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TESIS DOCTORAL

Designing and implementing digital educational tools for children and youth with special needs using Natural Interfaces

Benoît Bossavit

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ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
A	Achieved
AAC	Augmentative and Alternative Communication
ASD	Autism Spectrum Disorder
CAD	Computer Aided Design
CH	Crank Handle
CP	Cerebral Palsy
D	Development
DOF	Degree Of Freedom
DS	Down Syndrome
GMFCS	Gross Motor Function Classification System
GO	Grasping Object
GUI	Graphical User Interface
HB	Handle Bar
HCI	Human-Computer Interaction
HFA	High Functioning Autism
ID	Intellectual Disability

IQ	Intelligence Quotient
M	Mean
NASA-TLX	NASA Task Load Index
NPC	Non-Player Character
NUI	Natural User Interface
PD	Participatory Design
PECS	Picture Exchange Communication System
R	Rotation
RNT	Rotate’N Translate
S	Starting
SD	Standard Deviation
SDK	Software Development Kit
SEN	Special Educational Need
SG	Serious Game
SGD	Speech Generating Devices
SLI	Specific Language Impairment
SUS	System Usability Scale
T	Translation
TCT	Task Completion Time

TEL	Technology-Enhanced Learning
TR	Translation-Rotation
UK	United Kingdom
US	United States
VE	Virtual Environment
VLE	Virtual Learning Environment
VR	Virtual Reality
WIMP	Windows, Icons, Menu and Pointer

PUBLICATION AND DISSEMINATION

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SUMMARY / RESUMEN / RÉSUMÉ

SUMMARY

This thesis focalises on the pedagogical potential of Natural User Interfaces (NUIs) and their impacts in different educational contexts. NUIs are motion-based touchless interactions and have showed increase of engagement and motivation, which may have an effect on learning via the use of the body. However, most of the studies referred to typically developing people with only few evidence concerning children with Special Educational Needs (SEN). Consequently, this thesis based its research on the hypothesis that NUIs could also support learning on children with SEN.

Therefore, two interaction techniques using the Microsoft® Kinect were designed and empirically evaluated. On the one hand, the *Body Menu* that associates icons to the body and allows their selection by touching the corresponding body parts. This interface stems from the use of proprioception properties. On the other hand, the *Crank Handle* that permits the manipulation with one hand of 3D virtual objects. This interface is based on the metaphor of rotating crank handles to orientate the 3D objects. These two new interfaces built a basis to explore the potential of NUIs and were, thereafter, embedded in different educational tools through three studies.

The first one took place in a special school in Pamplona (Spain) with children with severe motor and cognitive disabilities. An Iterative Design approach was adopted in collaboration with the teachers of the centre to develop a framework of three activities that are adapted to the children's needs and skills: (i) painting with the hands, (ii) discovering the content of a blurred image, and (iii) playing music. These activities aim to promote children's creativity. The framework proposes several possibilities of interaction, including the *Body Menu*, in order to fit the children's motor needs. The results showed that the framework could adapt to the children's skills and improve their motivation. Thus, the outcome can be considered an adaptive assistive technology.

The second study took place in a special school in New Forest (UK) with teenagers with high functioning autism. The teenagers were involved through Participatory Design in the creation of a collaborative Serious Game that uses the *Body Menu* to increase the knowledge in Geography. The game consists in obtaining European countries by answering questions. Several strategic features were added so that users could collaborate against the computer or compete against each other. The results showed that the participants learnt Geography content although the difference in level of competitiveness created tensions within the peer teams, which led to a decrease of engagement towards the task.

The last work targeted mainstream schools in Pamplona (Spain) with the collaboration of the Oteiza's museum, which objective was to shed light on artistic concepts. Thus, a series of mini-games using the *Crank Handle* was developed through a Co-design approach with the didactics section of the museum. For this study, three sculptures were selected with different abstract concepts: negative aesthetic via addition, negative aesthetic via subtraction and the activation of space and time. The framework was tested by pupils from primary and secondary schools and students from educational practice. The analysis of the results showed that the participants did understand the artistic concepts among which the girls were more engaged and increased the most their knowledge.

The conclusions drawn from these studies confirm that the use of NUIs increase motivation and engagement of the participants. However, stronger evidence is still required to argue that NUIs might support learning to children with SEN. Moreover, the collaboration with stakeholders from educational settings is crucial in the design and development of educational tools that are adapted to the needs and skills of children.

RESUMEN

Esta tesis se centra en el potencial pedagógico de Interfaces Naturales de Usuario (NUIs) y su aplicación en distintos ámbitos educativos. Las NUIs son interacciones remotas basadas en movimientos gestuales del cuerpo y han mostrado mejoras en la implicación y motivación de los niños, lo que puede repercutir en el aprendizaje. Sin embargo, la mayoría de los trabajos publicados estudian su aplicación con personas de desarrollo cognitivo y motriz típico, dejando en segundo plano el estudio de su posible impacto en niños con necesidades educativas especiales (SEN). Por eso, esta tesis basa su investigación sobre la hipótesis de que las NUIs pueden también apoyar el aprendizaje en niños con SEN.

Con esta finalidad, se diseñaron dos técnicas de interacción con la Microsoft® Kinect y se evaluaron empíricamente. Por un lado, el *Body Menu* que asocia iconos con el cuerpo y permite su selección tocando las partes correspondientes del cuerpo. La interfaz se basa en las propiedades de la propiocepción. Por otro lado, el *Crank Handle* que permite la manipulación con una mano de objetos virtuales 3D. La interfaz se basa en la metáfora de rotar manivelas para orientar los objetos 3D. Estas dos técnicas establecieron la base para explorar el potencial de las NUIs y fueron integradas en herramientas educativas a través de tres estudios.

El primero de ellos se llevó a cabo con niños con discapacidades severas, tanto cognitivas como motrices, en una escuela especializada de Pamplona (España). Se adoptó una metodología de diseño iterativo, en colaboración con los profesores del centro, para desarrollar una aplicación compuesta de tres actividades adaptadas a las necesidades y habilidades de los niños: (i) pintar con las manos, (ii) descubrir el contenido de una imagen borrosa y (iii) tocar música. Con ellas se pretendía fomentar la creatividad de los niños. La aplicación proponía varias posibilidades de interacción, incluyendo el *Body Menu*, para adaptarse a las necesidades motrices de los niños. Los resultados mostraron que la aplicación desarrollada fue capaz de adaptarse a las dificultades de los niños y mejoró su motivación, por lo que puede ser considerada como tecnología adaptativa y de asistencia.

El segundo estudio se realizó con adolescentes con autismo de alto funcionamiento cognitivo en una escuela especializada de New Forest (Reino Unido). Se diseñó un juego serio colaborativo para desarrollar conocimientos de geografía integrando la técnica de *Body Menu*. Se aplicó una metodología de diseño participativo, contando con la colaboración de los adolescentes implicados. El juego consistía en desbloquear los países europeos respondiendo a preguntas, incluyendo elementos de estrategia para que los usuarios pudieran colaborar contra el ordenador o competir el uno contra el otro. Aunque los participantes aprendieron contenidos geográficos, la diferencia del nivel de competitividad generó tensiones entre las parejas, lo que llevó a una reducción del interés por la tarea.

El último trabajo se realizó en escuelas de Pamplona (España) con la colaboración del museo Oteiza y el objetivo era profundizar en contenidos artísticos. Para ello, se desarrollaron una serie de mini-juegos, utilizando la técnica del *Crank Handle*, en co-diseño con la sección didáctica de dicho museo. Se seleccionaron tres esculturas con diferentes conceptos abstractos: estética negativa por adición, estética negativa por substracción y activación de espacio y tiempo. La aplicación fue evaluada con estudiantes de primaria, secundaria y de magisterio, mostrando el análisis de los resultados que los participantes fueron capaces de comprender los conceptos representados, siendo las chicas las que mayor aprendizaje mostraron.

Como conclusión de estos estudios se puede afirmar que, si bien las NUIs aumentan la motivación y la implicación de los participantes, sin embargo siguen faltando evidencias para confirmar su apoyo al aprendizaje. Así mismo, que la colaboración con participantes de centros educativos es primordial para el diseño y desarrollo de herramientas educativas que puedan adaptarse a las necesidades y habilidades de los niños.

RÉSUMÉ

Cette thèse focalise sur le potentiel pédagogique des Interfaces Utilisateurs Naturelles (NUIs) ainsi que leurs impacts dans différents contextes éducatifs. Les NUIs sont des techniques d'interactions à distance qui se basent sur les gestuelles du corps. Elles ont démontré être motivantes et engageantes, ce qui peut répercuter sur l'apprentissage des enfants. Cependant, la plupart des études font référence aux enfants au développement typique, laissant peu de signes d'évidence en ce qui concerne les enfants aux besoins éducatifs spécialisés (SEN). Par conséquent, cette thèse base sa recherche sur l'hypothèse que les NUIs peuvent aussi soutenir l'apprentissage des enfants avec SEN.

Avec cet objectif, deux techniques d'interaction avec la Microsoft® Kinect furent développées puis empiriquement évaluées. D'un côté, le *Body Menu* qui associe des icônes au niveau du corps tout en permettant leur sélection en touchant les zones du corps correspondantes. Cette interface se base sur les propriétés de la proprioception. Et de l'autre côté, le *Crank Handle* qui permet la manipulation d'objets virtuels en 3D avec une seule main. L'interface se base sur la métaphore de tourner une manivelle pour orienter les objets 3D. Ces deux techniques fondèrent la base pour explorer le potentiel des NUIs et furent intégrées à des outils éducatifs au travers de trois études.

La première étude eut lieu dans une école spécialisée à Pampelune (Espagne) avec des enfants avec handicaps sévères autant cognitifs que moteurs. Une méthodologie de Conception Itérative fut adoptée en collaboration avec les professeurs du centre pour développer une application composée de trois activités adaptées aux besoins et compétences des enfants : (i) peindre avec les mains, (ii) découvrir le contenu d'une image floutée (iii) jouer de la musique. Ces activités prétendent encourager la créativité des enfants. L'application propose plusieurs possibilités d'interaction, incluant le *Body Menu*, afin de s'adapter aux besoins moteurs des enfants. Les résultats montrèrent que l'application développée fut capable non seulement de s'adapter aux difficultés éprouvées par les enfants mais aussi d'augmenter leur motivation ; elle permet donc d'être considérée comme technologie adaptative et d'assistance.

La seconde étude se déroula avec des adolescents avec autisme de haut niveau cognitif dans une école spécialisée de New Forest (Royaume-Uni). Un jeu sérieux collaboratif fut conçu pour améliorer les connaissances en Géographie en intégrant la technique du *Body Menu*. Une méthodologie de Conception Participative fut appliquée en collaboration avec les adolescents impliqués. Le jeu consiste à débloquer les pays européens en répondant aux questions correspondantes, incluant des éléments stratégiques pour que les utilisateurs puissent collaborer contre l'ordinateur ou concourir entre eux. Bien que les participants aient appris de nouveaux contenus géographiques, la différence de niveau de compétitivité entre les joueurs généra des tensions, ce qui amena à une baisse d'intérêt envers la tâche à réaliser.

La dernière étude se réalisa avec des écoles de Pampelune (Espagne) en collaboration avec le musée Oteiza ayant comme objectif l'explication de concepts artistiques. Ainsi, une série de mini jeux furent développés utilisant la technique du *Crank Handle*, en suivant une méthodologie de Co-Conception avec la section didactique du musée. Trois sculptures furent sélectionnées avec différents concepts abstraits : l'esthétique négative par addition, l'esthétique négative par soustraction et l'activation de l'espace et du temps. L'application fut évaluée avec des étudiants de primaire, secondaire et d'IUFM. Les participants furent capables de comprendre les concepts représentés et les filles présentèrent un meilleur apprentissage.

Les conclusions de ces études permettent d'affirmer que les NUIs augmentent la motivation et l'engagement des participants. Cependant, il reste un manque d'évidences permettant de confirmer le soutien à l'apprentissage. De plus, la collaboration avec des centres éducatifs est primordiale pour concevoir et développer des outils éducatifs adaptés aux besoins et compétences des enfants.

INTRODUCTION

This thesis explores the potential of the Natural User Interfaces (NUIs) within different educational contexts for children and youth with Special Educational Needs (SEN). Therefore, this is a combination of two research fields which are *Human-Computer Interaction* (HCI) and *Special Education*. In order to go into this multidisciplinary approach, an introduction about the end-users (SEN) and the technology (HCI) used in this thesis is provided below as well as some relevant existing research projects in the field.

1. SPECIAL EDUCATIONAL NEEDS

Education for children with special needs remains a challenging issue. The term "special need" refers to a person with mental, emotional or physical issues who generally requires a special setting for education (American Psychiatric Association, 2013). Inclusive education seems to be an appropriate system where children improve better academic skills and develop adaptive behaviours (Cole et al., 2004). However, no empirical studies significantly proved such results (Dessemontet et al., 2012).

The children who do not receive inclusive education will integrate special schools. The level and definition of the special needs are classified by a diagnosis of cognitive and motor capacities. Therefore, these special educational institutions must usually deal with a large variety of disabilities, which might generate real challenges since most of these children require specific and adapted structures (Keogel et al., 2011). In order to illustrate the diversity of disabilities that these schools are exposed to, some of these disabilities are described below. This list is not exhaustive but limited to the diagnosis the authors encountered during this thesis.

1.1. AUTISM SPECTRUM DISORDER (ASD)

It was believed that vaccines applied against the measles, mumps or rubella could cause brain damage that would lead to autism (Flaherty, 2011). However, scientific studies showed that vaccines were not the cause (Taylor et al., 2014).

Actually, researchers point out genetic and environmental factors as the source of autism (Chaste & Leboyer, 2012). ASD affects at least 1.16% of the children in the UK (Baird et al., 2006) and 1.47% in the US (Baio, 2014).

Autism Spectrum Disorder (ASD) is diagnosed according to pervasive difficulties in social communication and interaction, and repetitive and stereotyped behaviours (American Psychiatric Association, 2013). Autism is referred as spectrum since individuals' experience within each of these impairments may differ significantly. People who were formerly diagnosed with Asperger Syndrome are nowadays integrated in the autism spectrum and referred as High-Functioning Autism (HFA) (American Psychiatric Association, 2013). These do not usually have cognitive impairment and possess an average or above Intelligence Quotient (IQ) (Hill and Frith, 2003). Children with ASD usually require special structures at school with familiar routines, engaging and customisable learning activities (Millen et al., 2010).

Up to date there is no cure and no single standard treatment. The treatments that are applied are lifelong processes and mainly include educational therapies (speech/language, occupational, etc.), medication and family support (Myers & Johnson, 2007).

1.2. CEREBRAL PALSY (CP)

CP is a group of disorders that affect motor functions. It is the consequence of damage that occurred to the developing brain and it may appear during pregnancy or infancy (Gration, 2014). Overall prevalence of live births with CP is about 0.21% (Oskoui et al., 2013).

Symptoms may vary between people according to the level of damage caused. Consequently, the Gross Motor Function Classification System (GMFCS) was set in order to classify the degree of motor dysfunction (Rethlefsen et al., 2010).

Dysfunctions are usually permanent and may decline as people grow into adulthood (Hanna et al., 2009).

Up to date there is no cure and no single standard treatment. The treatments that are applied are lifelong processes and include medication, therapies (physical, speech/language, occupational, etc.), surgery (orthopaedic or dorsal rhizotomy that consists in cutting nerves) and assistive technology (Novak et al., 2013).

1.3. DOWN SYNDROME (DS)

DS is a chromosomal anomaly caused by the presence of an additional 21st chromosome (Patterson, 2009). In 2010, the overall prevalence of live births with DS is 0.1% (Weijerman, 2010) and is nowadays one of the leading causes of intellectual disabilities (Duchon & Herault, 2016).

People with DS show low sensorimotor performance (Hodges et al., 1995), motor (Anson & Mawston, 2000) and perceptual (Elliott & Bunn, 2004) dysfunctions, limitations in intellectual functioning as well as in adaptive behaviour (Hogan et al., 2000). Specific motor dysfunctions may affect the basis of verbal information when a sequence of movement is required (Heath et al., 2000). Furthermore, these sensorimotor difficulties may also have an impact on participation at school, independence in daily living, and social acceptance by peers (Pivik et al., 2002).

Up to date there is no cure and no single standard treatment. Treatments applied are lifelong processes that include medication, early intervention and educational therapies (physical, speech/language, occupational, etc.), and assistive technology (Guralnick, 2011).

1.4. INTELLECTUAL DISABILITY (ID)

ID is an impairment of cognitive and adaptive functions. It is defined by an Intelligence Quotient (IQ) below 70 (American Psychiatric Association, 2013). The causes may be various such as environmental (Shapiro & Batshaw, 2011) or genetic (Rauch et al., 2012). The prevalence is estimated at 1.03% (Maulik et al., 2011).

ID impacts conceptual (language, reasoning, memory, etc.), social (empathy, relationship, interpersonal communication, etc.) and self-management skills (personal care, organization, work tasks, etc.) (American Psychiatric Association, 2013). In addition, ID is usually coupled with other disabilities such as the ones previously cited (ASD, CP, DS).

Up to date there is no cure and no single standard treatment. Treatments applied are lifelong processes that include medication, behaviour therapies and family support (Brown et al., 2013; Mash & Wolfe, 2013).

2. TECHNOLOGY

In this thesis, the technology used is the Virtual Reality (VR). Although VR is usually associated to a three-dimensional space also called Virtual Environment (VE), VE is, actually, just one component among others. Indeed, VR can be defined by three components: the *input devices* which allow users to control the system, the *VE* which can be multi-sensorial (visual, acoustic, etc.) and the *output devices* which make users perceive the VE (Cobb & Sharkey, 2006).

Since the appearance of computer applications, all kinds of interfaces have been developed for helping humans to communicate with them. Research in Human Computer Interaction (HCI) focused on both the creation of new devices such as the combination mouse/keyboard, gloves or multi-touch surfaces and the development of interfaces that exploit these devices. Interaction techniques can be classified in 4 categories: *navigation* which consists in moving within the environment, *selection* which allows interaction with specific virtual objects, *manipulation* which transforms virtual objects and *system control* which sets up the application (Bowman et al., 2001).

VR is extensively applied in different fields such as Computer Aided Design (CAD), simulations, training or entertainment. It has also been used as Virtual Learning Environment (VLE) targeting cognitive, motor and behaviour skills (Rizzo et.al, 2002). VR technologies provide a safe and supportive environment to transfer knowledge to real world (Jeffs, 2009) and provide the opportunity for repetition and control over the learning process (Parsons & Cobb, 2011). However, three-dimensional space created in VLE may provoke difficulties to some individuals with severe disabilities whereas the use of two-dimensional environment could provide a more appropriate interface (Standen & Brown, 2006). Thus, it is important to design properly the applications according to the final users, which could promote motivation and engagement.

