplay to be proposed after the first game sessions, which will be used to acclimatize the children with the new system, it will be possible to propose them new experiences of increasing difficulty, so that their enthusiasm does not wane, and they are helped to complete their rehabilitation path. For example, a beta version of the famous retro-game *Arkanoid* has already been developed and adapted to be played in a large-scale interactive environment. This game requires greater visual-motor and coordination skills than its predecessors, thus providing a higher level of challenge for older children. The game consists of a paddle at the bottom of the screen and a set of colored blocks at the top. A ball moves across the screen and the aim is to make it crash into the blocks to eliminate them. The paddle is used to bounce the ball when it reaches the bottom of the screen. The ball moves independently while the child's position is used to move the paddle so that the child can intercept the ball by bouncing it off the blocks.

Finally, the last weakness of the system was its user-friendliness, as the first versions were much more complex to use without a technical background, making it more of a waste of time for the therapist than a good tool to use. Fortunately, thanks to the implementation of the Game Launcher and user-friendly configuration menus, we were able to overcome this problem to a large extent. However, there is still room for improvement (more attractive graphics, even more user-friendly menus, elimination of keyboard shortcuts to integrate options into the menus) which can be filled by some future implementations in accordance with the therapists using the system and their needs.

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