Medical Art Therapy of the Future: Building an Interactive Virtual Underwater World in a Children's Hospital

Ludivine Lechat[1], Lieven Menschaert[1], Tom De Smedt[1](✉), Lucas Nijs[1],
Monica Dhar[2], Koen Norga[3], and Jaan Toelen[4]

[1] St Lucas School of Arts Antwerpen (BE), Antwerpen, Belgium
ludivinelechat@gmail.com, lievenmenschaert@gmail.com,
tomdesmedt@gmail.com, lucasnijs@gmail.com
[2] Universiteit Antwerpen (BE), Antwerpen, Belgium
monica.dhar@uantwerpen.be
[3] Universitair Ziekenhuis Antwerpen (BE), Antwerpen, Belgium
koen.norga@uza.be
[4] Universitair Ziekenhuis Leuven (BE), Louvain, Belgium
jaan.toelen@uzleuven.be

Abstract. We are developing an interactive virtual underwater world with the aim to reduce stress and boredom in hospitalised children, to improve their quality of life, by employing an evidence-based design process and by using techniques from Artificial Life and Human-Computer Interaction. A 3D motion sensing camera tracks the activity of children in front of a wall projection. As they wave their hands, colorful sea creatures paddle closer to say hi and interact with the children.

Keywords: Procedural generation · Autonomous agents · Motion sensing
Quality of life · Evidence-based

1 Introduction

Children often experience a hospital stay as a setback in their life. Above all, they want to be like other healthy children: attend school and play with friends. Children may be hospitalized for a number of reasons, including diagnostic workup, postoperative care, and treatment for acute or chronic diseases or even psychological illness. During their hospital stay they are subject to stress because they are away from their safe home or because they do not understand yet why medical procedures are necessary. They may feel lonely because they are away from their family or they may be bored because they cannot play with their school friends [1–8]. This can lead to behavioral changes in the form of active responses (e.g., crying, yelling, aggression), passive responses (e.g., excessive sleeping, withdrawal, bedwetting) and psychological upset. The support efforts of hospital staff are commendable but their time is limited and their main concern is of course to treat the illness efficiently. Hospital staff is not always available to organize or play games. Also, hospital infrastructure is typically designed to be

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functional and perceived as “cold”. A growing number of studies suggest that our surroundings have an impact on our wellbeing [9–12]. For example, nature or depictions of nature, like a view on trees or a landscape painting, have a positive effect on the mental wellbeing of hospitalized patients [13, 14].

New hospitals take this into consideration by for example transforming their entrance hall into a plaza with playgrounds and an indoor garden, their hallways into an exhibition space, their patient rooms into homely bedrooms, and so on. In short, spaces that we identify as comfort zones [15–17]. For example, the Nationwide Children’s Hospital (Ohio, US) has a meeting place for parents, children and staff that is decorated as a “magic forest” with large trees and animals.[1] However, such architectural projects are also expensive. In the context of e-health [18] and serious gaming [19] affordable virtual alternatives are being considered more and more often. For example, the Great Ormond Street Hospital (London, UK) has LED wallpaper with animals that help children relax by accompanying them to the operating room.[2]

In Sect. 2, we discuss the current state of art therapy in pediatric medicine, and how new technologies can be applied to create new opportunities in this area. In Sect. 3, we outline our own approach, an immersive virtual underwater world, and its reception with hospitalized children.

2 Art-Based Therapy in Pediatric Medicine

2.1 State of the Art of Art-Based Therapy

Nowadays, most if not all modern pediatric hospitals offer activities that help minimize psychosocial complications: in-house schooling, play therapy, music therapy, volunteer storytelling, and so on. Another well-known intervention is art therapy: “the use of art and imagery with individuals who are physically ill, experiencing trauma to the body, or who are undergoing aggressive medical treatment” [20]. For an overview, see [21]. Engaging in art therapy (e.g., drawing, painting, dancing) provides patients with an opportunity to participate in their treatment. Allowing children to take an active role in communicating their experience alleviates feelings of helplessness and provides them with the opportunity to regain a sense of control. Prior research has shown that the development of an art therapy program within a children’s ward fosters socialization and provides a beneficial outlet for emotional expression related to the hospital experience [22–24].