This thesis focuses on the use of Natural User Interfaces (NUIs) and follows Serious Games (SG) guidelines to design and implement educational tools in practice settings.

2.1. NATURAL USER INTERFACES (NUIS)

Nowadays, the new paradigm in HCI tend to propose interfaces more and more natural and intuitive via motion-based touchless interactions, which are called Natural User Interfaces (NUIs).

NUIs are usually more ergonomic than other types of interaction (Grandhi et al., 2011; O'Hara et al., 2013). However, adapting the technology to users' capacities is challenging (Maike et al., 2014) and that is why defining proper guidelines to make NUIs accessible is very important (Maike et al., 2015). Additionally, NUIs are easily accepted by children (Bartoli et al., 2013) and adults (Saiano et al., 2015) with ASD. NUIs-based studies for people with SEN focused mostly on the autism spectrum.

Some evidences showed that NUIs can also support learning for typically developing youth (Hsu, 2011; Lee et al., 2012). A recent study showed that children with ASD might learn more effectively through 'hands-on' or kinaesthetic experiences (Latham & Stockman, 2014). Thus, the affordances of NUIs for promoting such interactions could offer real promise in supporting engagement and learning for children with special needs. In addition, it has been demonstrated that body movements and level of engagement are correlated: the more movements, the more engaged the users are with the game (Bianchi-Berthouze et al., 2007). Nevertheless, there is limited research that has specifically focused on the awareness of the body (Agarwal et al., 2013; Nielsen et al., 2004).

In 2011, Microsoft has released an affordable sensor, the Microsoft® Kinect, which enables the implementation of these new interfaces. This device can compute in real time the 3D skeleton pose of a person using a combination of a colour and a depth camera. The Microsoft® Kinect presents several advantages; for instance, it enables mid-air interaction, which permits users to give commands to a computer without the necessity of having any physical contact with it. Additionally, the interaction might be more intuitive and efficient since users utilise their body with a good perception of its position and orientation (Mine et al., 1997).

2.2. SERIOUS GAMES (SGS)

SGs are activities that aim at improving specific skills pedagogically contrary to video games which focus mainly on entertainment (Kapp, 2012). However, SGs benefit from video game mechanisms such as storylines, direct goals, increase of level of difficulties, or rewards (Whyte et al., 2015). The use of SGs in mainstream schools (Backlund & Hendrix, 2013) and in special education (Durkin et al., 2013) has shown positive results.

SGs are recognized to be effective mainly due to the engagement and motivation they provide to children (Girard et al., 2013; Molins-Ruano et al., 2014; Wrzesien & Raya, 2012), although there is still little evidence whether such skills are generalized to real life (Boot et al., 2008; Whyte et al., 2015). However, participants are willing to train longer which could contribute to further progress (Annetta et al., 2009).

3. SPECIAL EDUCATIONAL TOOLS

During the two last decades, assistive technologies have been researched to support children and youth with special needs. However, the use of technologies as educational tools is still in its early days and a gap remains between research and its applicability at schools (Parsons et al., 2013). The range of cognitive and motor disabilities is large. Therefore, it is important to define which skills can be supported by the technology. Research in this field can be narrowed down to five categories which are described below.

3.1. COMMUNICATION

Human's communication skills are developed within the context of communication (Tomasello, 2008). However, children with special needs may lack of active engagement due to bio-physical factors or motivation (Mattie & Kozen, 2007). As a result, this lack of communication with others hinders the improvement of speech and communication abilities.

Some researchers focused on the use of Augmentative and Alternative Communication (ACC). AAC is an intervention to facilitate communication by using either visual tools such as the Picture Exchange Communication System (PECS) or auditory ones such as Speech Generating Devices (SGD). These tools are common and easily found on the market and have been implemented with several technologies such as computers (Anwar et al., 2011), smartphones (Abou El-Seoud et al., 2014) or web-pages (da Silva et al., 2011). ACC improves the communication and increases children's vocabulary knowledge (barker et al, 2013). Furthermore, the use of AAC showed positive effects and may enhance interactions with typical developing peers and consequently improve social communication (Trembath et al., 2009). Social communication is a concept that groups several others concepts such as social interaction, (verbal and nonverbal) communication skills and language processing (Adams, 2005). However, its implementation in schools remains difficult due to the lack of information on teaching communication skills (Low & Lee, 2011) and the lack of trained teachers (Morrier et al., 2011).

The demand and the cost of speech therapy sessions are high which make them hardly accessible (Tan et al., 2013). An alternative would be the use of games. Videogames own the property of enhancing engagement, motivation and learning effect (Connolly et al., 2011). Children with Specific Language Impairment (SLI) may lack of engagement and motivation in improving their phonetic level or their language comprehension. Nowadays, speech recognition system can easily be integrated to videogames which allows an automatic progression within the game although speech intelligibility and time process of interpretation still require improvement (Navarro-Newball et al., 2014). In terms of language comprehension, games present advantages with their mechanisms such as storytelling or system of rewards to train and develop grammar knowledge (Hsu & Bishop, 2014).

3.2. ACADEMIC SKILLS

Academic skills remain an important learning area for children and youth with special needs. However, the literature reveals a very limited research on the use of technology to support the improvement of academic skills (Pennington, 2010). Although some scattered projects focused on specific content areas such as Math (Benton et al., 2012), Music (Cano & Sanchez-Iborra, 2015), or First-aid (Sáenz de Urturi et al., 2011), most of them are specialized in language skills (Knight et al., 2013). Consequently, Knight et al (2013) made a call for more research in other academic content areas of the curriculum, beyond English and literacy.

3.3. SOCIAL INTERACTION

Social interaction is characterized by the relationship between two or more people. Children and youth with social impairments usually found difficult the understanding of social conventions or the interpretation of body language and facial expressions (Hobson, 2005).

A common approach consists in teaching and training specific skills that hinder social interaction via the use of specific tools. For instance, the use of virtual agents via virtual environments tend to support children with social impairment who avoid eye contact with other people, and therefore to improve their communication skills (Bernardini et al., 2014).

Another paramount social reciprocity issue is the recognition of facial expressions to detect people's emotions. For instance, emotional patterns can be detected automatically via video processing and then be revealed to the children (Madsen et al., 2008). Emotions learning can also be supported via videogames such as playing in real time with a virtual face and deforming it to create emotional expressions (Hourcade et al., 2012) or using mnemonics by associating emotions with colours, for example, for a better assimilation (Serret et al., 2014).

Learning social conventions is also important to improve social integration. Children with social impairment may ignore when it is acceptable for them to act. Therefore, turn-taking games seem to be a good approach to train such skills (Battocchi et al., 2009; Piper et al., 2006). It is also essential to learn when to interact with people (Tentori & Hayes, 2010) and how to interact with them (Giusti et al., 2011).

The other approach to improve children's social interaction is team working within activities. Actually, involving children in the design process of activities presents a particular interest since it provides an opportunity for them to develop new academic and social skills, as well as to contribute to the design of new technologies (Guha et al., 2010). Consequently, several researchers focused on Participatory Design (PD) methods. The degree of involvement can be organized by roles such as user, tester, informant or design partner (Druin, 2002) and be influenced by the specific needs of those involved (Guha et al., 2008). Therefore, applications are designed by children with social impairment for children with special needs. The prototypes may focus on any skills such as Math (Benton et al., 2012), logic (Davis et al., 2010) or social communication (Frauenberger et al., 2012; Millen et al., 2011). These projects showed that PD approach can be very effective but methods need to be developed and applied sensitively and creatively when seeking to involve children with special educational needs, such as those with ASD (Frauenberger et al., 2013).

3.4. DAILY TASKS

One of the educational objectives is reducing the dependency of children and youth with special needs towards supervising adults (Servatius et al., 1992). One possible approach is scheduling activities, for instance through a visual support strategy that uses visual cues (photographs, drawings, words, etc.) to help children in following sequences of tasks independently (Koyama & Wang, 2011). Furthermore, visual schedules lessen anxiety and improve organisation and sequential memory (Mesibov et al., 2002). Consequently, such tools are successfully integrated in schools (Hirano et al., 2010) or at home (Burckley et al., 2015).

The other approach to help children in becoming autonomous is teaching the appropriate behaviour regarding the context of the situation (Mitchell et al., 2007). In that line, several researchers proposed simulations of specific tasks within specific environments such as shopping (Vera et al., 2007) or road-safety education (Saiano et al., 2015). Simulations provide advantages not only because children are naturally attracted by the technology but also because the environment is entirely controlled, which can provide a representation for abstract concepts (Parsons & Cobb, 2011).

3.5. PHYSICAL THERAPY

We usually associate special needs to cognitive disabilities; however, the term includes motor disabilities as well. Actually, many children with cognitive disabilities also have physical difficulties, which may hinder the use of applications (beyond the physical interaction) (Bryanton et al., 2006). Furthermore, a recent study showed that gross motor is related to cognitive functioning and higher levels of motor skills may facilitate academic learning abilities (Westendorp et al., 2011).

The arrival of NUIs promoted sport videogames by the use of gestures as close as possible of the real conditions. These kinds of games showed potential as rehabilitation tools (Luna-Oliva et al., 2013) and led to a new trend called *exergaming*, which is a portmanteau of "exercises" and "gaming". *Exergames* still require specific guidelines (Hernandez et al., 2013) but provide enjoyable experiences and implicitly improve balance (Gerling et al., 2014).

Gestures and postures have a considerable impact on social communication. For instance, it is socially important to wave or shake hands to greet people. As a result, research partly focused on the use of technologies to teach (Casas et al., 2012) and to rehabilitate (González-Ortega et al., 2014) via specific exercises. On the other hand, some gestures are considerate inappropriate such as stereotypical behaviours. Therefore, their detection is important in order to be corrected by therapists (Goodwin et al., 2011).

4. HYPOTHESIS AND OBJECTIVES

The current literature shows that technology has intrinsic potential to engage and motivate children with special needs in developing communication, academic, social, daily and motor skills. Since the development of new kinds of devices such as the Microsoft® Kinect, new paradigms in the HCI field have been researched particularly via motion-based touchless interactions. Actually, NUIs have showed evidence of supporting engagement and motivation, which may have an effect in learning via the use of the body. However, most of the studies referred to typically developing people with only few evidence concerning children with special needs. Consequently, this thesis based its research on the hypothesis that NUIs could also support learning on children with special educational needs.

Besides, literature reveals two gaps among others: (i) a lack of research in terms of academic skills and (ii) a lack of applicability of research in practice settings. Therefore, the overall aim of this thesis is to investigate the potential of NUIs to fill these gaps. However, the range of disabilities that can be encountered in schools is broad which hinders the generalisation of methods and tools. Therefore, three objectives have been defined:

1. *Exploration of the potential of Natural User Interfaces*. This objective focuses on the development of new techniques of interaction using the Microsoft® Kinect. These new techniques would be evaluated empirically by comparing their performance and usability properties.

2. *Design and implementation of educational tools*. This objective explores different methods to enhance the impact of educational tools by involving stakeholders and taking into account both the objectives of the institutions and children's needs.

3. *Evaluation of the developed tools in their corresponding educational context*. This objective analyses the impact of the educational tools taking into consideration the learning domains which are cognitive, affective, psychomotor and interpersonal.

5. THESIS OVERVIEW

This thesis straddles two research fields which are Human-Computer Interaction and Education. The first stage consisted in exploring the potential of

Natural User Interfaces via the creation of new interaction techniques. Then, these new techniques were subsequently applied within different works which objectives were the design and the implementation of educational tools within a specific context. Therefore, this thesis is composed of five main chapters which are illustrated in Figure 1. Due to the fact that each chapter refers to a self-contained study, their structure shapes a typical scientific publication with its own introduction, literature review, methodology, evaluation and discussion.

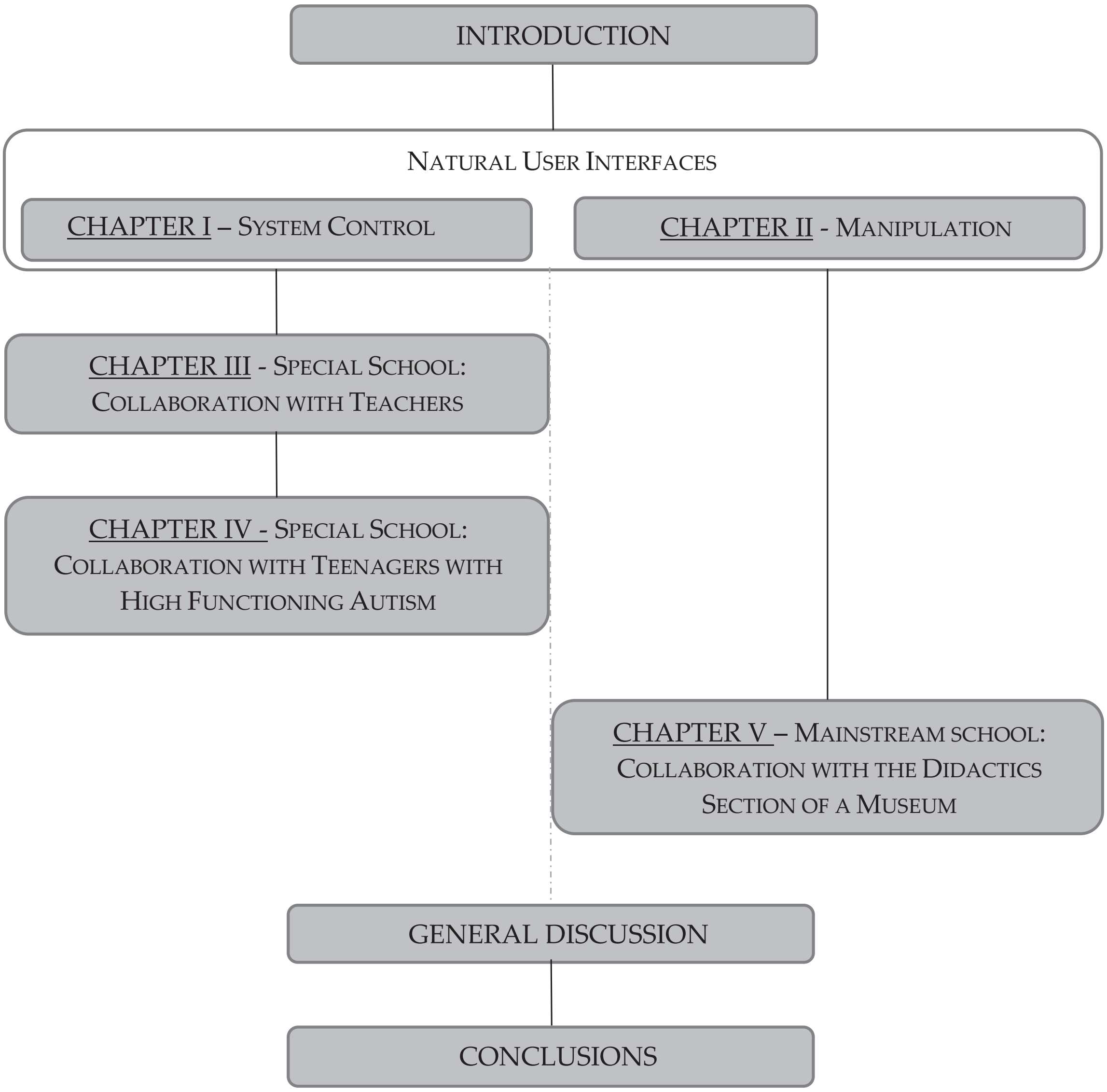

Figure 1: Structure of this thesis

CHAPTER I – NATURAL USER INTERFACES: SYSTEM CONTROL

This chapter explores the field of NUIs via the creation of a new interaction technique. The *Body Menu* is an interface that allows the control of the system via navigation throughout a hierarchical menu. The technique associates icons to specific parts of the body which can be activated when users touch these key areas with their hand. An evaluation has been conducted to compare its usability and efficiency with other techniques.

CHAPTER II – NATURAL USER INTERFACES: MANIPULATION

This chapter explores the field of NUIs via the creation of a new interaction technique. The *Crank Handle* is an interface that allows the manipulation of 3D virtual objects. The technique is based on the metaphor of crank handles in order to rotate the object around each of the three axes using one hand. An evaluation has been conducted to compare its usability and efficiency with other techniques. Furthermore, design guidelines on manipulation techniques are also discussed.

CHAPTER III – SPECIAL SCHOOL: COLLABORATION WITH TEACHERS

This chapter presents the fruit of the collaboration between researchers and teachers from a special school in Pamplona, Spain. Thus, an adaptive framework of activities has been designed and implemented based on the curricular project of the school. The objective is twofold. On the one hand, it is important to shape the activities according to the children's cognitive needs. On the other hand, the interaction techniques should be adapted to the children's motor skills so that they could benefit from the application regardless their physical capacity. The main interaction techniques stem from the study of the *Body Menu* carried out in the first chapter.

CHAPTER IV – SPECIAL SCHOOL: COLLABORATION WITH TEENAGERS WITH HIGH FUNCTIONING AUTISM

This chapter presents the fruit of the collaboration between researchers and teenagers with high functioning autism from a special school in New Forest, UK. The study follows a Participatory Design (PD) approach which empowers the stakeholders with specific roles so that each of them can express their voice by sharing power of decision. The output results in a serious game which objective is to learn about Geography content. Users interact with the application via the *Body Menu* technique described in the first chapter.

CHAPTER V – MAINSTREAM SCHOOL: COLLABORATION WITH THE DIDACTICS SECTION OF A MUSEUM

This chapter presents the fruit of the collaboration between researchers and the didactics section of a museum. The study follows a co-design approach to design a set of activities, via mini games, that explain the concept of the artist. Not only can the outcome be used by visitors at the museum, but it has mainly been thought to be used at schools. As a result, the application has been tested with children and youth at different key stages of mainstream schools. Participants interact with the application via the *Crank Handle* technique described in the second chapter.

GENERAL DISCUSSION

Each of the chapters presents a specific context-related study with its own discussion. Consequently, this section puts forward a transversal reading in which the hypothesis and objectives of this research are discussed across the different contexts of work.

CONCLUSIONS

This thesis concludes with a summary of the key findings from this doctoral research. Furthermore, some of my personal reflections about the overall experience from the different works as well as some ideas about potential future projects are outlined.

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CHAPTER I

NATURAL USER INTERFACES: SYSTEM CONTROL

ABSTRACT

Menus are a key mechanism for organizing different commands in Graphical User Interfaces. Nowadays low-cost devices which allow using different interaction techniques in remote interfaces have become widespread. Nevertheless, their corresponding menus are typically direct adaptations from traditional ones. As a consequence they are inaccurate, slow or produce tiredness. In this work, a menu selection technique for remote interfaces, the *Body Menu,* has been designed, implemented and evaluated. This technique permits whole-body interaction and is specifically designed to take advantage of the proprioception sense. The *Body Menu* attaches virtual menu items to different parts of the body and selects them when the users reach these zones with their hands. The Microsoft® Kinect was used to implement this system. The *Body Menu* was compared with the most representative menus. It was also compared with alternative layouts in order to study the best number of body parts to be used. Finally, an analysis about how children interact with the *Body Menu* was conducted.

