Design Strategy to Stimulate a Diversity of Motor Skills for an Exergame Addressed to Children

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ABSTRACT
A rich variety of videogames promoting physical activity has followed the emergence of new full-body interfaces. Known as exergames, these active videogames are often presented in the market as a ludic substitute to traditional sport. Although they present the benefit of being engaging, to date, the content and modality of interaction of these games cannot be granted as a regular mean to do exercise. This is an issue of particular relevance when they are perceived as a valid alternative to develop children's motor skills. This paper presents the design strategies and evaluation of the "Fish Game", an exergame that has been specifically designed to spur children to execute specific types of movement determined by health experts. In a controlled assessment with 150 children, we compared the diversity of movement in the Fish Game with respect to a previously designed game. Video analysis shows a richer variety of movements was executed in the Fish Game. We discuss the limitations of our current design procedure and future avenues that could be explored with health experts to enhance it.

Categories and Subject Descriptors
H5. Information interfaces and presentation (e.g., HCI): H.5.1 Multimedia Information Systems: Artificial, augmented, and virtual realities; H.5.2 User Interfaces (D.2.2, H.1.2, I.3.6) Ergonomics. K.4 Computing Milieux: Computers and Society K.4.1 Public Policy Issues: Computer-related health issues.

General Terms
Algorithms, Design, Experimentation, Human Factors.

Keywords
Exergame, Exertion Interface, Physical Activity, User Control, Children, Health, Sedentarism, Mixed Reality.

1. INTRODUCTION
A study from World Health Organization has shown that children within the Western population adopt more and more sedentary habits [4, 7, 9, 12, 17]. Also WHO has come to the conclusion that children do less physical activity compared to ten years ago since they prefer spending their time on more passive activities such as playing videogames, navigating through the Internet and interacting through social networks, or using computers. To tackle this growing problem, HCI community and videogame industry have explored over the last years alternative solutions using new full-body interfaces. Most of these solutions can be divided into these three categories:

- *Exertion interfaces.* They are interfaces designed to enrich a traditional physical activity based on cardiovascular, aerobics, flexibility or endurance exercises. The advantage of this approach is that it increases the sport experience by fostering motivation of the user over time. One example is Joggobot [11], a quadcopter robot companion designed to motivate the jogger in his activity by keeping him running with a preferred pace. The robot recognizes a pattern on the t-shirt of the jogger and flies in front of him to regulate his running pace.
- *Interactive playgrounds*. More specifically addressed to children, they are described as the modern generations of playgrounds, which embed interactive technologies to create new forms of active play. Not only do they augment outdoor play [19], but they can also lead to a rich social experience [23], foster collaborative play [24] and cardiovascular [13] and other types of exercise.
- *Exergames.* Active videogames created to engage users in physical activity in a playful way. These videogames are supported by interfaces, such as the Microsoft Kinect or the Nintento Wii.

All these solutions can have a positive impact on health. However, there are few studies that analyze whether this impact is significant in comparison to traditional forms of physical activity which have been broadly analyzed. In this study we are particularly interested in exergames and their design to achieve an impact on health. In this perspective, we believe it is important to design and evaluate exergames in collaboration with health and physical education experts. The goal of our research is to address this integration of expert knowledge in an exergame, specifically addressed to children, as the main focus in the design process.

2. OVERVIEW

In this paper, we first highlight the studies related to the impact of exergames on children health, and more precisely, on motor skills. Next, we present a novel design method for exergames, focused on working with heath experts to stimulate a richer variety of movement. To validate our design method, we have designed and evaluated an exergame named Fish Game. Finally, we discuss our evaluation method and results with respect to our design approach.

3. RELATED WORK

There are two key elements in physical activity related to child growth. The first is the daily amount of physical activity and the amount of energy spent in doing it, called Energy Expenditure (EE). The second is the development of motor skills. We define motor skills as the capability to execute a sequence of movements for a specific task. One example to illustrate this is the execution of a 3-point shot in basketball. To achieve a 3-point shot, the player must perfectly balance strength, coupling and precision. The skills involved in the execution of a movement can be divided into two categories: Conditional and Coordinative (Table 1). In Table 1, the conditional skills are related to the physiological aspect of energy management for movement execution encompassing strength, endurance and speed. The coordination skills are related to the process of regulation and control such as orientation or adequacy.