However, one of the concerns of any complementary program in the hospital is the budgetary restraint. For example, if art therapy is provided to an oncology patient who is kept in isolation (i.e., protected from infectious agents by limiting exposure to other people and by using face masks, gowns, etc.) then an individual therapist will probably spend one or two hours per day in the isolation room, at the bedside of the child, to engage in drawing or any other activity. The average hospital will usually have more

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[1] https://www.wsj.com/articles/SB10001424127887324581504578235592251544284.

[2] https://www.designweek.co.uk/issues/may-2012/great-ormond-streets-interactive-animal-wall.

than ten children in isolation. This necessitates a large number of therapists with significant financial implications.

2.2 Opportunities for Smart Health

Smart Health, the most recent manifestation of e-health, refers to the adoption of new ICT technologies in the healthcare sector, such as mobile devices, wearable biometric sensors, virtual reality glasses, and ambient intelligence or responsive environments [25]. Advances in the field of evolutionary art, combined with new hardware for human-computer interaction, offer unique opportunities for applications of art therapy. The advent of “smart” technology can overcome physical boundaries and engage several children with one therapist (even a virtual therapist) and can connect children in adjacent rooms, or in remote hospitals, without fear of contamination or infection. This technology can be used to open a metaphorical window in the hospital room – to create digital comfort zones where hospitalized children can regain control.

2.3 Related Work

Immersive virtual worlds where players are not encumbered by wired controllers such as gloves or glasses have a long history, dating back to work such as Myron Krueger’s VIDEOPLACE (1971) [26]. Applications in healthcare are relatively scarce however, and those that exist often do not share an established methodology. Below is a selection of projects that have served as inspiration for our work. What they share is their use of the nature theme, which seems to appeal to the mental world of children.

- PROBO (2008) [27] is a robotic stuffed toy, in the form of an imaginary animal with an elephant’s trunk that accompanies children to the operating room, offering socialization and expressing emotions.
- NATURE TRAIL (2012) consists of LED panels that distract children with animated silhouettes of horses, hedgehogs, deer and rabbits, located in the hallways of the Great Ormond Street Hospital.
- VALENCE (2012) [28] is a relaxation game where the player controls virtual agents that form cellular structures, by means of a wireless EEG headset that monitors alpha brain waves. The structures become more complex as the player relaxes.
- SCREENPLAY (2013) [29] consists of a pressure-sensitive floor and a projection screen located in the Holland Bloorview Kids Rehabilitation Hospital (Toronto, CA). Children can step on the floor to create images on the screen.
- CONNECTED WORLDS[3] (2015) is an immersive and responsive wall projection exhibited in the New York Hall of Science, where virtual plants and creatures will respond to the gestures of the visitors.

All of these projects incorporate a level of autonomous or self-organizing behavior, which is beneficial since they can keep children entertained and distracted without the need for additional staff.

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[3] https://nysci.org/home/exhibits/connected-worlds.

3 Interactive Virtual Underwater World

3.1 Setup and Approach

We used a combination of human-computer interaction hardware (i.e., motion sensing) and techniques from Artificial Life (i.e., agent-based systems) to develop an interactive virtual underwater world for the children's ward[4] (Fig. 1).

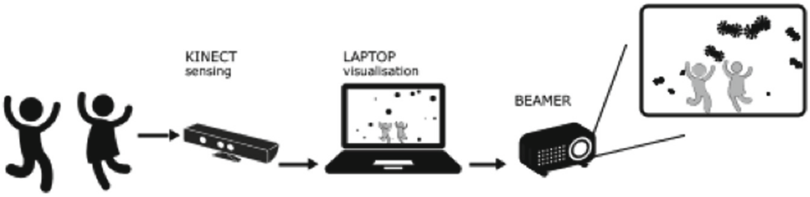

Fig. 1. Hardware setup. The camera tracks body movements, which serve as input for the agent-based simulation, which is rendered as a visualization and projected.