1. INTRODUCTION

Since the appearance of computer applications, all kinds of interfaces have been developed for helping humans to communicate with them. Punched cards led their way to text console and then to Graphical User Interfaces (GUIs). Windows, icons, menu and pointer (WIMP) are the main parts of almost all existing GUIs. The menu is one of the most important GUI elements, allowing users to choose between different commands, in order to access all the functionalities offered by the application. Designing a menu is a complex and challenging task; that is the reason why it was and still is a very active research topic. In addition to the crucial role for the application usability, it has to balance performance and ease of use (Cockburn et al., 2007). Thereby, novice users should be able to use the application without complex instruction, whereas expert users desire a faster access to the menu items. Maintaining the equilibrium between these two factors, throughput and usability, shapes the menu.

Similarly, the input device is a factor that influences the design, since the menu is highly dependent of it and is constrained by its accuracy and latency. Technological change paves the way to new interaction paradigms. Nonetheless, those new ways of communication require specialized interaction techniques and direct adaptations tend to not fulfil all its potential. First, applications endowed with GUIs were executed in a desktop computer, using a mouse and a keyboard as input peripherals. These devices offer a wide variety of interactions. The classical menu, also called *Linear Menu*, is a vertical list of items that can be accessed by clicking with the mouse or pressing a shortcut on the keyboard. In 1988, Jack Callahan introduced the Pie menu (Callahan et al., 1988), in which all the items were arranged in circle. Afterwards, Gordon Kurtenbach created the *Marking Menu* (Kurtenbach & Buxton, 1993) inspired by the Pie Menu. This new method selects an element when a line is drawn toward the desired item. The *Marking Menu* can be adapted equally for mouse and pen devices, and is suitable for both novice and expert users. Since then, many menus were created for mouse devices based on the *Marking Menu* (Bailly et al., 2008; Delaye et al., 2011; Guimbretiere & Winograd, 2000; Kurtenbach et al., 1999; Zhao et al., 2006).

With the arrival of multi-touch screens, previous menu techniques were adapted to these devices; however, most of them were not appropriate for this technology. What is more, this new technology has some inherent issues: the hand used for touching, which occludes the screen (Brandl et al., 2009); the size of the fingertip with more surface than a mouse cursor (Benko et al., 2006); or the impossibility of distinguishing between mouse movements and dragging. Nonetheless, multi-touch input presents some advantages, such as multiple input pointers or more natural gestures like pinch and zoom. New menus were designed using gestures or combination of various fingers (Bailly et al., 2010; Kin et al., 2011; Lepinski et al., 2010). Consequently, new techniques moulded to these conditions were created. A great number of researches are still being done in this regard.

Nowadays, it is possible to interact with the system remotely and without devices attached to our body. Novel ways of interaction with all kinds of applications are achievable due to new technology harnessed from videogame devices. Those devices are affordable, accessible and easy to deploy for everyone. For instance, Nintendo® Wii remote controller, with its accelerometer, can recognize several gestures; Sony® EyeToy, a webcam with vision recognition algorithms for extracting your silhouette; or Microsoft® Kinect, a combination of a colour and a depth camera, which computes your 3D skeleton pose or face in real time.

Some of those remote game controllers allow whole body interaction for providing new gaming experiences. Nonetheless, many of them adapt only previous interaction metaphors instead of taking advantage of new possibilities. The body possesses a rich set of abilities that permits the usage of body parts as mediators in human–computer interactions (Klemmer et al., 2006). Furthermore, a body centred interaction can take advantage of the proprioception sense to perform manoeuvres in the user personal space without reliance on visual feedback (Shoemaker et al., 2010). The proprioception sense is the inherent human ability to determine the relative position, applied strength and velocity of his body (Boff et al., 1986).

The design and implementation of a menu selection technique based on whole-body interaction, the *Body Menu,* is proposed. It allows navigating through a hierarchical menu without wearing any device and using a low-cost sensor. Virtual menu items are attached to different parts of the body and selected when the user's hand reaches the desired zone. It is expected that using parts of your body as reference will improve speed and accuracy for item selection. In the same direction, Mine et al. (1997) suggested that proprioception could be used to develop a unified set of techniques that allow users interacting with a virtual world intuitively, efficiently, precisely and effortlessly. This chapter describes the design and implementation of the *Body Menu* interface. Additionally, three user evaluations were performed comparing it with other representative menus and using different configurations for the *Body Menu*. Criteria such as selection speed, accuracy and physical and cognitive workload were used for the comparisons.

The first user study consisted of comparing the *Body Menu* with a remote adaptation of the *Linear* and *Marking* menus. The aim was to determine whether a person using our menu obtains similar usability and performance results to the ones obtained using well-known menus. Another objective was to explore the potential advantages of proprioception.

The second one is a complementary experiment with children. Remote interaction has become mainstream even at home environments, principally due to videogame devices. Therefore, children and adults are likely to use menus remotely. We wanted to detect whether the skeleton size may be a problem for using the *Body*

Menu or not. At the same time, we tried to verify whether our menu interaction is fun and easy to use, as children's lack of motivation can lead to poor performance.

Finally, the third evaluation consisted of comparing three different layouts of the *Body Menu* changing the number and placement of the menu items. It was measured how the number of items and depth levels influence usability and performance. Furthermore, it was determined the best body locations for those items.

2. RELATED WORK

This section describes researches about menu selection techniques with remote interaction. Three different kinds of interaction can be distinguished: pointing, motion-based and location-based interactions.

2.1. POINTING TECHNIQUES

Pointing techniques consist of controlling a virtual ray to move a cursor around the screen. The ray is casted from some part of the user and its intersection with the screen indicates the pointer position to the system. This is a basic simulation of a mouse device. Researchers tried to use different parts of the body to manipulate the cursor. Horie et al. (2012) propose Xangle, a pointing method which uses two accelerometers on the forefingers. Each finger controls a line and the selection is performed in the intersection point. The use of accelerometers could be a good solution; however, using your gaze can be more intuitive and fast. For example, in their work, Park et al. (2011) used a cap with a gyroscope to determine to where the user's eyes were gazing. The user could pre-select a menu item by looking at it and then gave a voice command to activate the action. Yoo et al. (2011) compared three pointing methods using one hand, two hands and a combination of one hand and the gaze. The results showed that the last option improved the performance and reduced the fatigue.

Pointing selection methods may seem a natural way of interaction for the user; however, we have come to a point where further improvement is limited. Owing to that fact, more and more researches are working on gesture detection. In this case, the action is not caused by a cursor and a trigger, but by a specific gesture. The gesture can be performed by the body itself or through a device worn by the user.

2.2. MOTION-BASED TECHNIQUES

The use of gestures to interact with an application has been previously explored in the world of videogames, mainly by Nintendo®, the first company that successfully introduced specific gestures for playing. The Wii-mote comprises an accelerometer and an infrared camera to determine its spatial position. This device is used to trigger certain actions when a specific gesture is detected. For instance, the user can move the Wii-mote vertically to play golf or horizontally to play tennis. Additional gestures like squares or circles can be detected (Schlömer et al., 2008).

Crossan et al. (2008) proposed to manipulate a pointer using the wrist tilt for selecting different targets. A mobile device endowed with accelerometers was attached to the user's wrist; its roll angle was mapped to the pointer position. Pointing performance across resting, seated, standing and walking scenarios was analysed. Results showed that wrist rotation can be used successfully to select targets in static conditions. Nonetheless, walking condition supposed to be a problem for the technique, mainly due to noise introduced from the gait.

In a subsequent study, an accelerometer was attached to a hat (Crossan et al., 2009) in order to control a pointer with the head tilt. Results implied that the technique can be used successfully; however, it was less accurate for the walking condition. Additionally, they analysed the noise produced while the users were walking and its effects on the interaction techniques.

Mobile devices can also be utilized for controlling large distant displays (Dachselt & Buchholz, 2009). In this study, roll and pitch angles were read from the tilt sensors of the mobile device and used for controlling a 2D pointer. This research showed how gestures controls can be transmitted from a handheld device to a remote display. Nonetheless, there was no formal user evaluation.

Yamamoto et al. (2011) proposed an item selection technique employing gestures used in the daily life. As a result, they developed a system with four accelerometers, located at both hands and feet. That way the user could select an item twisting the hand or shaking the foot horizontally.

A similar idea was developed by Ni et al. (2011). They described a new menu, using tilt and pinch gestures, in which the user must wear a glove equipped with an accelerometer and bend sensors. The menu was divided in groups and each group contained up to four items. The user could change the current group twisting the hand; pinching the corresponding finger with the thumb will select an item within the current group.

There are some motion-based techniques which do not force the user to wear a device, similarly to our technique they use a vision-tracking system. Lenman et al. (2002) proposed to make a gesture with your hand to navigate through a *Marking Menu*. The menu was spread out when the users opened their hands and then, tracking the trajectory, they were able to select the desired item.

Bailly et al. (2011) proposed a new menu based on the Finger-count Menu (Bailly et al., 2010) and compared it with the *Marking Menu*. The user could select one of the 25 (5 × 5) possible items raising the corresponding number of finger on each hand. The results of the evaluation showed that it was slower than the Linear and the *Marking Menu*, mainly due to the processing time needed for finger detection. Another technique was proposed by Bailly et al. (2012) in which the user can interact with free-hand gestures; however, the user needs to attach the Microsoft® Kinect to the foot looking vertically. They combined finger detection, hand gesture and arm gesture.

2.3. LOCATION-BASED TECHNIQUES

Previous research has shown that the spatial memory is helpful for performing efficient and intuitive interactions. The psychological foundations of the ability to work with objects located relatively close to the body were examined by Easton & Sholl (1995). In the literature, researches can be split into two different categories.

The first category includes the set of interactions in which the objects or selection zones are placed in front of the body. For instance, Li et al. (2009) proposed a menu with a virtual hemisphere placed ahead of the user. The menu items were positioned on the virtual hemisphere with different latitudes and longitudes. Orientating a mobile phone the user was able to select different items. This menu performed better than the default interface of the mobile phone.

Cockburn et al. (2011) made a comparison between three hand selection techniques using ray pointing, selection zones contained in a 2D plane and in a 3D volume. The results showed that selecting a zone in a 2D plane is faster and more accurate than the other alternatives.

Despite the results of the last study, Ren & O'Neill (2012) presented an adaptation of the *Marking Menu* to a 3D environment. The users had to move their hands inside a 3D volume for selecting items at its surface. In the original *Marking Menu*, items were deployed around a circle. Accordingly, in this work they were arranged around a sphere. Although they did not compare their menu with the original 2D marking Menu, the reactions of the users were positive.

In the second category, selection zones are within a close distance to the body surface. As an example Harrison et al. (2010) proposed a new technology in which a sensor below the elbow detects touches on different regions of the skin. Nonetheless, the interaction zone was restricted to the forearm. This study was complemented by Lin et al. (2011); they underlined the importance of the user sense of touch as a feedback mechanism. The technique was extended by Harrison et al. (2011) using a depth-sensor and a projection system to transform any surface into a multi-touch input, including the body. Harrison et al. (2012) published an evaluation of this technique implementing it into their system called *Armura*.

The concept of associating actions to different parts of the body was designed by Ängeslevä et al. (2003). This idea was implemented by Strachan et al. (2007). In their system, the user was able control a music player by placing a device on different parts of the body. For instance, the orientation of the device changes the current track when it is placed on the head, whereas the same movement would change the volume if the device was placed on the hip.

This idea was improved by Shoemaker et al. (2010). They proposed a system using several sensors and a Wii-mote. In this system, the user could pick an item placing the Wii-mote close to a body part and pressing the trigger for selecting it. This method was designed to interact with very large screens and in a collaborative environment. Nevertheless, no specific evaluation was conducted.

3. THE *BODY MENU*

Our menu selection technique takes advantage of low-cost whole-body tracking technologies and the human sense of proprioception. The *Body Menu* attaches menu items to different parts of the body. To select a menu item, the user has to reach the desired part with one hand, as shown in Figure 1. The selection can be performed with both hands. Different configurations of the *Body Menu* are determined by the number of items, their positions or the depth of the hierarchy.

The menu selection technique has been implemented using the Microsoft® Kinect hardware. The accompanying software provides functions for retrieving the

2D and 3D position of up to 20 tagged skeleton points. Our implementation checks every frame the distance between the hands position and the defined body parts. When the hand stays in the body part for a defined period of time, the corresponding item associated to that part is selected. Meanwhile, visual feedback is given by displaying a time gauge and turning the item translucent.

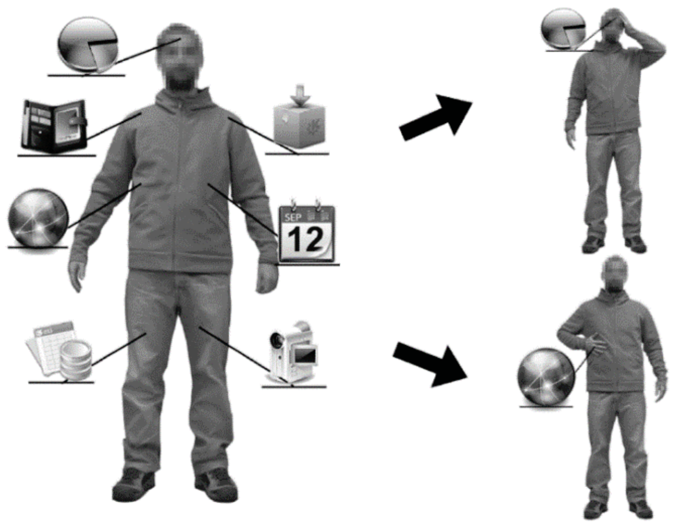

Figure 1: The *Body Menu* items are attached to different parts of the body. The navigation is performed reaching these specific body zones.

The period of time used for triggering a selection should be short enough for making the user feel that only touching the part will perform the selection. Nonetheless, it must also be long enough to avoid involuntary selections. For preventing repeated selections once that an item has been triggered, the system will ignore subsequent selections of this part until the hand moves out of it.

In order to measure the distance between the hand and the body parts, simple or weighted Euclidian distance does not behave as desired. This is caused as the skeleton offered by the Microsoft® Kinect SDK (Software Development Kit) does not consider the body thickness. Consequently, an axis-aligned bounding box offered the best results. There was no need to rotate it as the users always interact facing the Kinect frontally. Nonetheless, the maximum size of the bounding box is constrained by the fact that they should not intersect between each other. Nonetheless, it must be large enough to detect the selection in the majority of the cases. Previous tests revealed that the minimum half size of the bounding box required for detecting a selection was 10 cm. for the X and Y axes, and 20 cm for the Z axis. The dissimilarity in the Z axis is, in part, to compensate for the body thickness. Moreover, the Kinect sensor has lower precision in depth perception than in the other two coordinates. Khoshelham & Elberink (2012) conducted an experiment analysing the accuracy of the Kinect depth sensor. They found that the error of depth data increased up to 4 cm as the distance to the sensor augmented. Furthermore, the Z component of the measures had a larger standard deviation (1.0 cm for the X axis, 1.1 cm for the Y axis and 1.8 cm for the Z axis).

Items are located in specific points of the body such as the head, navel, left and right shoulders, ribs and legs. At the beginning it was decided to use the hips; however, it was detected that in rest position the user had his hands near them and unintentionally selected these items. In theory, other parts could be chosen although given the specified bounding box sizes, inserting more items would be uncomfortable and possibly unstable due to their overlapping

A non-uniform hierarchy of items was used, the first-level contains X items whereas sub-levels contain $(X - 1)$ new items. For example, when the user touches his left shoulder to select an item, the sub-menu items will appear on the other parts, thus the element placed on the left shoulder will be the same as before (Figure 2a). If the user touches this item again, he will return to the upper level. The functionality of going back is essential to navigate through the menu.

The element for going back will be displayed translucently to provide a visual clue. Additionally, different sounds were added for each kind of action, go back and item selection. Finally, when the selected item does not have more sub-levels, the corresponding action is sent to the application and then the menu is closed.

The proprioception sense permits to perform manoeuvres in the user personal space without a heavy reliance on visual feedback. Nonetheless, our *Body Menu* implementation has the possibility of drawing the shadow of the users' silhouette in real time. Additionally, menu items are drawn centred on specific body parts as an overlay (Figure 2). These visual feedback mechanisms are not completely necessary for expert users of the *Body Menu*, but novice users may rely on them.

In spite of the existence of devices with higher resolution and better accuracy, the Microsoft® Kinect has an affordable price and is widely available for almost everyone. Consequently, it can be considered as the default device that will be used for these interaction techniques and it will serve as a test bed for comparisons between different menus and configurations.

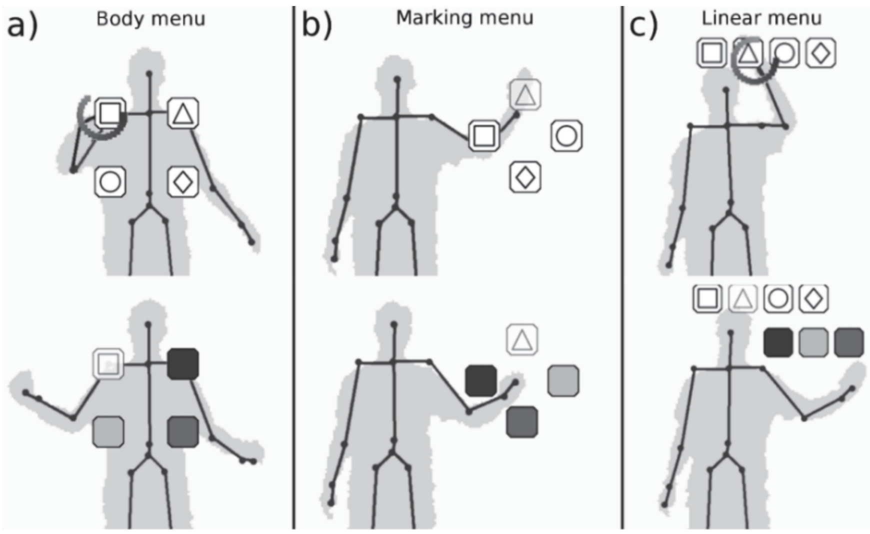

Figure 2: From left to right, Body, Marking and Linear menus. The top part represents level 0 and the bottom part represents level 1.

4. USER STUDY 1: COMPARISON WITH OTHER MENUS

The main purpose of this evaluation was to determine whether our technique is comparable with some well-established menus in terms of selection speed, accuracy and physical and cognitive workload. We also tried to establish how the use of proprioception influences the *Body Menu* performance. Additionally, we aimed to detect usability problems such as fatigue. Consequently, a user evaluation was conducted to compare our method, the *Body Menu*, with two other menus: the *Marking Menu*, which uses gesture interaction, and the *Linear Menu*, which uses pointing interaction.