Several studies from health experts have examined whether the exergames released on the market can have a positive impact on EE to a level comparable to traditional sport [3, 8]. The majority of these studies conclude that exergames are comparable to practicing sport in a range of light-to-moderate intensity. Yet, health experts recommend that children practice daily physical activity of a moderate-to-rigorous intensity for 60 minutes [1]. Therefore, well-known exergames on the market seem to have a low potential to achieve a significant impact on health.

Regarding motor skills, some exergames explicitly promote movement. For instance, the Kinect Dance Central rewards the player based on the accuracy of execution of movement. The greater the precision in the movement of the player, the more points he gains, thus fostering the link between motor skills and coordinative capacity. Yet, some exergames do not seem to be designed considering their impact on motor skills. For instance, Berthouze shows that player of Wii Tennis can increase their game performance by doing shorter movements rather than simulating the full natural movement executed when playing real tennis [2]. This not only reduces the improvement of motor skills, but can even be harmful for the users [22]. To better understand what impact the Nintendo Wii -with its balance board- can have on children's movement, Levac et al. have evaluated the game effect of four exergames for it [15]. This study shows a positive impact on children movement. However, they were being supervised during the execution of their movements by physiologists. This implies two important limitations of the Wii interface. First, as Berthouze mentions, there is always the possibility for the player to cheat and not perform a full movement. Consequently, without supervision, there is no guarantee that children will do the desired movement. Second, as these games were not designed by health experts, nothing guarantees that they encourage recommended movements for children. If experts in rehabilitation or physical activity can use them to stimulate certain movements, they need to be next to the children to make sure that they execute the correct movement.

From a design perspective, Peer's et al. have designed an exergame to improve the throwing ability of children using a wiimote [18]. The game consists of creating a digital collage. To do so, the player must throw soft toys on specific locations of the screen. When the toy hits the screen, a digital representation of it appears at that location on the screen. Unfortunately, the authors did not present any empirical evidence of the efficacy of their interface to improve throwing skills over time. Despite Peer's application, little research has been done to explore how to promote movement within exergames addressed to children.

In the light of these observations, we could conclude on the importance to design exergames together with health experts so that the events in the game naturally spur the user to execute adequate movements for the development of their motor skills. In the next section, we present a design guideline to create an exergame together with health experts, which aims at stimulating the execution of certain motor skills through movements based on a predefined interface.

4. DESIGN

In the process of finding a design method to develop exergames together with health experts, we have systematized our design procedure in three steps. Firstly, we preselected an interface, based on a traditional physical play platform known by children. Secondly, we have joined efforts with experts in physical activity to determine the dominant motor skills that can be worked out on

Table 1. Categories of Motor skills

Conditional Skills	Coordinative Skills
Strength: Tension exerted by a muscle or group of muscles.	**Balance**: Body's capability to keep itself in an optimal position according to the requirements of movement or posture. It may be static or dynamic.
Endurance: Capability of repeating and sustaining an effort during a long period of time.	**Coupling or Synchronization:** Capability to coordinate movements of body parts, individual movements and operations among them.
Speed: Capability of realizing one or a number of gestures, or cover a certain distance in a minimum amount of time.	**Orientation:** Capability to determine and change position and movement of the body in space and time.
	Differentiation: Capability to achieve a high degree of precision and fine economy of movement.

our interface. Finally, we have worked in partnership with children to design an exergame based on a short list of healthy movements identified for our interface.

4.1 Selection of the Interface

In this work, we explored our novel design method with the Interactive Slide (IS) [20] (Figure 1), a collaborative augmented platform that promotes physical activity and full-body interaction. The IS is an inflatable structure with a sliding surface of 4 by 3 meters on which we project a videogame and where the players are tracked by an infrared-based computer vision system. Previous ethnographic studies showed that the IS can facilitate socialization, an important element to keep users engaged in physical activity [21].