Artificial Life.

Artificial Life [30] refers to simulations or robotics based on natural life. Well-known examples include Craig Reynolds' BOIDS [31], which simulates flocking behavior, and Sims' VIRTUAL CREATURES [32], which simulates evolution. Well-known techniques are genetic algorithms [33] and agent-based systems [34], which typically use a small amount of randomness to elicit emergent or self-organizing behavior [35].

Human -Computer Interaction.

Human-Computer Interaction (HCI) has traditionally relied on a combination of mouse and keyboard (input) and windows and menus (output). Today, computers can be controlled by a variety of new inputs from speech to gesture recognition and motion sensing, and a variety of computer graphics toolkits exist for creating custom output. In our setup, we used the Microsoft Kinect 360, a commercially available gaming device for motion sensing that consists of a camera that estimates depth and computer vision software that tracks body movements of the player. The device is affordable, but one negative aspect is that it is sometimes not reliable due to light pollution or perspective distortion.[5] However, other devices are available as well.

Our setup consists of a wall projection that simulates a 2D underwater environment populated by autonomous agents (sea creatures and coral reef plants) that can be controlled by body movements and gestures. The camera tracks the player(s) facing the projection, the software program then adapts the virtual world, and a projector displays a representation of the current state of the virtual world. The program is an agent-based algorithm developed in openFrameworks [36], an open source C++ framework for computer graphics, and Box2D [37], an open source toolkit for simulating real-life

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[4] https://www.youtube.com/playlist?list=PLUmpXa_dPnDaQ0EEbEdCp99PZ64dmwDfv.

[5] https://techcrunch.com/2013/10/02/how-microsoft-built-the-cameras-in-the-upcoming-kinect.

physics. Realistic physics are important in our setup, since swaying fluid mechanics (and possibly their relaxing effect) define the virtual world.

We focus on an inclusive approach, where multiple children can play together, and consequently needed to simplify some computationally expensive procedures, ruling out Advanced Skeleton Tracking [38] techniques (input) or 3D rendering (output). Children within the camera's view range see themselves represented as a silhouette in the underwater world and can interact with the projected agents in front of them (Fig. 2). More specifically, after discarding the camera's depth data that is too close or too far away, two input signals are retained: one that roughly tracks the player's body contours and one that tracks hand movements. The body contour or silhouette can be used to catch and collect agents. Hand gestures can be used to introduce new forces to the system, dragging or pushing agents. A rule-based algorithm defines how agents behave (we are evaluating which mix of rules is the most "fun", see Sect. 3.4):

1. GROW: plant-life grows upwards,
2. SWIM 1: creatures swim around aimlessly,
3. SWIM 2: creatures swim to silhouette,
4. FLOAT 1: plant-life floats when grabbed,
5. FLOAT 2: floating agents bounce off silhouette,
6. FLOAT 3: floating agents can be caught in locked arms above head,
7. FLOAT 4: touching an air bubble spawns a set of smaller bubbles.