4.1. MENUS DESCRIPTION

Marking Menu

We decided to compare the *Body Menu* with the *Marking Menu* as the latter is thought to have several positive features. One key advantage is the quick selection time, due to its circular layout that reduces the mean distance between items (Zhao & Balakrishnan, 2004). Furthermore, expert users are able to perform eyes-free selection once they have mastered the technique (Kurtenbach & Buxton, 1993). In our opinion, it is the best menu due to its simplicity and performance.

Our implementation of the *Marking Menu* is based on the Multi-Stroke Menu in which the root menu and subsequent submenus share the same position. As a result, users only need to perform two simple strokes rather than a compound stroke. This leads to a high level of accuracy (Zhao & Balakrishnan, 2004). The menu is displayed around the dominant hand (Figure 2b).

Linear Menu

The *Linear Menu* is the classical menu found in several applications. It is easy to use and offers the possibility to quickly explore menu contents. This menu is the most representative menu which uses the pointing method.

The menu is displayed at a fixed position on the top part of the window to be accessible for both right- and left-handed users. When the user points to an item with the hand, a submenu will appear shifted to the right under the selected element (Figure 2c).

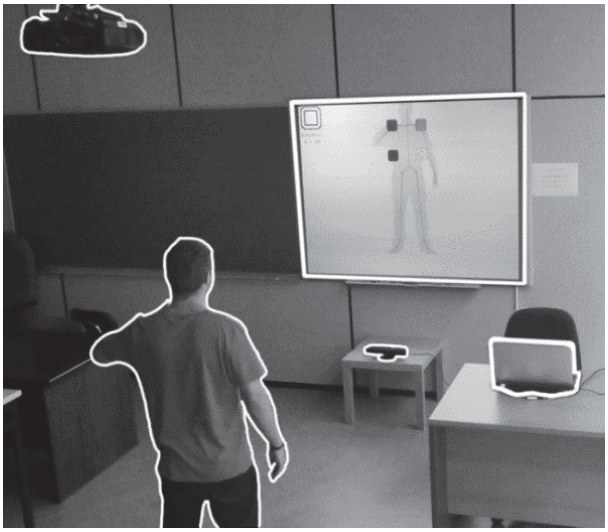

Figure 3: Overview of the apparatus with all the elements outlined.

4.2. EXPERIMENT

For the experiment, we used a laptop running Windows® 7 and a Microsoft® Kinect. The projected surface was 160 cm × 120 cm with a resolution of 1024 × 768 (Figure 3). The user was located in front of the Microsoft® Kinect at a distance of 2 m, although he was free to move during the experiment.

The values for the User Interface parameters such as icons width, dwell time for selection and bounding boxes size were determined through previous tests. According to the size of the screen and its resolution, the menus icons were displayed on the screen with a size of 8 cm for the three menus. That size was large enough to identify the icon without difficulty. The same feedback was given across all the menus, namely sound clip, time gauge and translucent selected icon. Nonetheless, each menu required specific adjustments.

Regarding the *Body Menu*, the size of the bounding box of each body part was set to 15 cm for the X and Y axes, and 23 cm for the Z axis. These dimensions are larger than the previously described minimum size for improving selection detection. The selection time was set to 0.5 s. This time is short enough for avoiding unwanted selections and sufficiently long for detecting it without causing nuisance to the user.

For the *Marking Menu*, the circle radius was set to 15 cm in order to avoid unwanted and ambiguous selections caused by icons overlapping. No selection time was necessary as the user's hand goes back to the centre for confirming the selection.

Concerning the *Linear Menu*, the space between two items was set to 12 cm horizontally and vertically as this distance was sufficiently short to avoid ambiguous selection. The selection time was similar to the *Body Menu*. This time resulted long enough to pass over items without selecting them, and short enough to quickly validate the selection.

The main task consisted of selecting an item in a 4 × 4 × 3 menu hierarchy. To simplify the task, all the items from a certain level were of the same type. The first level represented a shape, the second level a colour and the last a stroke style as used by Bailly et al. (2010).

We designed a normal and an expert selection mode for each menu. In the normal mode, icons were displayed whereas in the expert mode they were hidden. Nonetheless, we only hid the label and not the icons' box or the user's silhouette. These decisions were made in order to have the same behaviour across the three menus, as users cannot select a completely hidden item using the *Linear Menu*. The expert mode was proposed for measuring the speed and the accuracy that the users can reach when they know the location of the items.

Learning all the menu configurations would have taken a considerable amount of time to the users. Therefore, we decided to simulate the user expertise. Kurtenbach & Buxton (1993) simulated the expertise explicitly, indicating the corresponding gestures to perform in unlabelled selections. Differently, we decided to use the short-term memory alternating normal selections with unlabelled ones. The user had to select first a target in normal mode and then he had to select the same one in expert mode. This pair of selections was repeated 30 times for each target, thus the users made a total of 60 selections per menu type.

Between each target the user had to place one hand in a circle to toggle the menu visible. Once the target was selected, if it was correct a green tick was displayed otherwise a red cross was used. In addition to the graphical feedback, an appropriate sound was played.

When the menu appeared, we began to record data: the task completion time (mean time required to select a target); the accuracy (ratio between correct and wrong targets); the mean distance of both hands required to select a target and the amount of committed back steps.

The system was tried by 18 people (7 female and 11 male), aged between 17 and 36 ($M = 25.16$; $SD = 5.3$). Participants had heterogeneous professions and videogames or computer experience in some cases; one user was left-handed.

Previous to the evaluation, each participant had a small training. We explained how the menus work and they tried to select 10 items with each one. Afterwards, they interacted with the three menus in a different order following a Latin Square. Between each menu, participants filled in two questionnaires. The NASA TLX test (Hart & Staveland, 1988) which evaluates the mental and physical effort (100-point scale) and the System Usability Scale (SUS) test (Brooke, 1996), which evaluates the usability of the menu (5-point scale). At the end of the evaluation, the users ranked the three menus and gave some qualitative feedback.

Combinations of colour, shape and stroke style were used to create distinct items. The items order was different between each menu but the same for each participant. To summarize, the experiment involved 18 participants × 3 menus × 2 modes × 30 items = 3240 selections.

4.3. RESULTS

Data were analysed using repeated-measures ANOVA. For data which have violated the Mauchly's test of sphericity, we reported results using the Greenhouse–

Geisser correction (influencing df, F and P values). When a significant difference appeared, we performed a pairwise comparison adjusted by a Bonferroni correction.

Task completion time

In normal mode, users performed the task in 6.51 s (SD = 1.06) for the *Body Menu*, 6.54 s (SD = 0.97) for the *Linear Menu* and 6.74 s (SD = 1.49) for the *Marking Menu*. The data's sphericity was assumed and the analysis did not show significant differences $F(2,34 = 0.406, P > 0.05)$.

In expert mode, the sphericity was assumed and the analysis showed significant differences $F(2,34 = 4.177, P < 0.05)$. Nevertheless, the pairwise comparison did not show significant differences between groups; however, the P-value between the *Body Menu* and *Linear Menu* was close to the threshold (P = 0.057). The task completion time was 4.7 s (SD = 1.04) for the *Body Menu*, 5.27 s (SD = 0.89) for the *Marking Menu* and 5.41 s (SD = 0.68) for the *Linear Menu*. These results can be observed in Figure 4a.

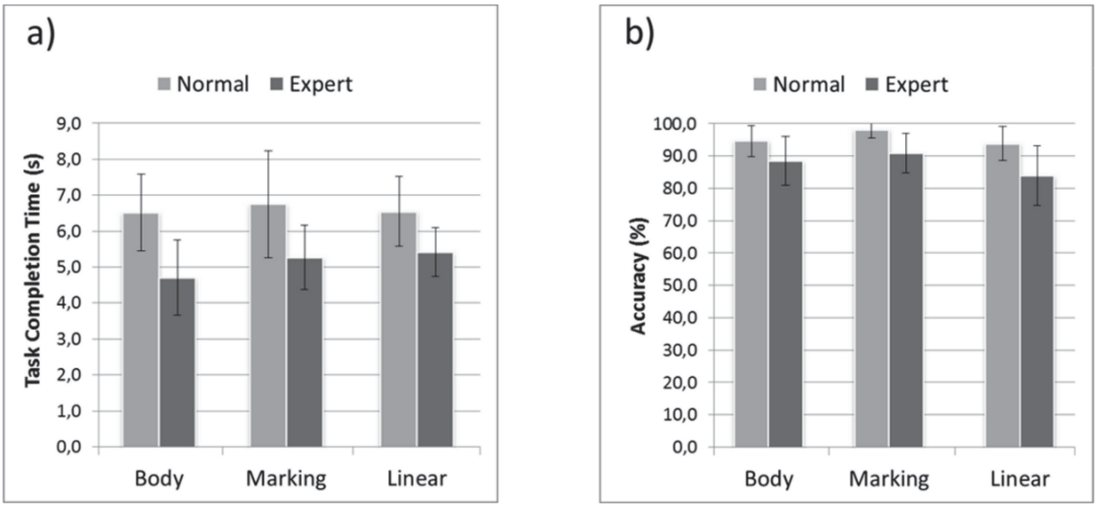

Figure 4: On the left, task completion time by menu type and mode. On the right, accuracy by menu type and mode.

Accuracy

In normal mode, the accuracy data's sphericity was assumed and the analysis showed significant differences $F(2,34 = 6.59, P < 0.01)$. The pairwise comparison showed that the *Marking Menu* (98.1%, SD = 2.61) was significantly more accurate than the *Body Menu* (94.6%, SD = 4.73) and the *Linear Menu* (93.8%, SD = 5.27).

The analysis showed significant differences F(2,34 = 5.01, P < 0.05) for accuracy in expert mode. According to the pairwise comparison, the Marking Menu (90.9%, SD = 6.13) was significantly more accurate than the *Linear Menu* (83.8%, SD = 9.16). The *Body Menu* was placed between both with an accuracy of 88.5% (SD = 7.6). These results can be observed in Figure 4b.

Differences between normal and expert mode

We performed the statistical test on the time difference between normal and expert mode. The data's sphericity was assumed and the analysis showed significant differences F(2,34 = 5.23, P < 0.05). According to the pairwise comparison, the time difference of the *Body Menu* (1.8 s, SD = 0.98) was significantly higher than the *Linear Menu* (1.1 s, SD = 0.79). The *Marking Menu* (1.4 s, SD = 0.87) was slightly lower than the *Body Menu*, but it was not statistically significant.

We also performed this test with the difference of accuracy. The data's sphericity was assumed and the analysis did not show significant differences F(2,34 = 1.83, P > 0.05). The loss of accuracy was 6.1% (SD = 1.4) for the *Body Menu*, 7.2% (SD = 1.43) for the *Marking Menu* and 10% (SD = 2.03) for the *Linear Menu*.

Number of user back steps

The number of back steps shows how many times the user had returned to the upper menu. We recorded the number of back steps during the users' sessions for each menu. We performed a statistical test, the data's sphericity was assumed and the analysis showed significant differences F(2,34 = 3.91, P < 0.05). According to the pairwise comparison, users went back significantly more times with the *Body Menu* (4.11 times, SD = 2.37) than with the *Linear Menu* (2.8 times, SD = 2.24). With the *Marking Menu*, users went back 2.8 times (SD = 2.82).

Distance travelled by hands

We recorded the mean distance per item of user's hand. The data's sphericity was assumed and the analysis showed significant differences F(2,34 = 65.57, P < 0.001). Pairwise comparisons indicated that users needed to significantly move their hands less with the *Marking Menu* (1.2 m, SD = 0.38) than with both the *Linear Menu* (2.8 m, SD = 0.60) and the *Body Menu* (3.3 m, SD = 0.69).

Hands position density map

We rendered a density map of the projected hands position (Figure 5), the right-hand side of the figure is the right-hand side of the user. Each menu had a different reference point for being able to superimpose data from all the users. The sternum was used for the *Body Menu*, the geometrical centre of items for the *Marking Menu* and the top left item position for the *Linear Menu*. We cropped the images to remove unnecessary black parts. Different transference functions were used to highlight contour shapes.

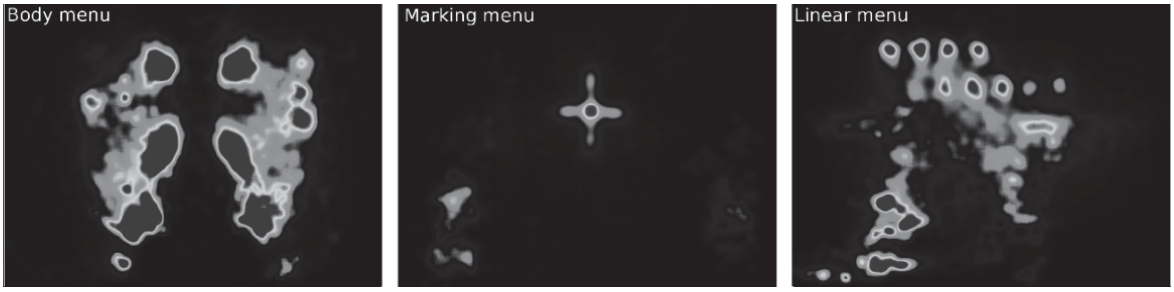

Figure 5: Density maps showing the *Body Menu*, the *Marking Menu* and the *Linear Menu* respectively. The gradient has a triangular shape, starting from black, fading to white on the middle sections and ending at dark grey.

Questionnaires

We statistically analysed the NASA TLX test, but it did not show significant differences F(1.508 = 1.11, P > 0.05). The score was 28.9/100 (SD = 15.6) for the *Body Menu*, 32.3/100 (SD = 16.2) for the *Marking Menu* and 32.7/100 (SD = 17.65) for the

Linear Menu. A low score means that the user did not make a meaningful mental and physical effort.

The SUS data's sphericity was assumed and the analysis did not show significant differences $F(2,34 = 0.72, P > 0.05)$. The score was 4.22/5 (SD = 0.5) for the *Marking Menu*, 4.15/5 (SD = 0.61) for the *Body Menu* and 4/5 (SD = 0.62) for the Linear one. The higher the score is, the more usable the system is.

The ranking of menus preference was analysed using a Friedman test ($\chi^2 = 1$, $df = 2$, $P > 0.05$) and it revealed no significant differences. The ranking was 1.83 (SD = 0.85) for the *Body Menu*, 2 (SD = 0.76) for the *Marking Menu* and 2.17 (SD = 0.85) for the *Linear Menu*.

5. SUPPLEMENTAL EXPERIMENT WITH CHILDREN

We considered that it would be important to observe the behaviour of children as they interacted with the three previously described menus. We were interested in identifying if the skeleton size could be a problem and if the menu was easy and entertaining to use for them.

5.1. EXPERIMENT

This experiment followed the same apparatus as described in the first study (Figure 3). For each menu, 20 items were required. The item order was different between each menu, but the same for each participant. Only the normal selection mode was tested. Six children (four girls and two boys) tried the system, aged from 10 to 11 years (M = 10.5, SD = 0.54), all were right-handed. They usually play videogames, mainly Nintendo® DS. Each participant tried the three menus in different order following a Latin Square. Before the evaluation, we explained to them how each menu worked and they tried the menus with 10 items. The participants sat down between each menu to rest. To summarize, the experiment involved 6 participants × 3 menus × 20 items = 360 selections.

5.2. RESULTS

Task completion time

The data's sphericity was assumed and the analysis did not show significant differences F(2,10 = 1.112, P > 0.05).

The task completion time was performed in 7.3 s (SD = 1.9) for the *Body Menu*, 7.4 s (SD = 1.13) for the *Marking Menu* and 8 s (SD = 1.27) for the *Linear Menu* (Figure 6a).Additionally, the results of adults are shown for comparison purposes.

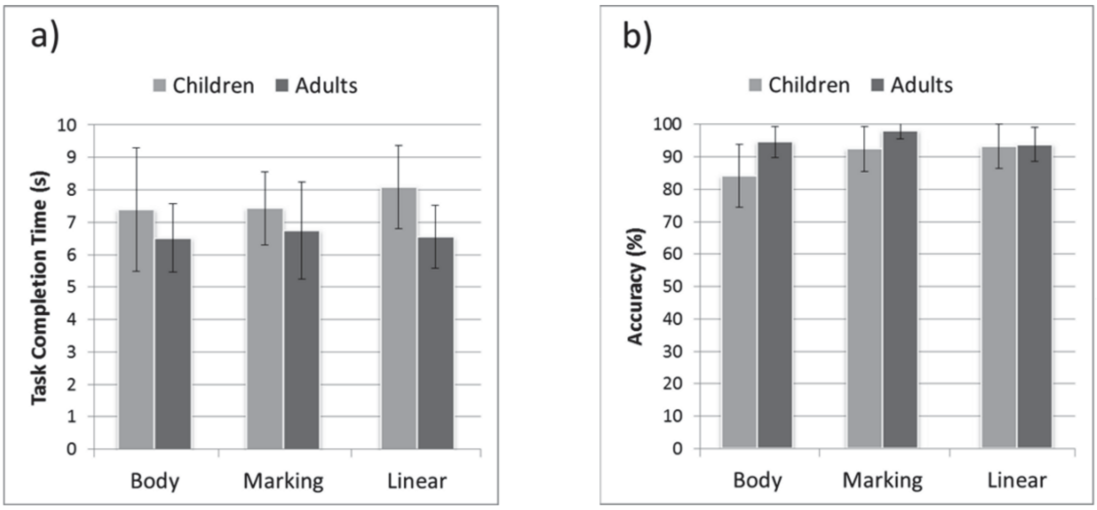

Figure 6: On the left, task completion time by menu type. On the right, accuracy by menu type. Children in light grey and adults from the first user study in dark grey.

Accuracy

The data's sphericity was assumed and the analysis did not show significant differences F(2,10 = 3.491, P > 0.05). The accuracy was 93.3% (SD = 6.83) for the *Linear Menu*, 92.5% (SD = 6.89) for the *Marking Menu* and 84.1% (SD = 9.7) for the *Body Menu* (Figure 6b).

Questionnaires

Children did not fill the questionnaires as the questions were too complex for them. Instead, we asked them about their ranking of preferences and their ranking of fatigue.

A Friedman test was performed on these two rankings. For the preference order, the analysis revealed a significant effect ($\chi^2 = 6.33$, $df = 2$, $P < 0.05$). We performed a post hoc test based on the Wilcoxon signed-rank tests with a Bonferroni adjustment (dividing the significance level with the number of tests, resulting in a threshold of $P < 0.017$). No significant differences were found between the three menus. The *Marking Menu* was in the first place with a score of 1.5 (SD = 0.54), then the *Body Menu* with 1.6 (SD = 0.81) and lastly the *Linear Menu* with 2.8 (SD = 0.4).