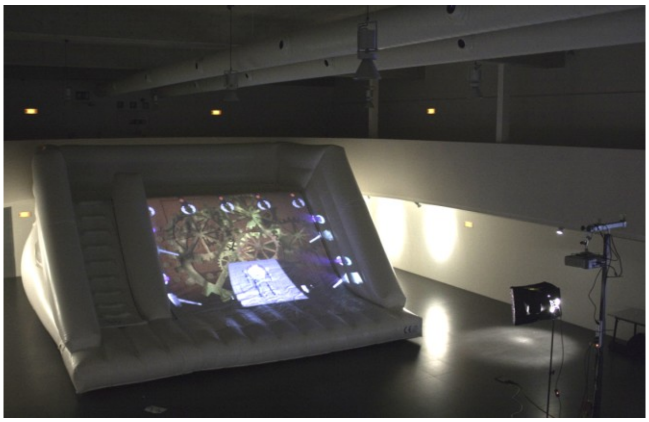

Figure 1. The Interactive Slide

4.2 Understanding Motor Skills

To understand the full potential of the development of motor skills on the IS, we worked in close collaboration with the National Institute of Physical Education in Catalonia (INEFC), a public institution specialized in teaching and research in the realm of sport and physical education.

It is important to remember that one movement is not driven by one skill only, as we illustrated earlier in the example of a 3-points basketball shot. In our previous work, we have shown that the IS is a good interface to promote a rich diversity of movements [5]. In this research, our experts in physical activity have looked into dominant motor capacities that should be considered for any exergame designed for this interface.

The IS shows a natural potential to stimulate all conditional skills. Additionally, we have identified two predominant coordinative skills that can be fostered on the IS, namely: balance and coupling. On the IS, balance is defined as keeping control of the body with respect to the center of gravity. Since the IS is an inflatable structure it provides a constantly unstable activity surface. Hence, in general, being on the slide will demand the users to apply static balance; i.e. muscle contraction to avoid loss of control of the centre of gravity. When the users are in motion (e.g. sliding or climbing) on the IS, they must perform a dynamic balance to keep control of the body. Coupling is defined as the capability to coordinate the movement with a team member or an interactive event.

From these skills we have defined a set of movements grading each capability involved from 0 to 3. For example, hanging from the top of the slide to try to contact a virtual object in the game will require a high strength level (3) but null speed (0). From a coordinative point of view, this movement will require high vision-leg coupling and static balance. From the full set of movements we have selected a list of the 15 movements that best fit the specific qualities of the IS. We also wanted these movements to be easily understandable by children. Figure 2 shows two of them.

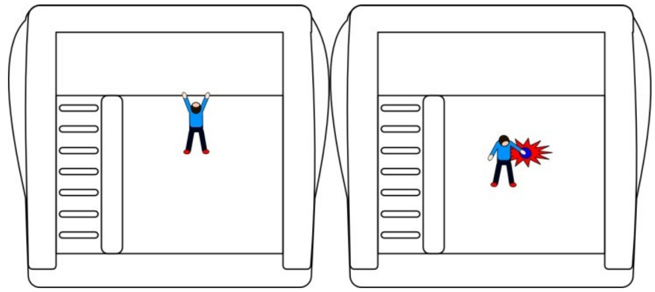

Figure 2. Movements for the Interactive Slide. Left, the child hangs on the top, stimulating at first strength and resistance. On the right, the child intercepts a virtual object, stimulating eye-arm coupling.

4.3 Design of an Exergame

These movements were gathered in a design grid used for a Participatory Design (PD) activity held with 50 participants aged between 11 and 12 years old [14]. The ultimate goal of this PD activity was to create an exergame with rich movement activity and attractive to children. The PD strategy fostered the emergence of the favorite themes, movements and modality of interaction of children. Moreover, these should be based on the list of 15 movements of our grid. The results would be used as inspiration for the final exergame design.