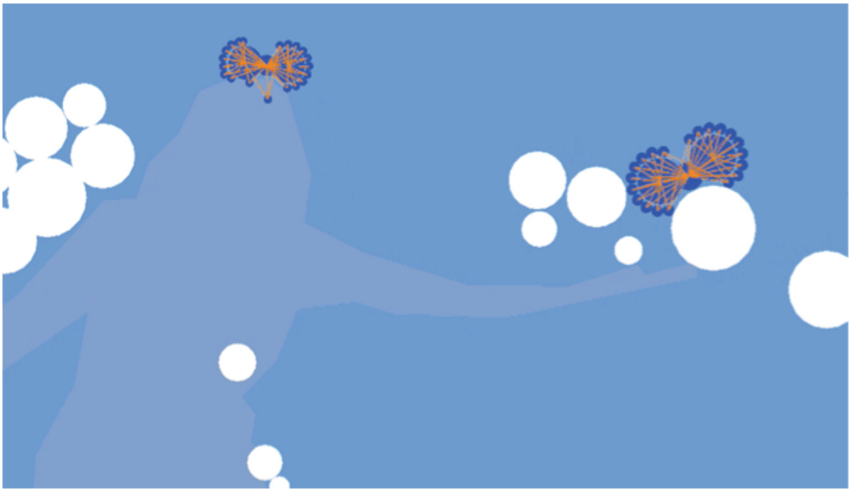

Fig. 2. Visualization. Player silhouette interacting with particles and particle clusters.

Once the camera data is processed and the program has updated the state of the virtual world, agents are rendered and projected using building blocks of artwork (see Sect. 3.3).

3.2 Procedural Generation: Evolving Physics System

The implementation of physics introduces forces to the simulation that mimic nature in terms of gravity, attraction, repulsion, and fluid dynamics. Forces can shape, alter and move agents in the system. The virtual world is based on two Box2D fundamentals: particles that have mass, and possibly velocity, and joints that connect particles. Joints can differ in type and friction (e.g., rigid, hinge, spring) and may have constraints based on angle and distance. By combining different joints we can generate a variety of plants and creatures, rendered either as skeletons (Fig. 3) or embellished with human-made artwork (Fig. 4, see also Sect. 3.3). The interaction of multiple forces leads to a complex evolving virtual world.

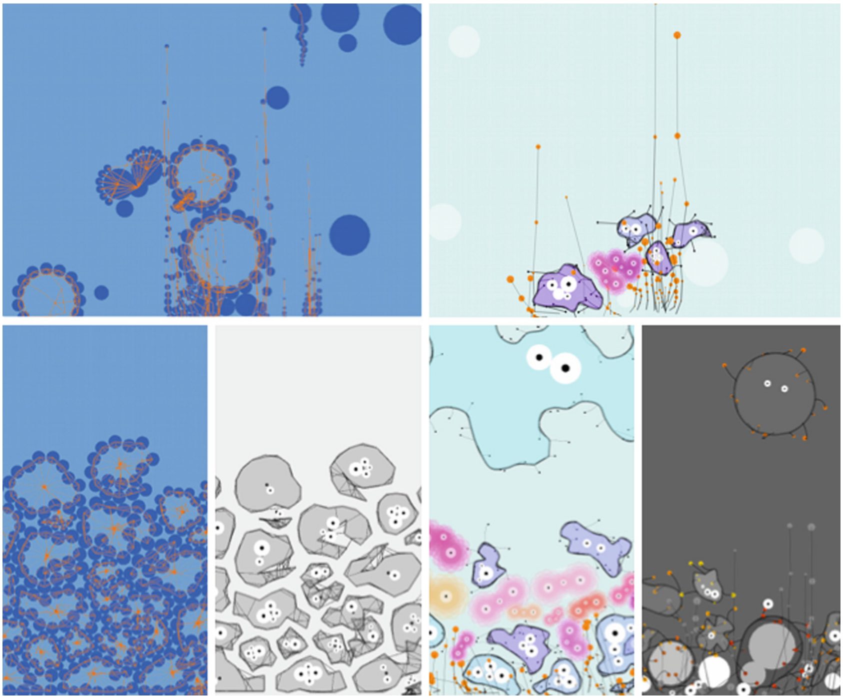

Fig. 3. Visualization. Different representations are possible, depending on the needs.

Fig. 4. Visualization. Particles represented as sea creatures and coral reef plants.