We also performed the Friedman test on the ranking of fatigue and the analysis showed a significant effect ($\chi^2 = 10.33$, $df = 2$, $P < 0.01$). The post hoc tests revealed no significant difference. The *Linear Menu* was in the first place, the one which produced more fatigue, with a score of 1.1 (SD = 0.4), then the *Marking Menu* with 1.8 (SD = 0.4) and finally the *Body Menu* with 3 (SD = 0).

6. USER STUDY 2: *BODY MENU* CONFIGURATIONS

Some applications require more menu elements than others. Consequently, our menu technique must be adaptable and accept different amount of items. Therefore, the aim of this evaluation was to determine how the number of items and sub-levels affects the menu performance. Moreover, we tried to determine the best locations for these items.

Kurtenbach & Buxton (1993) had demonstrated that for a hierarchical menu the error rate increases as the number of levels and items per level augment. Based on their study we proposed three *Body Menu* configurations choosing different body parts. As observed in Figure 7, the Body 4 uses four different body positions (left shoulder, right shoulder, left hip and right hip), the Body 6 employs six different positions (left shoulder, right shoulder, left hip, right hip, head and navel) and the Body 8 uses eight different positions (left shoulder, right shoulder, left hip, right hip, left knee, right knee, head and navel).

Owing to the different number of parts, we modified the amount of depth levels in order to keep the same range of target items. We used three depth levels for the Body 4 configuration (4 × 3 × 3) and two depth levels for the Body 6 (6 × 5) and Body 8 (8 × 7) hierarchies.

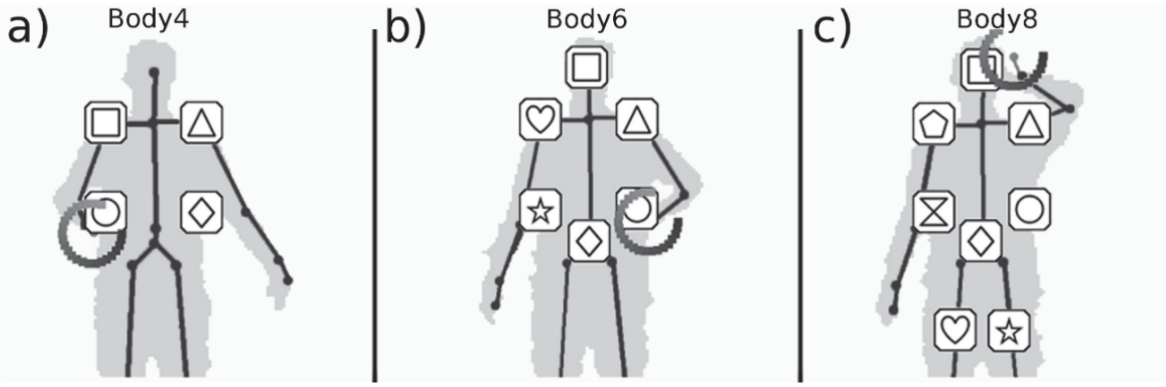

Figure 7: From left to right the top level of Body4, Body6 and Body8 configurations.

6.1. EXPERIMENT

This experiment followed the same apparatus (Figure 3) as the previous study. All participants tested both normal and expert modes. The item order was different between each menu, but the same for each participant.

Twelve new participants (7 female and 5 male) tried the system, aged from 21 to 43 years (M = 26, SD = 5.66). Participants had heterogeneous professions and videogames or computer experience in some cases; all of them were right-handed.

To summarize, the experiment involved 12 participants × 3 configurations × 2 modes × 30 items = 2160 selections.

6.2. RESULTS

Task completion time

In normal mode, the analysis showed significant effects $F(1.369 = 15, 353, P < 0.005)$ in the task completion time. The pairwise comparison showed that the configuration Body 4 (5.7 s, SD = 1.44) was significantly slower than configurations Body 8 (4.3 s, SD = 0.8) and Body 6 (4.2 s, SD = 0.95).

In expert mode, the data's sphericity was assumed and the analysis also showed significant differences $F(2,22 = 19.233, P < 0.001)$. The pairwise comparison showed that the configuration Body 4 (4.0 s, SD = 0.95) was significantly slower than configurations Body 6 (2.9 s, SD = 0.53) and Body 8 (2.8 s, SD = 0.67). These results can be observed in Figure 8a.

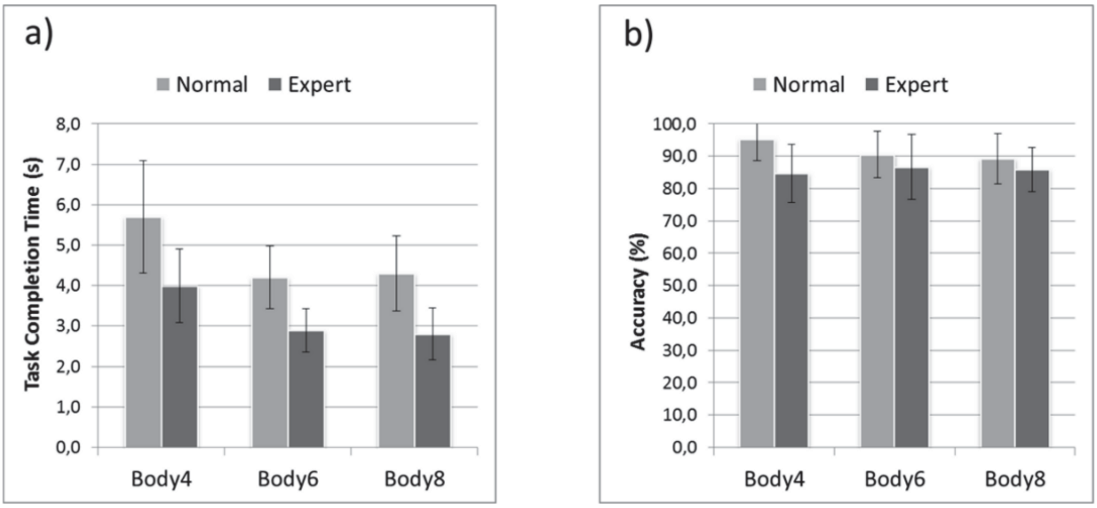

Figure 8: On the left, task completion time by configuration and mode. On the right, accuracy by configuration and mode.

Accuracy

In normal mode, the accuracy data's sphericity was assumed and the analysis did not show significant differences $F(2,22 = 2.57, P > 0.05)$. The pairwise comparison reported a significant difference between the Body 4 and Body 8 configurations. To remove the α-inflation, we did not take into account this result. The accuracy data were 95% (SD = 6.89) for the Body 4, 90% (SD = 7.24) for the Body 6 and 88.8% (SD = 7.95) for the Body 8.

In expert mode, the data's sphericity was assumed and the analysis did not show significant differences F(2,22 = 0.13, P > 0.05). The accuracy was 86.1% (SD = 10.23) for the Body 6 configuration, 85.5% (SD = 7.01) for Body 8 and 84.1% (SD = 9.22) for Body 4 (Figure 8b).

Differences between normal and expert mode

We performed a statistical analysis on the differences of time between normal and expert mode and it did not show significant differences F(1.305 = 0.973, P > 0.05). The increment of time was 1.7 s (SD = 1.13) for the Body 4 configuration, 1.5 s (SD = 0.36) for Body 8 and 1.3 s (SD = 0.52) for Body 6. We also performed this test with the differences in accuracy; the data's sphericity was assumed and the analysis did not show significant differences F(2,22 = 2.88, P > 0.05). The loss of accuracy was 3.1% (SD = 5.68) for the Body 8 configuration, 3.8% (SD = 7.08) for Body 6 and 10.8% (SD = 11.11) for Body 4.

Number of user back steps

We recorded the number of back steps during all the user sessions for each menu. We performed a statistical test and the data's sphericity was assumed, the analysis did not show significant differences F(2,22 = 3.104, P >.05). Users went back 2 times (SD = 0.49) for the Body 8, 2.1 (SD = 0.64) for the Body 6 and 4.4 (SD = 1.09) for the Body 4.

Distance travelled by hands

We recorded the mean distance per item of the user's hands. The analysis showed significant differences F(1,29 = 28.262, P < 0.001). Users needed to move their hands over a larger distance with the Body 4 configuration (3.4 m, SD = 0.68) than with Body 6 (2.4 m, SD = 0.56) and Body 8 (2.2 m, SD = 0.42). The first configuration had three levels instead of two, consequently the proportion with the others is close to two-thirds.

Hands position density map

As described on the first user study, we also plotted the density map of the three menu configurations (Figure 9).

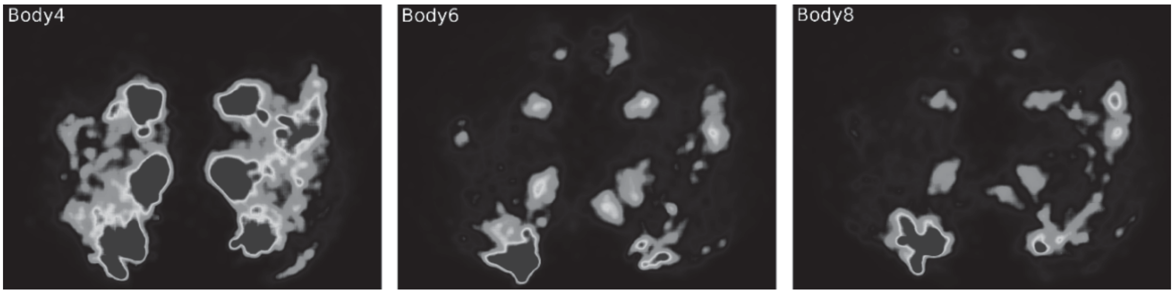

Figure 9: Density maps showing the Body4 configuration, the Body6 configuration and the Body8 configuration, respectively. The gradient has a triangular shape, starting from black, fading to white on the middle sections and ending at dark grey.

Questionnaires

The NASA TLX data's sphericity was assumed and the analysis did not show significant differences $F(2,22 = 0.036, P > 0.05)$. The score was 19.44/100 (SD = 11.24) for the Body 6 configuration, 19.86/100 (SD = 14.82) for Body 8 and 20.27/100 (SD = 11.96) for Body 4.

The SUS data's sphericity was assumed and the analysis did not show significant differences $F(2,22 = 0.233, P > 0.05)$. The score was 4.43/5 (SD = 0.4) for Body 8, 4.39/5 (SD = 0.41) for Body 4 and 4.39/5 (SD = 0.4) for Body 6.

The ranking of menus preference was analysed using a Friedman test ($\chi^2 = 2$, $df = 2$, $P > 0.05$) and revealed no significant differences. The ranking was 1.83 (SD = 0.57) for Body 6, 1.83 (SD = 0.93) for Body 8 and 2.33 (SD = 0.88) for Body 4.

7. DISCUSSION

7.1. COMPARISON WITH OTHER MENUS

The results of our experiments show that users completed the task with the *Body Menu* as fast as with the two other menus, despite the Kinect sensor being less precise in depth perception than in the other two coordinates. This issue particularly affects the *Body Menu* since it significantly relies on the depth component as it needs to confirm whether the hands are below a determinate distance of the body or not. The *Linear* and *Marking* menus are not hindered by the lack of accuracy since they do not employ the depth coordinate. They only use the X and Y coordinates of the hands. Furthermore, users made twice more back steps with it. Many of these back steps were made involuntarily due to the flickering noise intrinsic to the skeleton recognition produced when the hands were relatively closed to the body. If the user's hand was placed close to the boundary of a selection zone, this noise provoked 'go in' and 'go out' events. The selection times of Linear and Marking menus were approximately within the same range as the implementations of Bailly et al. (2011); therefore, our implementations are faithful to the originals.

In our experiments, the *Marking Menu* was the most accurate one with significant differences, whereas the accuracy of the *Linear Menu* was the lowest. To understand the reasons, we plotted the density map of hands trajectory (Figure 5). We could observe that, in the *Linear Menu* density map, the third row of items is fuzzy. In several occasions, users did not circumvent those items and selected the wrong target. Opposite as what is observed in the *Marking Menu* density map, in it the gesture was precise and the distance was considerably shorter. Additionally, it presents a vertical line thinner than the horizontal one; implying that the vertical gesture was performed faster or more accurately than the horizontal one. Regarding the *Body Menu*, we could not deduce anything about the accuracy difference; however, we could discern the four body parts and the two rest positions. It is also noticeable that occasionally users kept their hands between the shoulders and the ribs. The reason was that sometimes they did not return their arms to rest position. Their hands stayed in that position for being ready for the forthcoming selection.

In our opinion, the effect of proprioception is 2-fold. Firstly, it can help to remember the item's positions as the brain can build a representation of the personal space (Darling & Miller, 1993). Secondly, it can assist to reach a body part faster since the brain has a separate mechanism to guide the user to touch his different body parts (Cocchini et al., 2001). To support this idea, we compared the time increase and the loss of accuracy between normal and expert mode. The *Body Menu* was faster than the *Marking Menu* and significantly faster than the *Linear Menu*. Moreover, the loss of accuracy was lower with the *Body Menu*, followed by the *Marking Menu*, although there were no significant differences. It could be inferred that the *Linear Menu* does not use proprioception, contrarily to the *Marking Menu* which uses it at least to some extent and the *Body Menu* which employs proprioception in a deeper way.

Remote interaction using a hand which is not moving or stays in a different position than the rest pose can provoke fatigue. This can be reduced by arm motion across different paths (Baudel & Beaudoin-Lafon, 1993). From our point of view, the *Body Menu* takes advantage of it as the user has to perform different arm motions for selecting the items. To support this idea we recorded the mean distance per item selection of the hands. We performed a Pearson test to reveal a correlation between that distance and the subjective question concerning the physical effort from the NASA TLX questionnaire. A small correlation exists but not significant ($r = -0.145$, $N = 54$, $P > 0.05$). Nevertheless, if we use the mean values of all the participants per menu type the correlation is higher ($r = -0.99$, $N = 3$, $P < 0.05$). This variation can be explained by the fact that the question about fatigue is subjective and its perception varies from one person to another. Nonetheless, the results tend to correlate the distance travelled by the hands and the reduction of fatigue.

Finally, the SUS test did not show any significant difference between menus; therefore, we can conclude that our menu is as easy to use as the two most representative menus, Linear and Marking.

7.2. USAGE BY CHILDREN

We also wanted to determine whether the *Body Menu* is usable by children. Results were positive as they found the *Body Menu* as easy to use as the *Marking Menu*. All children said that they felt less tired using the *Body Menu*, although the results were not significant due to the reduced number of participants.

The selection performance in both terms of time and accuracy was slightly worse in children than in adults. This could be explained by the age gap and also because they performed three times less selections than adults. No statistical test for comparing adults and children could be performed as the conditions were different.

There were no significant differences between the three menus, although we could notice that the accuracy was lower with the *Body Menu* (Figure 6). An explanation could be the difference in skeleton proportion between children and adults. In fact, for this experiment, the bounding box size was fixed and independent of the skeleton size. Nonetheless, tests which adapt the bounding box size taking into account the body proportion and also the distance from the user to the Kinect must be done to confirm that explanation.

7.3. *BODY MENU* CONFIGURATIONS

The choice of which body parts to employ seems important as the user should be able to reach the parts easily. Therefore, they should be far enough from each other. Additionally, if the bounding boxes were bigger than necessary, they would undesirably occupy other selection areas. These reasons limit the maximum number of available parts.

For the Body 6 and Body 8 configurations, we decided to use the navel position as we thought that keeping a structured form, in this case hexagonal for the six items, would be easier for the analysis of items positions. Observations during the evaluation, supported by user's feedback, revealed that the navel position was not an adequate position since it provoked several mistakes with the ribs. This issue can be observed in the Figure 9 which is a density map of the hands positions. It shows that the navel zone is not centred on the body, but skewed to the right side. This was due to the fact that the skeleton recognition of the hand was placed on the palm instead of the fingers and participants approach the navel with the right hand, as they were dextral. We can observe that there are two intense zones at both sides of the head. This fact suggests an improvement for the technique; the head could be split into two parts: left and right ears.

The difference in time and accuracy between normal and expert mode did not reported any significant difference. Nevertheless, users found easier to remember items positions in the Body 6 and Body 8 configurations.

We can also highlight that the Body 4 configuration is slower than the Body 6 and Body 8 configurations, although it is more accurate but without any significant differences. All menus obtained a low score for the NASA TLX test and a high score for the SUS test, without any significant differences. We can conclude that those three configurations of the Body menus are easy to use and require low mental and physical effort.

7.4. LIMITATIONS

The *Body Menu* is considerably dependent on the technology used. In our case, we used the Microsoft® Kinect since it is a device easily accessible for everybody. Nonetheless, this sensor has some known limitations, namely it is not suitable for outdoors usage or heavily lighted spaces. This is mainly caused because it employs a structured light technique (Freedman et al., 2008), as a result depth measurements often fluctuate and depth maps contain holes (Izadi et al., 2011). As a consequence, the hand was not detected properly when it was in front of the body and close to it; that provoked flickering noise in the skeleton recognition process. For example, the forehead, chest and navel were problematic. In order to solve this issue, only those *Body Menu* configurations with lateral body parts should be employed. Another detected issue was the increase of imprecision and noise when the users wore black or loose clothes, which caused arm-tracking problem. This phenomenon was especially noticeable for the ribs parts.

8. CONCLUSIONS

We have presented the *Body Menu*, a remote interaction technique to navigate and select items through a hierarchical menu. Based on the sense of proprioception, menu items are selected when the user reaches a body zone with his hand. We have implemented the *Body Menu* technique with a commercial low-cost remote device endowed with a depth camera, the Microsoft® Kinect.

An experiment comparing the *Body Menu* with two different remote hierarchical menu selection techniques, *Linear* and *Marking* menus, showed that our system is easier to use. Additionally, the *Body Menu* is as fast as the other two menus and has similar accuracy despite the lack of precision in depth measurement of the Kinect. By changing the number of items and levels, we developed three different layouts for the *Body Menu*. All of them are easy to use and require low mental and physical effort. Nevertheless, due to hardware limitations, our implementation of the *Body Menu* supports a restricted number of items. Furthermore, body zones in the centre of the body, namely the navel, were not appropriate.

We believe that the *Body Menu* technique is suitable for being used in applications with distant displays, such as video games for consoles or public interactive displays, since they do not require complex GUI elements like text fields or lists. Moreover, the *Body Menu* could take advantage of its compatibility with gesture and pointing methods. For example, in the context of an interactive presentation, the speaker could point to the screen or use gestures to enhance his speech without interfering with the menu selection.

Density maps and feedback from the users revealed some ways for improving the body selection zones such as splitting the head zone into two parts or removing the navel position. Nonetheless, a more thorough approach could be taken for a future study. Using Fitts' law (Fitts, 1954) for analysing simplified non-hierarchical selections would extrapolate the ease of reaching each zone. These results would be generalizable to different bounding box dimensions.