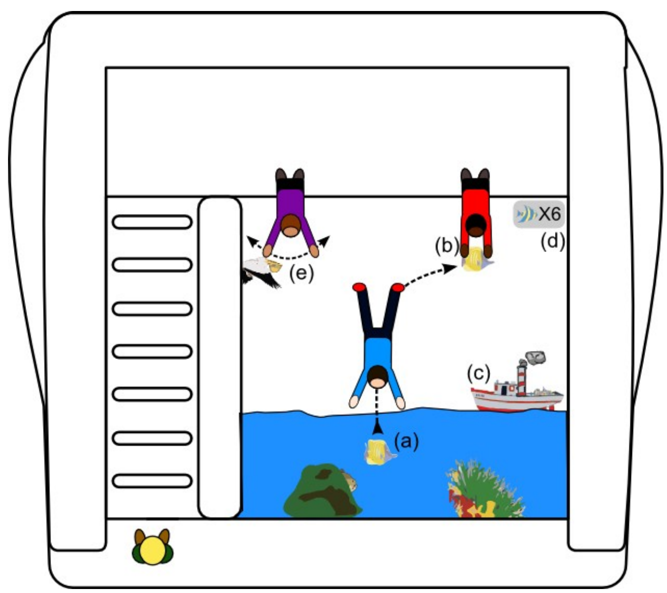

Figure 3. Fish Game overview

Children were individually invited to imagine and draw a simple game situation for each of the 15 movements in the grid. Figure 2 shows two examples of how we visually described the movements to children. After that, children were grouped in teams of four to merge their ideas into a complete game for the IS. For more detail on the PD procedure please refer to [14]. Out of these sessions, we took in consideration the children's most recurrent ideas as well as the most innovative, to finally design the new exergame which was called "Fish Game" (Figure 3).

In the Fish Game, the users must collect ten fish to pass to the next level. To catch a fish, one player must slide over it (Figure 3.a) when it appears from behind an element in the virtual sea. When the fish is correctly hit, it jumps out of the water. Another player at the top of the slide must then catch the fish by hitting it with any part of the body (Figure 3.b). If timely hit, the fish is directed into the fishing boat that moves from side to side on the surface of the virtual sea (Figure 3.c). Catching each fish increases the players' score (Figure 3.d). Once in a while, a bird appears on either side of the top of the play area. The bird flies over the ship and dives down on it to steal a fish. The players must try to scare the bird away as soon as it appears, before it dives on the ship, by intensively waving their arms over it. If they do so on time and with sufficient intensity, the bird flies away (Figure 3.e).

The game incorporates movements related to speed, endurance, strength, balance and coupling, as recommended by the experts from INEFC. This is achieved through two main movements: arm waving and the slide-hit combination. Arm waving fosters coupling, speed and endurance since the child must do it on time and with sufficient intensity. The slide-hit combo fosters strength and balance since the children must either react quickly to the fish appearing in the virtual sea and throwing their body down the slide, or hanging down to reach the jumping fish. There is also a collaborative coupling component since they have to act in a coordinated arrangement.

5. THE STUDY

The goal of our study is to test our new game. We want to verify that our design approach successfully motivates children to perform our list of movements. We also want to verify whether it encourages a richer diversity of physical activity.

To evaluate the richness of movement in the Fish Game, we decided to compare it with another exergame we had defined for the IS in the past: the Balloon Game (Figure 4). This game was not designed with the goal of achieving a diversity of movement. Rather, its goal was to promote cardiovascular activity.

5.1 The Balloon Game

In the Balloon Game, children must synchronize to slide over virtual balloons (Figure 4.a) that appear from the sides of the projection area. If they successfully slide over a balloon they pop it and obtain a virtual object (Figure 4.b). These objects must be piled up at the bottom of the projection area (Figure 4.c) to reach a target circle on a level bar (Figure 4.d). From time to time, a bomb appears instead of a balloon (Figure 4.e). If the bomb falls to the bottom of the play area and explodes, it destroys the structure of objects that has been constructed until then and displaces the target to a new position. Children must slide over the bomb to defuse it before it falls. Overall, this game demands teamwork and promotes intense physical activity. However, no event in the game was designed to require a specific movement.