The algorithmic construction of an agent starts with a particle that is assigned a position and a mass. This particle can also be the center of a cluster of particles, again with mass, position, angle, distance. A skeleton structure is obtained by connecting the center to each new particle with a joint. Mass keeps particles from overlapping (i.e., big fish push aside small fish), and different joints make some agents more rigid and others more fluid. Movement is introduced by adding velocities to particles. For example, underwater plants have a fixed particle at the bottom that keeps them on the ground, while all other particles that make up the plant have an inverse gravitational force tilting them upwards, constituting the GROW behavior. When a plant is grabbed, its bottom particle is unhooked so that the plant can be caught. In a similar way, creatures will steer towards the silhouette by exerting forces on their particles in the direction of the silhouette (SWIM2). If a creature touches the silhouette, the forces are inverted, so the creature steers away again (FLOAT2), unless grabbed. In this case, the silhouette can be penetrated, allowing the player to collect stuff inside of it (FLOAT3).

In pseudo code, the gist of the algorithm can be described as follows. First, a setup procedure creates the creatures and plants and defines their individual behavior:

```
for creature in world:
  if creature.type == GUPPY:
    creature.motion = DART // start fast
  if creature.type == JELLY:
    creature.motion = BOB  // start slow, up & down
```

All life is subject to fluid resistance. Creatures wander around aimlessly by adding a small random value (e.g., –0.1 to +0.1) to their steering force during each iteration:

```
for creature in world:
  world.drag(creature)     // fluid resistance
  creature.steer(RANDOM)
```

Creatures are attracted to the player, but will steer away if they come to close, relaxing again once they are farther away (this is accomplished with a force dampener). If a creature touches the player's hand, it moves in the same direction with the same speed as the hand. If the creature ends up inside the player's silhouette in this way, it is trapped there:

```
for creature in world:

  if player in world:
    m = distance(creature, player)
    creature.steer(player, force=m)
  else:
    continue

  if creature.near(player):
    if not creature.near(player.hand):
      m = 1 / distance(creature, player)
      creature.steer(-player, force=m)
    else:
      creature.steer(-player.hand)
      if creature.inside(player):
        creature.bounds = player
```

3.3 Procedural Artwork: Evidence-Based Building Blocks

The look & feel of the virtual world (i.e., coral reefs and sea creatures) follows an evidence-based design approach [39]. Evidence-based design means that the artist does not simply design what he or she likes, but what credible literature has shown to have a positive impact on the psychological wellbeing of children. Broadly, younger children tend to focus more on the dominant feature of a stimulus, while older children tend to pay more attention to the various stimuli [40]. In terms of visual preferences, this means that younger children are more sensitive to *theme* while older children are more sensitive to *style* [41].

In the children's ward, all age groups are together. By consequence, it is not possible to cater to all tastes within a single setup; there is no one-size-fits-all approach [42]. However, prior research has also shown that all age groups prefer *representative* art (i.e., photorealistic) over abstract art in the hospital, and that all age groups prefer depictions of nature, in particular waterscapes and wildlife, along with bright colors [43]. One intuitive explanation is that a painting of a pleasant landscape is less taxing mentally than a composition of haphazard lines, at least to an already fragile audience. In one study [44], children were involved as an advisory group to rate different themes and all age groups preferred the waterscape theme, in particular the underwater world. Another study [45] observed a calming effect and increased attention in children that were taken on a visit to an aquarium.

Since older children tend to provide their own entertainment more often (e.g., smartphones, chat apps, books), we focus on younger children. We use the underwater world as an all-round starting point and aim for more representative depictions of sea creatures, while not rejecting imaginative visual details that may help a child to enter a distracting mental comfort zone.

Our artwork consists of a PNG file database of visual building blocks [46] that can be combined into compositions in different ways, either by a human artist or through rule-based algorithms. For example, the database contains components of sea creatures (e.g., eyes, mouths, fins) and plants (e.g., stems, leaves) that can be combined into a range of virtual agents and then manipulated with physics-based animations. The most recent iteration of our setup aims to integrate this new artwork (Figs. 5, 6 and 7).