With the appearance of new devices or upgrades of the Microsoft Kinect, an increase in the accuracy may be expected. Thereby, more body parts could be used and overall, the *Body Menu* could improve its performance. Consequently, it would be interesting using those sensors or other technology based on wearable sensors, like the system proposed by Shoemaker et al. (2010) even though it would lead to a more cumbersome and expensive system.

The *Body Menu* reduces fatigue and is easy to use. Furthermore, the Body 4 configuration supports its use while seated since it only employs upper body parts. This could make the *Body Menu* more accessible for elderly users or people with special needs.

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CHAPTER II

NATURAL USER INTERFACES: MANIPULATION

ABSTRACT

Manipulation is one of the most important tasks required in virtual environments and thus it has been thoroughly studied for widespread input devices such as mice or multi-touch screens. Nowadays, the Kinect sensor has turned mid-air interaction into another affordable and popular way of interacting. Mid-air interaction enables the possibility of interacting remotely without any physical contact and in a more natural manner. Nonetheless, although some scattered manipulation techniques have been proposed for mid-air interaction, there is a lack of evaluations and comparisons that hinders the selection and development of these techniques. To solve this issue, we gathered four design choices that can be used to classify mid-air manipulation techniques. Namely, choices are based on the required number of hands, separation of translation-rotation, decomposition of rotation, and interaction metaphors. Furthermore, we developed, adapted, and compared three manipulation techniques selected for studying the implications of the design choices. These implications are useful to select among already existing techniques as well as to inform technique developers.

1. INTRODUCTION

One of the main issues in Virtual Reality is the manipulation of 3D objects (Bowman et al., 2001). Manipulation tasks comprise setting the position and orientation of virtual objects, although other properties such as colour, scale, or texture can be manipulated (Poupyrev & Ichikawa, 1999). Every singular value of an object that can be changed is called a Degree Of Freedom (DOF); thus, in 3D environments both position and rotation represent 3 DOF each. Similarly, input devices support a different number of DOF. For example, the traditional mouse has 2 DOF (X and Y position). The purpose of a manipulation technique is to define how the DOF of the input affects the DOF of the virtual object. Normally, position and rotation are some of the most challenging types of manipulation as 3 DOF have to be manipulated in a coordinated way. Consequently, they have been thoroughly studied for mainstream devices such as mice and multi-touch surfaces.

However, Natural User Interfaces (NUIs), which involve mid-air interaction via the body, offer a new dimension and consequently new possibilities of interactions. Due to the advantages of the NUIs (Mine et al., 1997) and the importance of manipulation interactions, some manipulation techniques have been developed for the Microsoft® Kinect and similar devices. Previous research has mainly focused on creating manipulation techniques and does not empirically compare existing techniques with the implications of the design choices that were taken to create the techniques. As a result, the literature on manipulation techniques for Kinect consists of just isolated techniques and no indications are provided about which technique should be used in each case. Moreover, the lack of information regarding the effects of the design choices also hampers the development of new techniques.

In order to clarify and guide the selection or development of manipulation techniques for mid-air interaction, we collected four design choices from the existing literature for other interaction modalities. Afterwards, we selected three techniques to cover the most important combinations of design choices. Finally, the three techniques were evaluated in two empirical studies employing the docking task. As the techniques covered the most important combinations of design choices, the consequences of these choices were revealed in the results. These design implications can be used to guide the development and selection of manipulation techniques using the Kinect sensor.

2. EXISTING TECHNIQUES

Existing uni-manual and bi-manual interactions for 3 DOF (3D rotations) and 6 DOF (3D translation + 3D rotation) mid-air manipulations are presented subsequently. Some techniques were implemented for hardware different from the Kinect. Nonetheless, their findings are also relevant for our study.

2.1. UNI-MANUAL INTERACTIONS

Segen & Kumar (1998) developed GestureVR, a system that recognizes hand gestures using a video processing algorithm. It was improved by O'Hagan et al. (2002) with a more robust algorithm. The authors proposed a set of hand gestures that allows the user to manipulate translation and rotation. The rotation was performed by twisting the wrist, whereas the translation was done by closing and moving the hand. It was detected that light conditions could negatively affect the tracking and that this can be solved using infrared cameras.

Another issue derived from previous hand-tracking recognition is the short distance that must be kept between the interaction space and the camera. Lu et al. (2009) proposed a system to rotate and translate a 3D object in an immersive environment. They used a data glove to allow the user to interact from a wider range of distances.

Across all one-hand manipulation techniques, translations are usually made by a drag gesture with the hand closed, whereas rotations are made by twisting, tilting, or swiping the wrist. Raj et al. (2012) compared wrist gestures to control rotation, namely wrist tilt with wrist swipe. Results showed that participants used more the swipe gesture.

2.2. BI-MANUAL INTERACTIONS

Schlattmann & Klein (2009) proposed a bi-manual manipulation technique based on video recognition. They employed the metaphor of grasping an object with both hands. Specifically, a virtual object can be grasped by moving both hands closer. Then, the user could translate the object, displacing both hands concurrently. The rotation of the virtual object followed the averaged orientation between the hands and the middle point between them. Finally, to release the object the users had to separate their hands. The study showed that for precise movements, this technique was faster than a 3D mouse.

Wang et al. (2011) suggested separating translation from rotation. Translation was made by dragging one hand while it was closed. For rotations, they employed the metaphor of rotating a sheet of paper. That is, the gesture of pinching with both hands allowed the user to rotate around the three primary axes.

Iacolina et al. (2011) designed a mid-air manipulation analogous to an existing multi-touch technique. Contrary to the previous bi-manual techniques, one-hand gestures were used for rotating around the X and Y axes. Two-hand gestures were used for translations and Z-axis rotation.

Researchers such as Bettio et al. (2007) and Hackenberg et al. (2011) developed basic two-hand manipulation techniques in order to validate their hand-tracking system. These techniques were improved by Song et al. (2012) producing a two-hand 7 DOF manipulation technique (3 DOF for translations, 3 DOF for rotations, and 1

DOF for scale). This technique allows manipulation of multiple objects at the same time and modification of translation and rotation simultaneously. They used the metaphor of manipulating a handle bar with two hands that pierces the objects.

3. DESIGN CHOICES

During the design of a manipulation technique, several key decisions have to be taken. These design choices will have a major effect on the usability of the resulting technique. Namely, usability encompasses speed, accuracy, user's error rate, ease of use, and user's level of satisfaction (Bowman et al., 2002). In this section we have gathered from the existing literature four design choices and embodied them in the form of questions.

Despite being fundamental questions, conclusions differ depending on the technology or from one study to another. There are studies with even opposite conclusions. The most recent studies tend to be less assertive and to conclude that there is not a definitive answer. In any case, the presented design choices can be used to classify manipulation techniques, as they have a major impact on the techniques.

3.1. SHOULD THE TECHNIQUE USE ONE OR TWO HANDS?

In 1986, Buxton & Myers (1986) showed that using both hands in sequential tasks can reduce the task completion time since it avoids task switching. Later, Guiard (1987) proposed a theoretical model for human asymmetric bi-manual interactions in which the non-dominant hand can cooperate with the dominant hand even when their roles were different. Nevertheless, opinions about this model are divergent.

Some researchers agree with the model and posit that using two hands is more efficient when the task associated to each hand has the same conceptual objective

(Leganchuk et al., 1998; Owen et al., 2005). In this case, bi-manual interactions have physical and cognitive advantages.

In contrast, some researchers suggest that the non-dominant hand can complicate the interaction as the user has to synchronize both hands (Kabbash et al., 1994; Seay et al., 2000). Nonetheless, the second hand can be used in parallel for simple actions.

Nancel et al. (2011) demonstrated that for Pan and Zoom actions, bi-manual interaction was faster than uni-manual interaction. Nonetheless, 3D translations and rotations require further analysis as they are more complex.

3.2. SHOULD THE TECHNIQUE INTEGRATE TRANSLATION AND ROTATION?

From the point of view of Jacob et al. (1994) and Wang et al. (1998), translation and rotation are not separable. They concluded that tasks should not be separated when they belong to the same perceptual structure. Additionally, they showed that translation and rotation have a parallel and interdependent structure, although translation is a more dominant process.

Nevertheless, subsequent studies have shown that even when the input device allows the simultaneous manipulation of translation and rotation, users frequently manipulate them separately (Masliah & Milgram, 2000). Additionally, Froehlich et al. (2006) concluded that separated manipulation is more suitable for a docking task because it has better usability and produces less manual motor fatigue.

On the other hand, an evaluation reported that the best option is to design interaction techniques that allow the user to perform both separated and simultaneous manipulations (Hancock et al., 2007).

3.3. SHOULD THE TECHNIQUE DECOMPOSE ROTATION BY AXIS?

Chen et al. (1988) and Jacob et al. (1994) have shown that the fastest and more intuitive way to complete a rotation task is through free rotation; for example, by not decomposing rotation.

Nonetheless, Veit et al. (2009) showed that decomposing rotation is as precise as not decomposing it, but faster. They also detected that in composed rotation users generally used only up to 2 DOF at the same time, even when the technique supported 3 DOF.

For both types of rotation, Parsons (1995) concluded that users encounter significant difficulties for mentally rotating objects, particularly when the rotation axis did not coincide with one of the viewer primary axes.

3.4. COULD THE TECHNIQUE BE DESCRIBED WITH A METAPHOR?

It seems fundamental to create interaction techniques that bear some resemblance to actions already known by the users (Shank & Gebler, 2002); that is, a metaphor that naturally explains an unfamiliar domain (Bowman et al., 2012). Fishkin (2004) highlights the importance of a metaphor as an enormously powerful component in thought and design that also plays a vital role in interaction techniques.

4. SELECTION OF THE TECHNIQUES

The purpose of this section is to select and describe techniques that represent the most relevant combinations of the presented design choices. Therefore, by evaluating the selected techniques it will be possible to determine the consequences of the design choices.

To increase the significance of the evaluation we intend to use a within-subjects design. That is, the subjects must try all the techniques in different orders. Therefore, the number of techniques to test should be kept low in order to guarantee the evaluation feasibility. Consequently, we carried out a pilot study to narrow the selection of techniques to the three most representative ones. The pilot study took into account the techniques covered in the literature and four main conclusions were extracted from it. First, metaphors are always helpful and thus the evaluated techniques must employ a suitable metaphor. Second, if a technique integrates translation and rotation, it also should not decompose rotation. On the other hand, when translation and rotation are performed as separated actions, it is better to decompose rotation on primary axes. Finally, for two-hand techniques it is more reasonable to integrate translation and rotation.

To synthesize, we need three techniques that employ metaphors. Specifically, one technique must use one hand, separate translation from rotation, and decompose rotation. Another one has to use also one-hand but integrate translation and rotation, and compose rotation. Finally, the last technique should use two hands, integrate translation and rotation, and compose rotation.

A classification of the current techniques attending to the design choices (see Table I) revealed insufficiencies in one-hand techniques. Specifically, they did not employ a metaphor and none of them separated rotation by axis. Therefore, we had to design the two one-hand interaction techniques required for the evaluation. The last three techniques are presented in this study.

In the following subsections, we describe the three manipulation techniques. For the first technique, we created the *Crank Handle*, a one-hand technique that separates translation from rotation and decomposes rotation into the primary axes employing the metaphor of rotating three different cranks. For the second one, we adapted the RNT algorithm (Kruger et al., 2005) to 3 DOF inputs. It resulted in a one hand technique that integrates translation and rotation without decomposing rotation. It is called the *Grasping Object* technique. Finally, for the third technique we reproduced the *Handle Bar* (Song et al., 2012), an existing two-hand technique that integrates translation and rotation.

Table I: Classification of mid-air manipulation techniques according to the design choices.

	Number of hands		**Translation - Rotation**		**Rotation axis**		**Metaphor**
	One	**Two**	**Separated**	**Integrated**	**Decomposed**	**Mixed**	
O'Hagan et al. (2002)	X		X			X	-
Lu et al. (2009)	X		X			X	-
Raj et al. (2012)	X		X			X	-
Schlattmann et al. (2009)		X		X		X	Grasp
Wang et al. (2011)		X	X			X	Sheet of paper
Iacolina et al. (2011)		X		X		X	-
Song et al. (2012)		**X**		**X**		**X**	Handle bar
Crank Handle (created)	**X**		**X**		**X**		Rotate Cranks
Grasping Object (adapted)	**X**			**X**		**X**	Friction

4.1. *CRANK HANDLE* TECHNIQUE (CH)

Our main objective for this technique was to design a one-hand technique that separated translation from rotation and decomposed rotations in primary axes. Additionally, we employed the metaphor of rotating three crank handles to rotate across each of the primary axes.

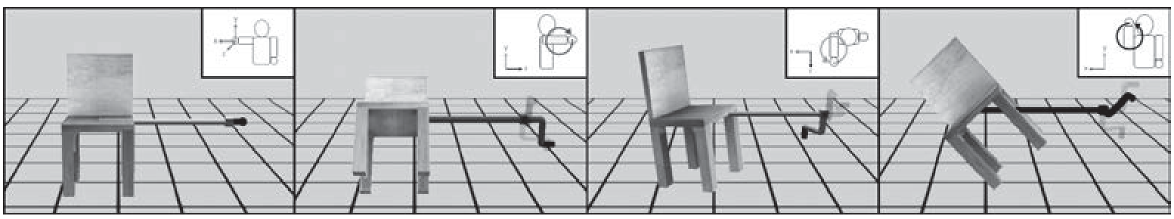

Figure 1: *Crank Handle*. From left to right, translation mode, rotation mode X-axis, rotation mode Y-axis and rotation mode Z-axis.

Description

This technique has three modes: *idle mode*, *translation mode*, and *rotation mode*. A bar is rendered at one side of the virtual object to provide visual feedback about the current mode. The bar appears at the right or left side of the object depending on the dominant hand of the user.

The system starts at the *idle mode* and returns to it whenever the user opens his hand. In this mode, the user can rest or change the hand placement without changing the object transformation. Throughout this mode the bar is translucent and grey.

From the *idle mode* the user can close the hand to enter *translation mode*. While the hand remains closed, its movement is transferred to the virtual object. The bar turns opaque and a black handle appears during this mode. To pass to the *rotation mode* the user has to open and close the hand in less than 0.6 seconds. This value was chosen after various tests and seemed to be the most usable.

During the *rotation mode*, three translucent crank handles appear at the end of the bar, one for each primary axis (see Figure 1). Afterwards, the user has to describe a circle with the hand around the primary axis in which he or she wants to rotate the object, exactly as he or she would interact with a real crank handle. When the user rotates one of the crank handles, it becomes opaque and its orientation is updated following the user's gesture. The gesture can be performed continuously and the gain factor varies depending on the gesture linear speed.

Crank Handle Algorithm

The *Crank Handle* algorithm has three steps: the detection of the rotation axis, the detection of the rotation angle, and the choice of the gain factor to be applied to this rotation.

To detect the primary axis in which the user wants to rotate the object, the algorithm stores a trail of the last hand positions. From this trail, the average of the normal formed from subsequent triplets of points is calculated using the cross product. The algorithm considers that the user is rotating around a determinate axis when the angle between this axis and the previously calculated average vector is less than 30 degrees. This threshold was chosen after previous tests to avoid confusion between primary axes but at the same time, to afford a certain degree of imprecision in the gesture.

Once the primary axis is detected, the curvature of the trajectory is analysed to detect direction changes or undesired movements such as lines. Then, the algorithm computes the centre and radius of the circle using the method proposed by Bourke (2014). When the centre of the circle is known, the angle between subsequent points can be determined.

Finally, a gain factor is applied to the angle according to the gesture linear speed. When the hand speed is less than 10 cm/s no rotation will be applied to the virtual object as we consider the movement indecisive. Between 10 cm/s and 65 cm/s a linear function is used; it transforms 50 loops at lower speeds or 30 loops at higher speeds to 360 degrees. Above 65 cm/s, an exponential function that transforms 10 loops at lower speed to 360 degrees is used; and it is capped at 360 degrees per 2.5 loops at higher speed.

4.2. *GRASPING OBJECT* TECHNIQUE (GO)

We propose a second one-hand manipulation technique. Opposite to the *Crank Handle*, it combines translation and rotation and does not decompose rotation in primary axes. Its metaphor comes from the physics of moving an object against friction or through a stream.

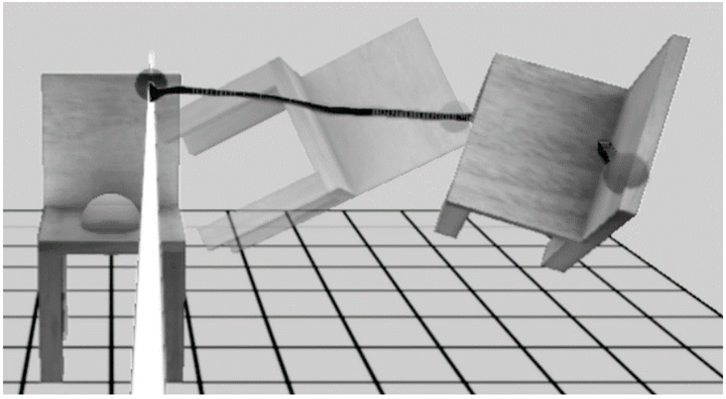

Figure 2: *Grasping Object*. Transformation made by grasping the object on the left and following the black path with the hand. The object is in *idle mode* on the left, and in *transform mode* on the centre and right.

Description

The *Grasping Object* is based on the RNT algorithm (Kruger et al., 2005) and on its 3D extension for 2 DOF inputs (Hancock et al., 2007). In this work, we extended the algorithm to support 3 DOF inputs.

The technique starts in the *idle mode* and returns to it whenever the user opens his hand. In the *idle mode* the user can aim a virtual ray with his or her hand. When the ray intersects a point of the object, a blue sphere is drawn in this point. Subsequently, the user can grab the object by closing the hand. The virtual ray will disappear and the blue sphere will turn green to indicate the change to the *transformation mode*. Then, the object will be modified in translation and rotation according to the hand trajectory (see Figure 2). The grabbed point will follow the trajectory of the hand as described by Hancock et al. (2007). In order to facilitate the pointing of the virtual ray, its range is limited to the bounding box of the object.

This technique manipulates translation and rotation simultaneously; however, it was not feasible for the users to precisely manipulate the object in this way. A previous study (Hancock et al., 2007) reported the same issue with the technique and added a *translation-only mode*; we proceeded likewise. Namely, if the selection ray intersects a translucent sphere centred in the object, the system changes to *translation* *mode* and only translation is modified. The diameter of the sphere is 30% of the object size and was chosen to be large enough to enable a good selection and sufficiently small to allow the user to grasp any corner of the object.

4.3. *HANDLE BAR* TECHNIQUE (HB)

For the third technique we decided to replicate the *Handle Bar* Metaphor (Song et al., 2012). It is a recent technique that can be implemented using the Kinect sensor. The employed metaphor of this technique consists in manipulating a virtual handle bar that pierces the object (see Figure 3).