5.2 Participants of the Comparative Study

Approximately 150 children aged between 11 and 12 years old were recruited from different schools of different milieux in Barcelona. The participants were healthy and did not suffer from any motor limitations. All children were informed of the study and came to the study with a signed informed consent from their parents. All children without consent were allowed to play but no data was collected from them.

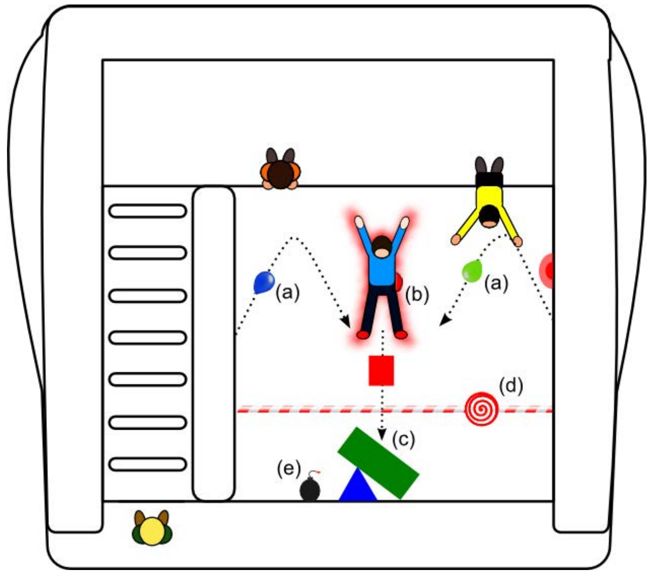

Figure 4. The Balloon Game overview

5.3 Procedure

The study was held in our university during two weeks. Every morning, one or two classes were welcomed to our lab. Before the study started, the children were informed of the experimental schedule. Once the schedule was understood, children were randomly grouped in teams of four. Each group was taken to the IS room at a time while the others waited in room watching videos without doing any physical activity. Before playing one of the two exergames on the IS, children had to watch a one minute video tutorial explaining the rule of the game. When these rules were understood, the children played for 9 minutes. After each session, the children were accompanied back to the waiting room to rest before playing the second exergame. The order in which they played the games was also randomized to compensate for order effects.

5.4 Measures and Data Analysis

A JVC mini DV camcorder recorded all participants in all sessions for post-study analysis. Motor skills on the IS were analyzed using the Observational System of Motor Skills, OSMOS [6] applied to the video recordings. OSMOS is a grid to analyze coordinative skills, such as balance, as presented in Table 1. Moreover, OSMOS allows coding motor behaviors specific to game environments, such as manipulation of objects or group interaction. OSMOS has previously been adapted for the IS [5] to facilitate the analysis of motor behavior response on the IS. Every single motor action based on OSMOS was coded using the video analysis software LINCE developed by INEFC [10]. This software allows the observers to mark motor actions of each player individually over time. This allows us to estimate the diversity of movement that the game fosters. For instance, Figure 5 illustrates the coding process for a player sliding down the IS and interacting with a virtual object in the center of the ramp. First, observers note where the event takes place: BC, referring to the center of the sliding surface. Then, they note the action of the