Fig. 5. Artwork. Sea creatures constructed from visual building blocks.

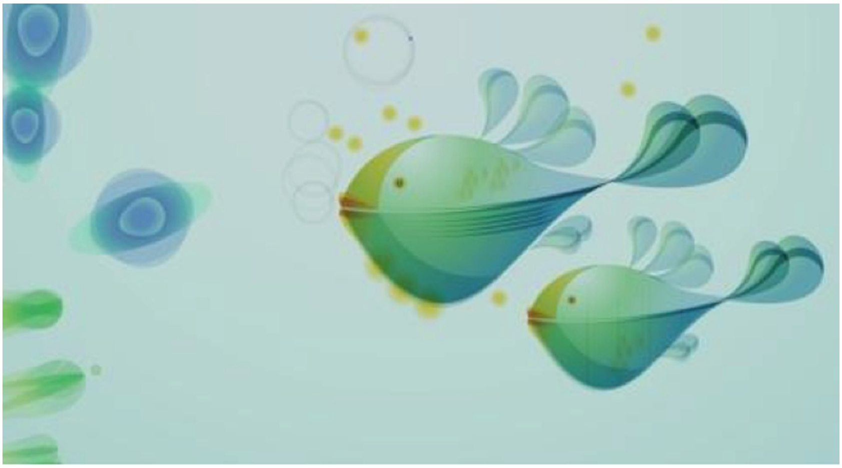

Fig. 6. Artwork. Sea creatures constructed from visual building blocks.

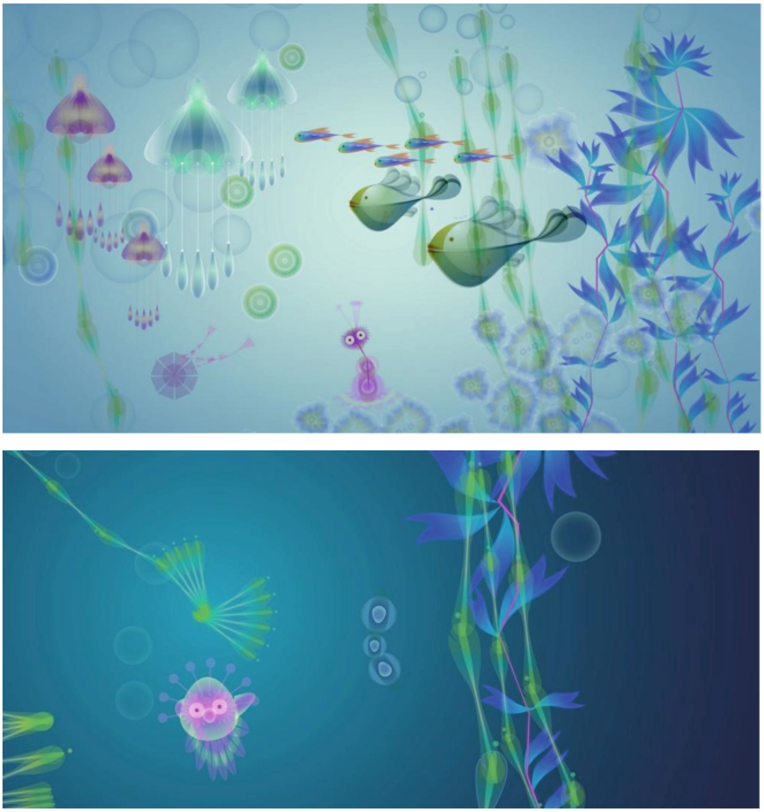

Fig. 7. Artwork. Sea creatures and plants roaming the underwater world.

3.4 Evaluation

The installation is being offered as a new game in the children's ward of the University Hospital Leuven (Leuven, BE). In September 2016, we visited the playroom of the children's ward and passively observed 10 children (approximately aged 4–16) playing. In December 2016, we visited the waiting room of the children's ward and observed 33 children (approximately aged 2–15) playing.