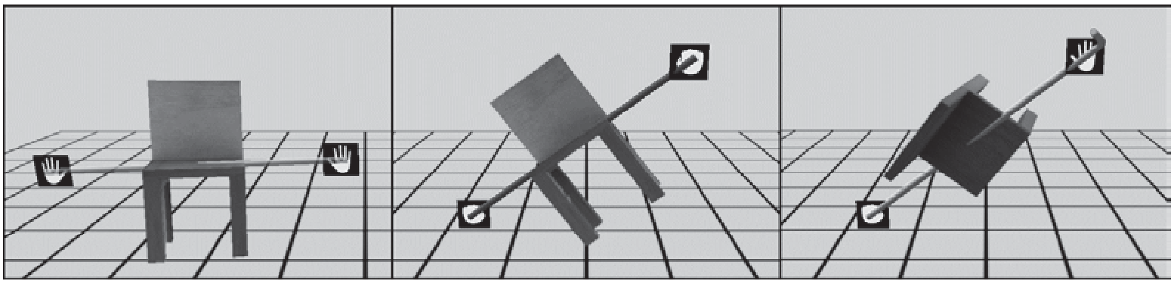

Figure 3: *Handle Bar*. From left to right: idle mode, transformation mode and constrained rotation mode.

Description

In this technique both ends of a handle bar are grabbed and controlled with each hand. The user can control the translation and rotation of the object since it behaves as if it was pierced by the bar.

With both hands open the user remains in the *idle mode*. In this mode, the user can orientate the handle bar without transforming the virtual object. The bar is displayed translucently and in grey. Once a virtual object is selected, the virtual handle bar is drawn through the virtual object with the representation of the two hands in each side.

If the user closes both hands, he or she enters the *transformation mode*, in which he or she can manipulate the 6 DOF of the object. The handle bar is displayed in blue during this mode. With a parallel movement of the hands, the user can move the virtual object without rotating it. With a horizontal or vertical asymmetric movement, the user will be able to rotate the object around the Y axis or Z axis, respectively. Finally, to rotate around the X axis, the user can perform a pedalling gesture with both hands.

Additionally, when the user opens only one hand, the handle bar colours violet and the system enters the *constrained rotation mode* (see Figure 3 right). In this mode the user can describe a circle with the open hand to rotate the object around the bar axis.

5. USER STUDIES

We conducted two user studies that compared and evaluated the three techniques in order to extract insights about the effects of the design choices. The techniques were tried by 18 people (5 female and 13 male), aged between 16 and 49 (M = 27.3, SD = 8.9). Two users were left-handed but both one-hand techniques support this.

The experiment was performed using a 47'' 3D TV with a Microsoft® Kinect placed over it. The software ran under Windows® 7 and was developed using C#, the Microsoft® Kinect SDK, and GoblinXNA. Participants were located in front of the Microsoft® Kinect at a distance of 2 m. As suggested by Bowman et al. (2008), in order to enhance the spatial perception of the user we employed stereoscopy, perspective, occlusion, and shadows. One meter in the real world was equivalent to 5 m in the virtual world.

5.1. STUDY 1: 3D DOCKING TASK

In this study, we used a 3D docking task (Zhai & Milgram, 1998). Participants were asked to overlap a moveable dark tetrahedron over a static pale tetrahedron (see

Figure 4). The dark tetrahedron was initially located on the centre of the scene. The edges of the tetrahedrons were 1.63 m. The position of the target tetrahedron was randomly generated at a distance of 3 m from the moveable tetrahedron. Each corner of the tetrahedrons had a different colour so there was only one correct orientation. The error tolerance was represented by a sphere on each corner of the target tetrahedron. The size of these spheres was 45% of the tetrahedron size. Our pilot study had shown that a lower threshold reduced considerably the number of successful dockings. The spheres were red but turned green when the correct corner was inside. Similar to Froehlich et al. (2006), the docking trial ended successfully when the four corners remained inside their corresponding spheres for 0.8 s. If a participant could not complete the trial within one minute, the docking ended in failure. To continue to the next docking trial, participants had to activate a button. Then, they had 3 seconds before the trial started in order to analyse the situation or to place their hands as desired. Object selection was disabled for the study and the manipulation was directly applied to the moveable object.

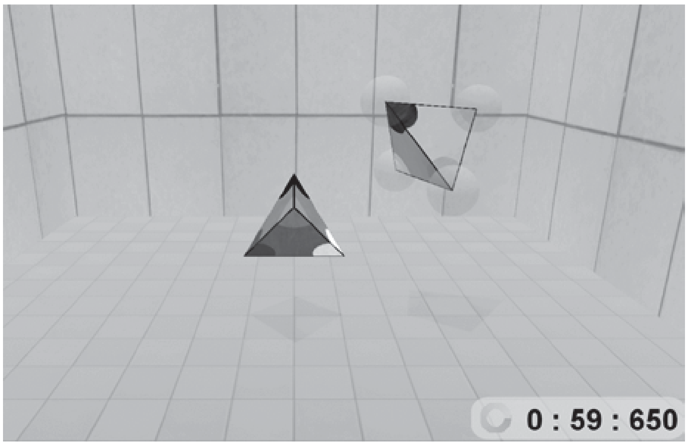

Figure 4: 3D Docking task: Participants had to move the dark tetrahedron inside the pale one in 1 min. Spheres represent the error tolerance.

We used a within-subject design. The independent measured variables were *Technique*, *Rotation*, and *Angle*. The values of the *Rotation* variable were *Simple* (around one primary axis) and *Complex* (around a random axis). The values of the *Angle* variable were *Acute* (between 30 and 90 degrees) and *Obtuse* (between 91 and 150).

Participants performed 6 blocks of 5 trials. The order of the trials was: *No Rotation*, *Simple Rotation with Acute Angle*, *Simple Rotation with Obtuse Angle*, *Complex Rotation with Acute Angle*, and *Complex Rotation with Obtuse Angle*. With this study we wanted to measure the performance of the techniques in terms of speed, accuracy (percentage of successful dockings), inefficiency (amount of misused work in rotation and in translation) (Zhai & Milgram, 1998), and reaction time. Additionally, we aimed at analysing each technique by assessing the time passed in each mode and by gathering two specific metrics. These metrics are the coordination translation/rotation, based on the ratio between actual trajectory and the optimal one (Zhai & Milgram, 1998); and the *m*-metric, that analyses the use and efficiency of the different combinations of DOF (Masliah & Milgram, 2000).

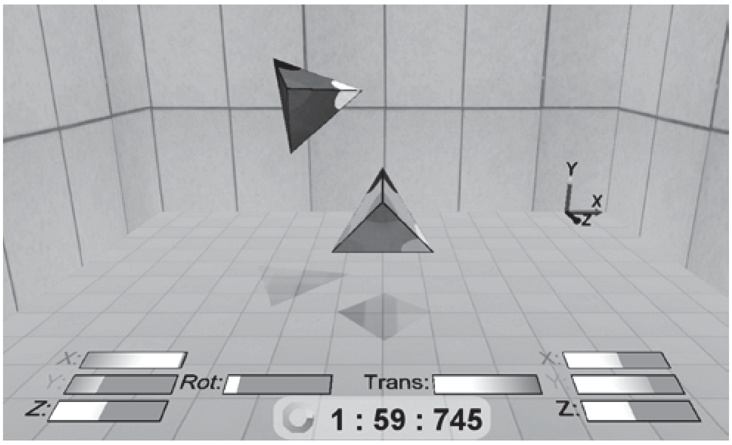

Figure 5: Precise 3D Docking task: Participants had to move the dark tetrahedron over the pale one in 2 min. Gauge bars represent the error in translation and rotation and its decomposition into primary axes.

5.2. STUDY 2: PRECISE 3D DOCKING TASK

In the second study, participants were asked to place the tetrahedron as precisely as possible within 2 minutes. Contrary to the first study, the target was always placed at the centre of the scene. Two main error gauges were displayed, one for the global rotation error and another for the global translation error. Additionally, each of the two gauges was decomposed into the three primary axes. The gauges had two scales going from red to yellow and yellow to green (see Figure 5). The gauge entered in the second scale when the error was less than 25 cm for translation or 30 degrees for rotation.

Participants performed 3 blocks of 2 trials. The first trial was a *simple rotation* and the second a *complex rotation*. The aim of this study was to determine the minimum error achievable in translation and in rotation.

5.3. PROCEDURE

Participants performed the evaluation across 3 days, one day per technique. Each session lasted approximately 1h and consisted of two studies. First, we explained and showed to them how the technique works. Then, as training they tried a complete block without any time limit. Afterwards, they performed the first task and then the second one. They could rest between each trial. Finally, they were asked to fill the NASA TLX questionnaire (Hart & Staveland, 1998) and a custom questionnaire that evaluates the usability of the technique (7-point Likert scale). Moreover, at the end, the participants had to rank the three techniques according to their preferences. Participants interacted with the techniques in a different order following a Latin Square. The transformations of the trials were randomly generated and were different for each technique but the same for each participant.

To summarize, the experiment consisted of: 18 participants x 3 techniques x ([6 blocks x 5 trials] + [3 blocks x 2 trials]) = 1944 docking tasks.

5.4. RESULTS

Data were analysed using Repeated Measures ANOVA. For data that violated the Mauchly's test of sphericity, we reported results using the Greenhouse-Geisser correction. When a significant effect appeared, we performed a *t-pair* pairwise comparison with Bonferroni correction to detect significant differences. Only completed trials were included in this analysis. CH stands for *Crank Handle*, GO for *Grasping Object*, and HB for *Handle Bar*.

5.4.1. TECHNIQUES COMPARISON

Task Completion Time (TCT).

For docking trials with only translation, the analysis revealed a significant effect of the technique, $F(2,34 = 5.780, P < 0.01)$. The pairwise comparison showed that CH (7.6s, SD = 0.8) was significantly faster ($P < 0.05$) than HB (11.8s, SD = 1.1). GO average TCT was 10.4s (SD = 1.2).

For *Simple Rotation* docking trials, the analysis revealed a significant effect of the technique, $F(2,34 = 50.506, P \approx 0)$. The pairwise comparison showed that CH (23.2s, SD = 1.2) was faster ($P < 0.01$) than HB (29.5s, SD = 2) and faster ($P \approx 0$) than GO (36.2s, SD = 1.6). HB was also faster ($P \approx 0$) than GO.

For *Complex Rotation* docking trials, the analysis revealed a significant effect of the technique, $F(2,34 = 10.391, P \approx 0)$. The pairwise comparison showed that HB (31.7s, SD = 1.6) was faster ($P < 0.05$) than CH (36.6s, SD = 1.7) and faster ($P < 0.01$) than GO (38.8s, SD = 1.9). The TCT of each technique split by trial type is shown in Figure 6.

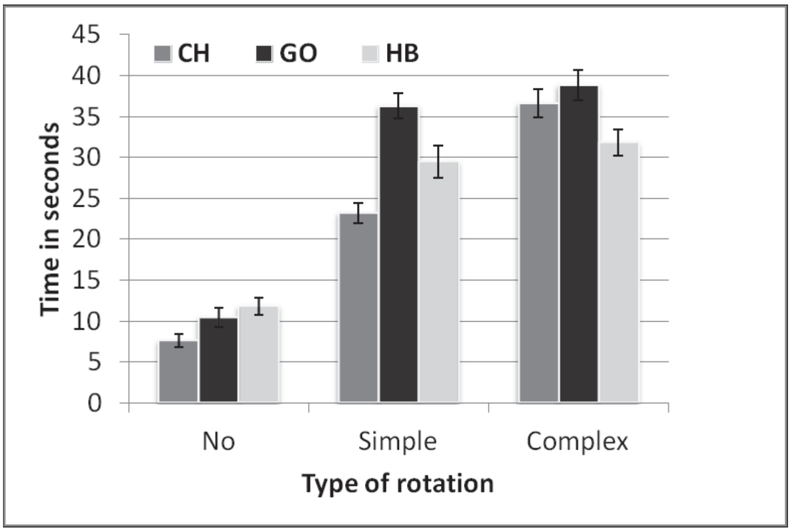

Figure 6: Task completion time per technique and per type of trial.

Accuracy

For all docking trials (successful or not), the analysis showed a significant effect, F(2,34 = 9.308, P < 0.01). The pairwise comparison showed that HB (86.1%, SD = 3.4) and CH (83.1%, SD = 2.6) were significantly more accurate (P < 0.05) than GO (75.9%, SD = 3.1).

Inefficiency in translation

The translation inefficiency value represents the ratio between the length of the followed path and the length of the optimal one. For only translation docking trials, the analysis showed a significant effect, F(2,34 = 4.097, P < 0.05) although the pairwise comparisons did not show any significant difference. The inefficiency value was 1.43 (SD = 0.2) for CH, 1.83 (SD = 0.2) for GO and 2.12 (SD = 0.3) for HB. For all the other sets of docking trials, no significant difference was revealed. Inefficiency in translation is shown in Figure 7.

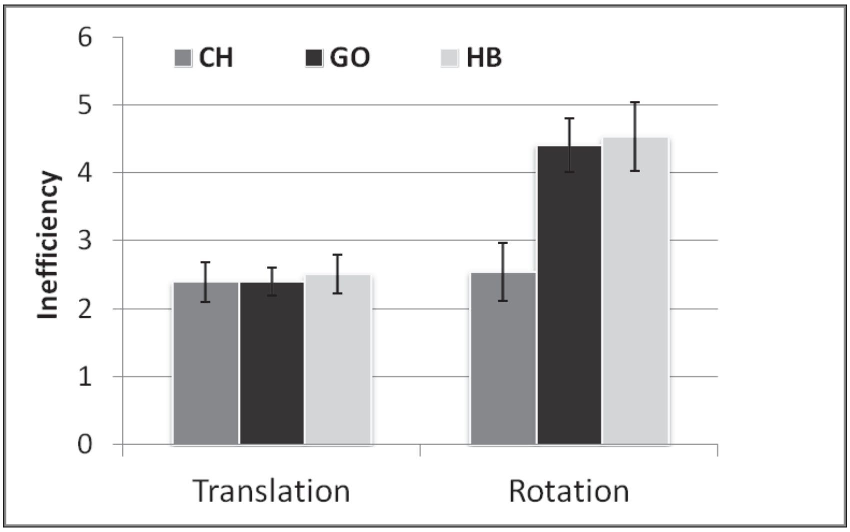

Figure 7: Inefficiency in translation and rotation.

Inefficiency in rotation

The rotation inefficiency value represents the ratio between the sum of all the performed rotations and the optimal rotation. The analysis showed a significant effect, F(2,34 = 9.731, P ≈ 0). The pairwise comparison showed that CH (2.54, SD = 0.4) was less inefficient ($P < 0.01$) than GO (4.4, SD = 0.4) and HB (4.5, SD = 0.5). Inefficiency in rotation is shown in Figure 7.

Reaction time

We report the data of all the docking trials, as the results of the set of *Simple* and *Complex Rotation* trials were similar. The analysis showed a significant effect, F(1.436,24.416 = 16.336, P ≈ 0). The pairwise comparison showed that CH (0.7s, SD = 0.06) provoked a smaller reaction time ($P < 0.01$) than HB (1.7s, SD = 0.3) and GO (2.2s, SD = 0.1).

Precision in translation

These results are derived from the second study. We report the data of all the docking trials, as the results of the set of *Simple* and *Complex Rotation* trials were similar. The analysis did not show any significant effect. The maximum precision reached in translation was 3.3 cm with HB (SD = 1.5), 7.2 cm (SD = 11.4) with CH, and 8.7 cm (SD = 5.4) with GO.

Precision in rotation

These results are also derived from the second study. For the set of all the trials that required rotation the analysis showed a significant effect, F(2,34 = 29.448, P ≈ 0). The pairwise comparison showed that CH (1.48, SD = 0.9) and HB (1.478, SD = 0.6) were more precise (P ≈ 0) than GO (3.18, SD = 1.1).

For all the *Simple Rotation* docking trials, the analysis showed a significant effect, F(2,34 = 38.134, P ≈ 0). The pairwise comparison showed that CH (0.798, SD = 1.1) was more precise ($P < 0.05$) than HB (1.48, SD = 0.6) and more precise (P ≈ 0) than GO (3.38, SD = 1.3). HB was also more precise (P ≈ 0) than GO.

For all the *Complex Rotation* docking trials, the analysis showed a significant effect, F(2,34 = 8.43, P = 0.01). The pairwise comparison showed that HB (1.58, SD =

0.7) was more precise (P < 0.01) than GO (2.98, SD = 1.2). CH had a maximum precision of 2 degrees (SD = 1.3).

5.4.2. *ANALYSIS OF THE TECHNIQUES*

Transformation coordination

The coordination between rotation and translation (Zhai & Milgram, 1998) is plotted in Figure 8 split by technique.

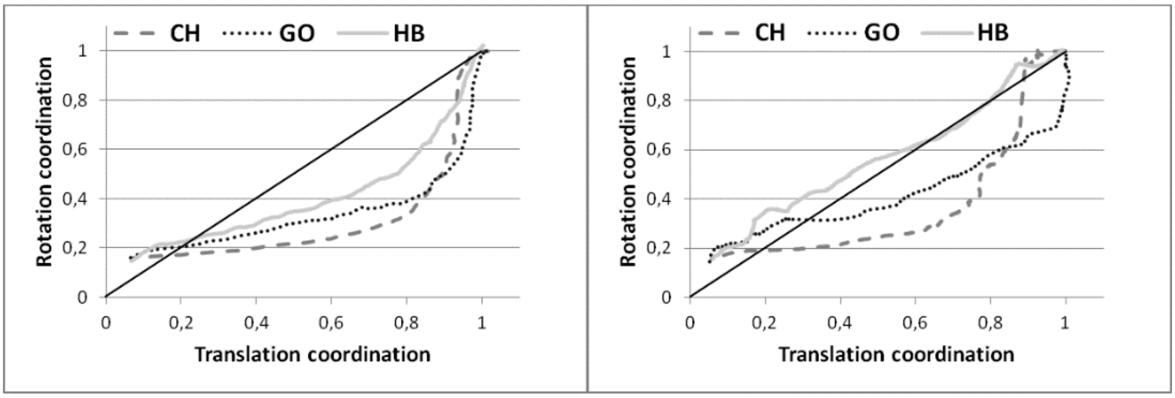

Figure 8: Translation-rotation coordination: average of all the participants on the left, and a specific participant on the right. For both charts, the curve begins at (1, 1) and ends at (0, 0) plus the error tolerance.

m-metric

m-metric (Masliah & Milgram, 2000) defines the allocation of control as the product between usage and efficacy of a certain set of DOF. For our study the 6 DOF are X, Y, Z, RX, RY, and RZ. Therefore, there are 15 metrics for groups that combine 2 DOF (size 2), 20 for groups of size 3, 15 for groups of size 4, 6 for groups of size 5, and 1 that combines the 6 DOF. As the complete report of *m*-metric is large, we report the most relevant statistical tests. The analysis was applied for each technique separately.