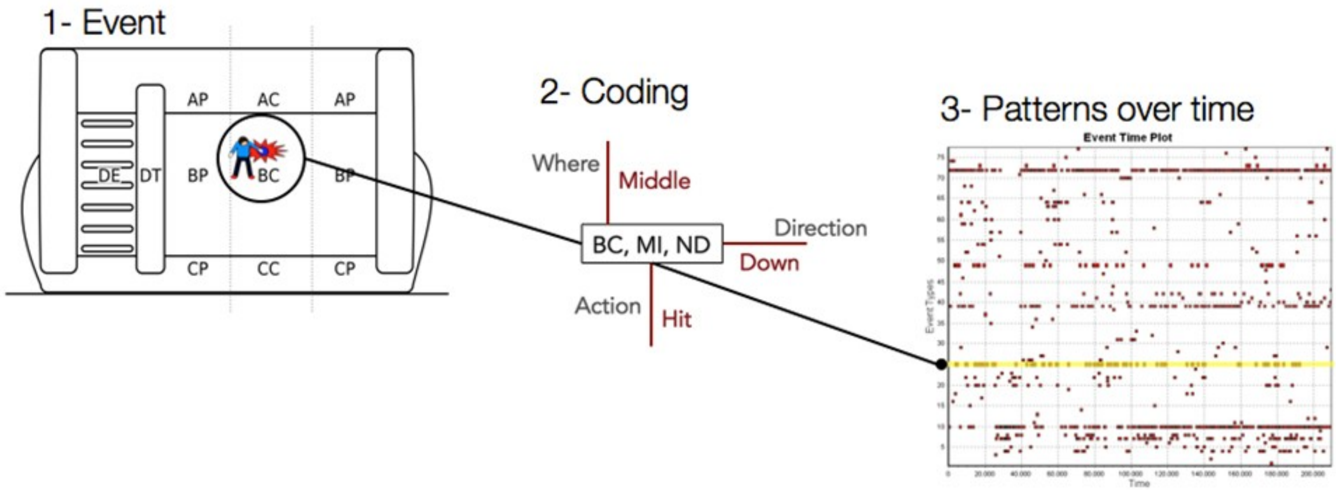

Figure 5. Coding of a motor behavior over time.

player: MI, referring to *impact manipulation*; i.e. hitting an object with the hand. Finally, they code the body action: ND, for a *downward change in spatial level*; i.e. sliding down. As a whole, these three coding atoms confirm a single specific user action: sliding down the center of the ramp and hitting a virtual object.

The relations between these movements over time were extracted using the Theme 5.0 software package [16]. These relations are referred to as Temporal Patterns (T-Patterns) and help understand how an event influences a sequence of movements. This analysis is used to evaluate the behavior of players over time. For example, we may ask: "What happens after a child slides over a fish. Is there a team member trying to catch it at the top or not?" The T-patterns that emerge from such an analysis indicate whether a specific event in the game incites the execution of the desired movements and behaviors, such as coupling or collaboration.

6. RESULTS

In total, two observers analyzed ten groups of four children, playing with both the Balloon and Fish Game. Each video was coded four times, once for each child playing, by each observer. Cohen's Kappa coefficient was calculated to validate the level of agreement between the observers. For the Balloon Game, the level of agreement coefficient was Kappa=.94 ($p<.001$), which is highly satisfactory. For the Fish Game, the level of agreement calculated reached Kappa=.98 ($p<.001$). Next, we analyzed if the Fish Game (a) spurred children to do a more diverse combination of movements, (b) fostered the specific movements expected and (c) showed greater collaboration between users.

6.1 Diversity of Combination of Movements

Regarding the diversity of movement, a greater number of combinations were recorded for the Fish Game, compared with the Balloon Game. In total, 77 different movement combinations were observed for the Fish Game over ten groups compared to 48 combinations for the Balloon Game. Per group an average of 30 specific movements was observed at each session of the Fish Game, compared to 22 for the Balloon Game.

6.2 Specific Expected Movements

One of the specific movements promoted in the Fish Game is arm waving, coded as "MC" (*conduction manipulation* of stimuli). This movement was observed over 190 times in the Fish Game for ten game sessions, which corresponds to approximately 19 occurrences of the same movement per game. This movement was observed to be clearly associated with the appearance of a bird, with the objective of scaring it away. In every nine-minute session, a total of 22 birds appeared, hence on average the users detected almost all the birds and tried to scare them away. It was also noted that the arm waving presented a number of variations. Sometimes it occurred in the top-center of the slide and sometimes in the top peripheral areas. Also sometimes the action was undertaken by two players simultaneously to more effectively scare the bird away, creating a cooperative play situation.