- **Visit 1.** Long-term hospitalized children are free to visit the playroom whenever they want to before noon. The setup of the game was a first prototype with skeleton structures floating on a blue background. Of the 10 children we observed, 8 showed interest and 4 actually played, of which 3 returned to play again. Children that entered the playroom noticed the new big screen right away. While curious, most kept their distance and reached out to the traditional toys in the playroom that they are familiar with. Once encouraged by the hospital staff and parents, most of them did explore the setup and quickly grasped the game mechanics. Common interactions include: *peekaboo* (i.e., step in and out of camera view), *wave*, *grab* and *duck*. The most inventive children appeared to be those that conversed with their parents about what they were trying to do. One child was confined to a wheelchair and could not play very well, because the camera did not recognize the child's gestures. Teenagers appeared to be more shy to play in front of other people.
- **Visit 2.** The waiting room can at times be bustling, with up to 200 children per day. The setup of the game was a new prototype with more advanced mechanics. We observed 33 children, of which 25 showed interest and 15 actually played, of which 13 returned to play again. We noticed that the absence of hospital staff giving play instructions is not necessarily bad, since it also appears to promote exploration and socialization. Some children grasped the game mechanics on their own and were likely to come back to play again. Other children observed those who played and were comfortable to watch (which arguably also provides a level of distraction) or became curious and tried too. Children in wheelchairs were able to play with new technical improvements (Fig. 8).

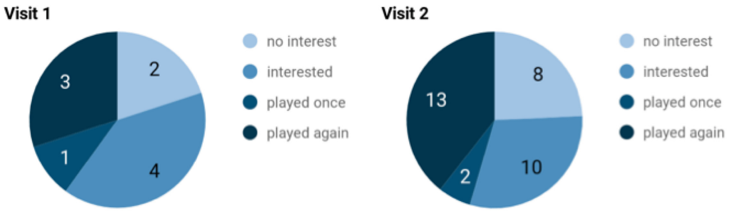

Fig. 8. Children's involvement during our observation in the hospital. (Color figure online)

At this time we have a general idea of how children play (or would like to play) with the setup. For example, when one child saw his silhouette on the screen he proudly exclaimed: "Look, that's me!" and we want to make the player a more tangible presence in the virtual world. The next question is how to improve the interactions, in order to offer the most enjoyable experience, while also promoting interactions that have a calming effect on the body. For the visual part, we aim to integrate new artwork – more creatures and plants – with a higher variation for discovery. We consider workshops and pictogram surveys for new experiments, to collect more specific feedback from children (e.g., which creatures do they like most?). Another approach is to save the skeleton data and the state of the virtual world, which we can then use for comparative analysis (e.g., which creatures do children interact with more?).

4 Discussion

The mental wellbeing of young people is a central focus point in the European 2020 objectives. Moderating psychological trauma (stress) and social exclusion during this crucial phase in a child's development promotes positive effects in the form of resilience, aptitude and interpersonal skills, with a long-lasting impact on our economy and quality of life. Attention to mental wellbeing and the application of technological solutions (e-health) are fairly recent developments in healthcare [47]. We see an opportunity for progress through participatory research between the healthcare sector, the arts & humanities and the computer science community.

5 Future Work

The work was conducted in the context of the STORY TABLE project (2016–2020) funded by the St Lucas Antwerpen School of Arts. Story Table aims to develop automatic fairy tales with "talking animals" for hospitalized children. These animals would be affective virtual agents that build a relationship with the child. For example: the sea creatures could become excited when they interact with a child who needs surgery the next day and talk about a goldfish that is afraid of needing an operation. Using projections, tablets and smartphones an adventure trail could then start in the patient room or ward to locate the goldfish and comfort it. In that way the game is not a form of babysitting, but a method to empower the child in its own medical care.

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