The specificity of movements was also observed in the slide-hit combo over 68% of the time a user was sliding on a fish.

6.3 Collaboration between Users

Finally, a high recurrence of cooperative behavior was observed in the Fish game. Cooperation was encouraged by one specific event where a player slides over a fish and another player hits the fish when it jumps out of the water. This relation is recurrently observed in the T-Pattern analysis of both observers (Figure 6).

7. DISCUSSION

In general, the Balloon Game was considered by INEFC too restrictive, with a limited number of movements performed by children. Moreover, although the game fosters certain collaborative behaviors, none of them were observed in the motor actions. Collaborative behaviors were mostly limited to a queuing arrangement where players determined who should slide next to maximize the chance of intercepting a balloon and to keep a balanced participation in the game.

In comparison, players in the Fish Game tended to execute a greater diversity of movement. Moreover, the results of the systematic observations reveal that these movements were mainly

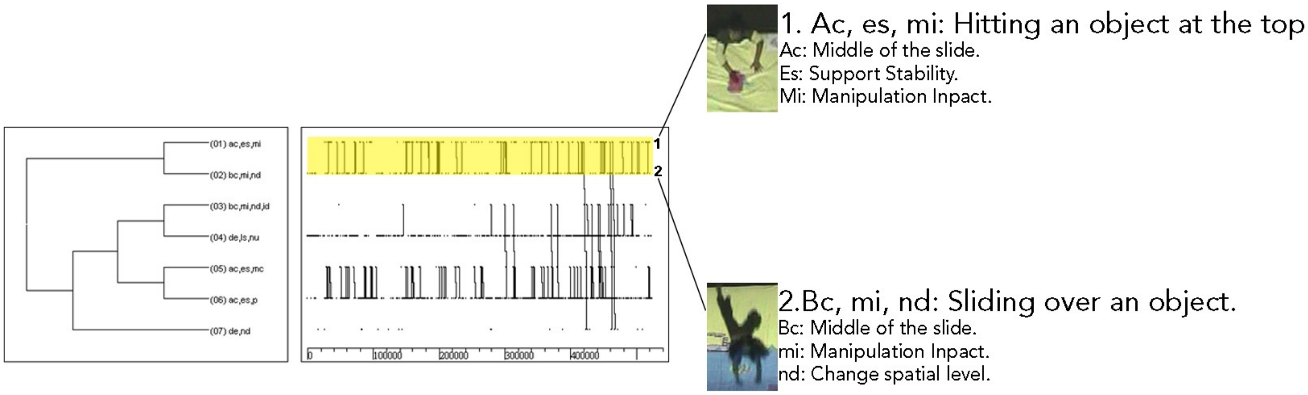

Figure 6. Occurrence combo slide-hit movements instructed for the Fish Game represented by the sequence of the two motor actions: Ac, es, mi (hitting an object at the top) and Bc, mi, nd (sliding over an object) .

those depicted in Figure 6; i.e. those that were fostered by the design approach. One interesting observed limitation was that some children tend to go back to the same position at the top of the slide. According to this preferred position, children were adopting a certain role in the game play. For instance, a child that tends to position himself in the lateral area of the slide was more subject to scare away a bird since the mechanic of the game makes the birds come from the lateral side of the interface. Therefore, some children did not exercise the same skills as other team members. This opens new interesting challenges for the design of games for the IS. It will be important to try to make gameplay more homogeneous for all children and for all positions on the slide in order to maintain the same level of physical activity in all children.

Regarding the specific movements in the Fish Game, the combo slide-hit has enriched the social experience in the game by fostering one player to coordinate her actions with the actions of another for a given event. The success of this strategy opens the door to many more coordinated actions between two, three or even four children to achieve a common goal and keep them all active within the play session.

In the case of arm waving, this movement was performed almost every time a bird appeared. This intense upper body motor action was lacking in previous games designed for the IS. Hence, this is another successful incorporation of a motor action into the gameplay of the IS.

In some rare cases children realized they could scare a bird away from a sitting position on the upper edge of the playing surface, by moving their legs rapidly over the bird. Of course this was also partially effective. However, arms can be moved with greater ease and fluidity than legs, which poses the issue to children about what is the most optimal motor action for each event in the game. This teaches children about motor action and enhances their proprioceptive development. One possibility would be to try to force a specific action from the detection of the motor activity of users by the artificial vision system. This is not a simple task due to the complexity of the slide environment. For example, many children move very close together or even overlap in some areas. Also, the area to be tracked is quite large to have sufficient image quality on the detection of the shape or skeleton of each child. New technological solutions such as using a Kinect to detect the motion done with the limbs for a specific game action can be explored to reward desired movements and penalize others. However, there still exist technological limitations such as the fact that the Kinect has quite low resolution and it cannot detect objects that are more than approximately 5m away from it, when the slide configuration actually needs longer distances.

The coding system we have applied has been transferred from the context of systematic analysis of sports activities. In this study, we have shown that the same coding system can be used to analyze exergames. This system allowed us to explore whether our design strategy to encourage movement was achieving its goals. In a deeper analysis, this system could also extract movements that were not expected to appear during play sessions or events that could lead to harmful movements. It is necessary to clarify that conditional skills can be detected but not measured through this method. In other words, OSMOS can detect whether strength activities are being performed through observation but cannot quantify their intensity or effect on children. Nonetheless, the sole fact of observing that these motor activities are being performed already provide important information for the interdisciplinary teams of interaction designers, medical experts and physical education experts. To quantify the effect of conditional skills, as well as energy expenditure, we would need invasive equipment. This is not comfortable for children and even less in a play context in which all their bodies are placed in contact with the surfaces of the slide. It will be interesting for future research to try to correlate some of the parameters that our system detects in a non-invasive manner, with physiologic measures taken by invasive systems in special sessions. This would then allow us to quantify conditional skills and energy expenditure in regular play sessions without having to use the invasive equipment.

Finally, one dimension of movement that was not explored in this study was related to affective states. With the same system, emotional movements could also have been coded so as to better understand the affective state of children towards events in the game. Such analysis could tell the designer what elements in the game are more enjoyable, which can be frustrating, etc., in order to enhance the design or adjust its level of difficulty. We believe that the more a game adapts its pace with regard to affective states, the more active the player will be, and the more it can potentially be used as a healthy tool for exertion. Another element that should be observed in future work is the social behavior between the players. As we explained, only collaboration in terms of sequences of motor behavior was analyzed. However, we did not analyze situations in which children talk to each other and negotiate to develop game strategies and participation roles. These behaviors could also be analyzed using our coding method in the future, with the premise that the more a game encourages socialization, the more it has the potential to make the players engaged in the game.

8. CONCLUSIONS

Analyzing the impact of exergames on motor skills is an important issue to understand how they affect the health of users. In this study, we have joined efforts with health and physical education experts to define a design method for exergames addressed to children. By analyzing a given interface with expert knowledge, we were able to extract the predominant executable movements for it. Taking into account children's movement and theme preferences, we first compiled a short list of movements and organized Participatory Design sessions to obtain ideas for a new game that would enhance quality of movement, understood as richness and diversity. This led to the design of the Fish Game.

In a study run with 150 children, we analyzed whether it promoted specific and diverse movements. This was done through systematic observation methods using a video coding system developed by physical education experts. Our results confirm the Fish Game fosters the execution of specific movements and a richer variety compared with the Balloon Game designed previously. We have also shown that we were able to implement an event in the game that successfully encourages collaborative motor behavior. This method could be used with any other form of full-body interfaces to create games that have a significant impact on children motor skills. Also, we claim that the coding system we chose to analyze our design can be used with any other exergame to understand the motor experience it provides.

9. ACKNOWLEDGMENTS

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