Attending to the groups that contain only translation (XY, XZ, and YZ), the analysis showed a significant difference between pair of planes for every technique.

For CH, $F(2,34 = 67.901, P \approx 0)$, the *m*-metric value of translations on the plane XY was 0.35 (SD = 0.09), 0.29 (SD = 0.07) on plane XZ, and 0.22 (SD = 0.06) on plane YZ.

For GO, $F(1.484,25.229 = 128.219, P \approx 0)$, XY was 0.31 (SD = 0.07), XZ was 0.22 (SD = 0.04), and YZ was 0.19 (SD = 0.04).

For HB, $F(2,34 = 89.068, P \approx 0)$, XY was 0.3 (SD = 0.07), XZ was 0.23 (SD = 0.07), and YZ was 0.2 (SD = 0.06).

More specifically, the pairwise comparisons revealed significant differences at XY > XZ ($P \approx 0$) and XY > YZ ($P \approx 0$) for the three techniques.

Comparing groups of only translation (T), coupled translation-rotation (TR), and only rotation (R), statistical tests showed a significant difference for groups of size 2 and 3 on both GO and HB techniques. In more detail:

For GO and groups of size 2, $F(2,34 = 245.347, P \approx 0)$, the *m*-metric value was 0.24 (SD = 0.05) for T groups, 0.04 (SD = 0.009) for TR groups, and 0.15 (SD = 0.03) for R groups. For groups of size 3, $F(1.467,24.947 = 164.838, P \approx 0)$, 0.12 (SD = 0.03) for T groups, 0.02 (SD = 0.004) for TR groups, and 0.08 (SD = 0.02) for R groups.

For HB and groups of size 2, $F(1.1397,19.356 = 113.658, P \approx 0)$, the *m*-metric value was 0.24 (SD = 0.06) for T groups, 0.11 (SD = 0.02) for TR groups, and 0.12 (SD = 0.02) for R groups. For groups of size 3, $F(1.107,18.818 = 72.179, P \approx 0)$, 0.13 (SD = 0.04) for T groups, 0.05 (SD = 0.01) for TR groups, and 0.06 (SD = 0.01) for R groups.

For both techniques and group sizes, the pairwise comparisons revealed that TR groups had significantly lower values than the two other groups (see Figure 9).

For GO, a t-paired test revealed that groups which contain RZ had significantly lower values than groups without RZ for groups of size 2 ($P \approx 0$, $\Delta M = 0.009$, $\Delta SD = 0.007$) and groups of size 3 ($P < 0.001$, $\Delta M = -0.003$, $\Delta SD = 0.003$).

For HB, a t-paired test showed that groups which contain RX had significantly lower result than the groups without RX for groups of size 2 ($P \approx 0$, $\Delta M = -0.03$, $\Delta SD = 0.03$) and groups of size 3 ($P \approx 0$, $\Delta M = -0.02$, $\Delta SD = 0.012$).

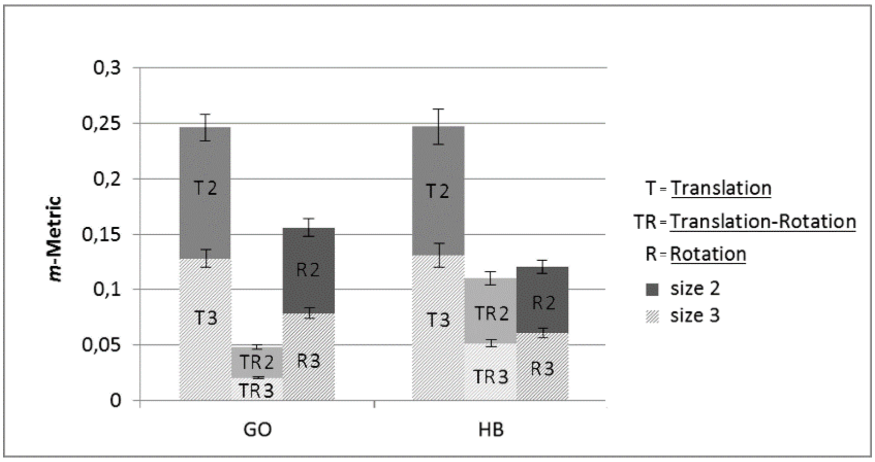

Figure 9: *m*-Metric values for groups of size 2 and 3 for GO and HB techniques.

Time spent in modes

For CH, participants spent 10.4% of the time in *idle mode*, 34.1% in *translation mode*, and 55.5% in *rotation mode* (7.2% for the X-axis, 7.5% for the Y-axis, 7.7% for the Z-axis, and 33.1% without performing rotations).

For HB, participants spent 14.1% of the time in *idle mode*, 59.1% in *transformation mode*, and 26.8% in *constrained rotation mode*.

For GO, participants spent 60.4% of the time in *idle mode*, 23.3% in *transformation mode*, and 16.3% in *translation mode*.

5.4.3. SUBJECTIVE RATINGS

The scores for NASA TLX were 35/100 (SD = 32.7) for HB, 38/100 (SD = 32.8) for CH, and 39.9/ 100 (SD = 30) for GO. A low score means that the task did not offer a meaningful mental and physical effort to the user.

The usability questionnaire is shown in Table II. Statistical tests did not reveal any significant effects. The ranking of techniques preference was analysed using a

Friedman test (χ^2 = 5.44, df = 2, P > 0.05) and it revealed no significant effects. The ranking was 1.61 (SD = 0.18) for HB, 2 (SD = 0.16) for CH, and 2.39 (SD = 0.2) for GO.

Table II: Averaged scores of the usability questionnaire.

Questions (7-point scale)	CH	GO	HB
I found the technique easy to understand	6.3	6.5	6.3
I found the technique easy to use	5.8	5.1	5.5
I would need practice to use the technique	3.6	4	3.3
The object reacted as I expected	5.6	4.9	5.8
I found rotation easy to do	5.6	4.8	5.5
I found translation easy to do	6.3	6	6
I felt precise	5.2	4.1	4.8

6. DISCUSSION

This section examines the results of the evaluations and it is divided into two parts. The former analyses the effects of the different design choices. The latter focuses on the evaluated techniques.

6.1. IMPLICATIONS OF THE DESIGN CHOICES

6.1.1. SHOULD THE TECHNIQUE USE ONE OR TWO HANDS?

Regarding physical fatigue, one might think that two-hands techniques are the most tiresome as both hands must be coordinated and kept up while interacting. However, participants expressed that they felt slightly more fatigued using one-hand techniques. This may be caused by the fact that when users interacted with only one hand, the other hand that was resting served as a point of comparison. As a result, although two-hand techniques may be more physically demanding, the subjective perception of the users is the opposite. In general, another cause of physical fatigue could be the lack of haptic feedback as users could not rest their hands against the objects. Possibly, other types of feedback such as audio could reduce the perception of fatigue.

The two-hand technique was slower than the one hand techniques in translation but twice as precise. Possibly, the average of the two hands softened the input sensor error. Consequently, with the current hardware, using two hands implies a slower but more precise translation.

We suggest that applications that need to manipulate a single object at time can use a one-hand technique without decreasing their performance. This recommendation arises from the fact that the *Crank Handle* performed in general terms as well as the *Handle Bar*.

6.1.2. SHOULD THE TECHNIQUE INTEGRATE TRANSLATION AND ROTATION?

Concerning the integration of translation and rotation, it is not possible to completely generalize as the two techniques that integrated them obtained opposite results: The *Grasping Object* showed the worst results but the *Handle Bar* was satisfactory. The poor results of the *Grasping Object* could be caused by the metaphor. Although it is intuitive, it is also hard to perform precise rotations with it. Nevertheless, the necessity of adding an *only-translation mode*, the inefficiency (see Figure 7), and the *m*-metrics (see Figure 9) suggest that the combination of rotation and translation had a negative effect in the *Grasping Object*.

Even though people could use up to 6 DOF in the *Grasping Object* technique, *m*-metric revealed that they tended to separate rotation and translation. These results coincide with Masliah et al.'s (2000) and Veit et al.'s (2009) conclusions. We suggest that as one hand represents a 3DOF input it should be assigned to manipulate no more than 3DOF at the same time. Therefore, if we focus on one-hand techniques, we may argue that separation between translation and rotation is beneficial. For two-hand techniques it is possible to satisfactorily integrate translation and rotation as the two hands represent a 6DOF input.

6.1.3. SHOULD THE TECHNIQUE DECOMPOSE ROTATION BY AXIS?

Attending to the decomposition of the rotation in primary axes, the *Crank Handle* (decomposes) and the *Handle Bar* (not decompose) had similar results. However, results imply that the *Crank Handle* is better for rotation around one primary axis, whereas the *Handle Bar* is better for rotations around a random axis (see Figure 6). Additionally, although both techniques had similar completion times and precision at rotations, the *Crank Handle* was more efficient (see Figure 7).

This result suggests that decomposing rotation in primary axes could be more efficient. Veit et al. (2009) obtained a similar result. Nonetheless, not decomposing could be more useful for free exploration of objects or other tasks that require less efficiency (Kruger et al., 2005).

6.1.4. COULD THE TECHNIQUE BE DESCRIBED WITH A METAPHOR?

We argue that using a metaphor is always beneficial for a technique. This assertion is supported by the literature review, the pilot study, and the feedback of the users. Nonetheless, although metaphors always facilitate the interaction with a technique by making it more intuitive, they do not guarantee high performance. That was the case with the *Grasping Object* metaphor.

Quantifications of the metaphors' adequacy could not be made as the subjective ratings did not reveal significant differences. Nevertheless, participants' comments coincided in indicating the *Handle Bar* as the most intuitive metaphor. This preference is reflected on the ranking but not in the questionnaire.

6.2. OTHER IMPLICATIONS

The *m*-metric analysis revealed that participants had a better control of translation on the plane parallel to the TV (XY). Consequently, if the manipulation technique requires manipulating only one or two DOF, it could be better to employ the X and Y position of the hand as input instead of the Z position.

The transformation coordination (see Figure 8) shows that participants started adjusting the rotation of the object and then the translation. Those results are opposite to Martinet et al. (2012) who compared three manipulation techniques on multi-touch surfaces. We suggest that the interaction patterns of users in docking tasks are different in mid-air from those of multi-touch interactions. This fact obstructs to some point the generalization of our implications to other interaction modalities different from mid-air.

6.3. ANALYSIS OF THE TECHNIQUES

In general, the *Crank Handle* performed as well as the *Handle Bar* in terms of accuracy, task completion time, and maximum precision. The *Grasping Object* was entirely outperformed. The results showed that the *Crank Handle* is operative and even within the same range of performance as the two-hand technique. The following subsections analyse individually each technique.

6.3.1. CRANK HANDLE TECHNIQUE

The time passed in each *rotation mode* was similar and rotations were equally difficult around all the axes. We detected that up to 33% of the time, participants unsuccessfully tried to perform a rotation. We plotted the 3D hand positions and detected that in those cases the traced circle was irregular. The algorithm should be improved to be more adaptable at detecting circles.

6.3.2. GRASPING OBJECT TECHNIQUE

Participant passed 60% of the time in the *idle mode*. We observed that during a significant amount of this time the users were targeting the ray to the desired point or thinking about from where to grasp the object. *m*-metrics revealed that rotations around the Z-axis had a lower performance than the rest. In fact, Z-axis manipulation in free rotations like *Arcball* (Shoemake, 1992) is a known issue and techniques are usually extended with specific gestures to mitigate this problem (Iacolina et al., 2011).

6.3.3. HANDLE BAR TECHNIQUE

In the *m*-metrics charts, we observed that the *Handle Bar* is the only technique that uniformly uses all DOF combinations. Similarly, the *Handle Bar* is the closest technique to the optimal coordinated manipulation of translation and rotation (see Figure 8). *m*-metrics reported that rotations around the X-axis were slightly worse than in the rest of the axes. This kind of rotation is difficult to perform without entering the *Constrained Rotation mode*.

7. CONCLUSIONS

In this study we collected four design choices for manipulation techniques. We classified the existing mid-air manipulation techniques according to these design choices. The classification revealed deficiencies in the one-hand techniques, such as the lack of interaction metaphors and the absence of techniques that decompose rotation. Consequently, we developed two one-hand manipulation techniques to address these absences.

We conducted an evaluation that compared the two developed one-hand techniques and an existing two-hand technique. These techniques can be classified attending to the design choices of using one or two hands, separating or integrating translation and rotation, and decomposing or not rotation per axis. Additionally, all the techniques had a metaphor associated with the interaction.

The selection and evaluation of the techniques were designed to analyse the implications of the design choices. Consequently, the results gave insights on how the design choices influence the performance of a technique. For instance, separating translation from rotation and decomposing rotation in primary axis improves efficiency. The priority of the design choices will depend on the final use of the technique. For example, modelling software may take advantage of an accurate manipulation technique on rotations whereas video games may require only ease of use.

Additionally, results revealed that the *Crank Handle*, a novel one-hand technique, performs similarly to a two-hand technique such as the *Handle Bar*. Therefore, the *Crank Handle* technique can be used when it is required to manipulate only one object, leaving the other hand available for different tasks or resting. Finally, the results can also be used to select among the three presented techniques and as a point of comparison for future techniques.

The analysis of the techniques also showed points to improve. The *Crank Handle* should improve the algorithm of circle detection. Additionally, the *Grasping Object* would take advantage from a specific gesture for Z rotation. Similarly, the *Handle Bar* could be improved with a more rapid access to X rotation. In the future, the new version of the Kinect will be able to detect wrist rotation and tilt. This would provide more input DOF that could be used to improve the interaction techniques.

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CHAPTER III

SPECIAL SCHOOL: COLLABORATION WITH TEACHERS

ABSTRACT

New technologies and computer applications prove to be powerful tools for children with special needs in order to improve specific skills. However, there is still a gap between research development and its applicability at schools. Thus, we have created a workgroup with a specialized state school in Spain. Based on their curricular project, we have identified the need for training the body such as working stabilization, coordination and knowledge of the body as well as other educational competences. As a result, the Microsoft® Kinect has been used since its way of interaction is based on the entire body. The children of the school present a great variety of motor and cognitive skills. Consequently, the framework must adapt itself to the child's motor capacities. Therefore, the outcome of the iterative design with teachers is a framework based on a user's profile system which is composed of several interaction techniques for a same action in order to interact with three activities. The framework was installed and evaluated at the school with 6 children. The children showed interest in participating and were willing to follow the instructions given by the teachers. The customization of the interaction techniques allowed almost all the children to play with the system. Moreover, one of them improved the control of his gestures.

1. INTRODUCTION

Nowadays, new technologies such as multi-touch surface or Kinect sensor are used to motivate children with special needs in improving both motor and cognitive skills. Although many computer applications using these technologies are developed, these are usually designed to improve a specific cognitive skill for a specific disability such as autism or syndrome of Down. However, children at specialized state schools present a great diversity of motor and cognitive capacities. Furthermore, motor disabilities may hinder the use of applications (beyond the physical interaction) (Bryanton et al., 2006). Therefore, when an application is designed, it should take into account children's motor skills. The use of motor skills is essential during the learning process because some children learn more efficiently through kinaesthetic experiences (Hsu, 2011; Latham & Stockman, 2014). Natural User Interfaces (NUIs) involve the use of the whole-body during the interaction with the software. Therefore, NUIs implicitly motivate children in working coordination, stabilization and knowledge of their own body (Ilg et al., 2012). Another important aspect to take into account during the learning process is the motivation and engagement of children towards the activity. Motion-based touchless experiences provide insights of engagement (Bartoli et al., 2013). Indeed, evidence showed a correlation with the body; the more movement, the more engaged (Bianchi-Berthouze et al., 2011). However, a gap between research and practice still exists due to the lack of research that takes place in schools (Parsons et al., 2013).

Thus, this study explores the possibility of using NUIs in a special school for children with severe disabilities. We created a workgroup with the specialized state school Andres Muñoz, in Pamplona, Spain. Then, from their curricular project, we identified the need for training the body such as working stabilization, coordination and knowledge of the body as well as other educational competences. We followed an iterative design approach with three teachers and developed an adaptive framework with three activities: "painting", "discovering an image" and "creating music". The framework was iteratively improved and adjusted for two months at the school. Then, the three trained teachers taught 6 children about the use of the framework and an evaluation was conducted to measure children's interest and motivation as well as to validate the flexibility of the framework.

2. RELATED WORK

Recently, the research in education has been looking for frameworks that focus on the development of motor skill through the use of specific gestures (Sheu et al., 2013). One important topic focuses on *exergames* which are video games that take advantage of their embedded motivation to undertake physical activity (Staiano & Calvert, 2011). Moreover, *exergames* can be adapted for children with special needs by following specific design guidelines (Hernandez et al., 2013). For instance, Hernandez et al. (2013) suggest to reduce the simultaneous actions and to provide simple control scheme in order to develop action *exergames* for children with cerebral palsy.

Engaging the whole body can enhance control, pleasure and engagement (Norman, 2010). The use of Microsoft® Kinect proved to be a potential tool for rehabilitation. An experiment was lead on children with cerebral palsy playing video games with the Microsoft® Kinect. Results showed that their balance was improved (Luna-Oliva et al., 2013).

Additionally, detecting the body can support accessibility to children in wheelchair. Indeed, they usually cannot be placed near a table which may hinder the use of several applications. JeWeels is a serious game which only requires the use of arms. In addition to leisure, physiotherapists suggested its use as a rehabilitation tool (Sáenz de Urturi et al., 2012).

Applications which use gesture recognition are not only aimed at rehabilitation. For instance, stereotypical movement, which can occur for example with individuals with Autistic Spectrum Disorder (ASD), can be detected. Gonçalves et al. (2012)

proposed an algorithm based on the recognition of similar patterns. Their framework, which uses the Microsoft® Kinect, can record a movement and then, when users reproduce very similar gestures an alarm can be triggered.

Pictogram Room is a framework which offers several activities based on Augmented Reality and gestures detection (Casas et al., 2012). The objective is teaching postures and specific gestures to children with ASD in order to improve their social communication skills.

The applications that focused on improving specific cognitive skills such as collaboration (Giusti et al., 2011), mathematics (Van Veen et al., 2009) or spatial sense (Lin et al., 2013), are typically designed for a specific disability. Only few researchers tend to adapt their applications to the child's capacities (Fernández-López et al., 2013) typically through the use of user's profile.

3. ADAPTIVE FRAMEWORK

3.1. COLLABORATION WITH THE EXECUTIVE TEAM OF THE SCHOOL

This work was partly motivated to reduce the gap between research and practice. Consequently, it was important to find a school which was interested in exploring the use of new technologies in their educational project. Andrés Muñoz is a growing specialized state school with approximatively 80 children who present a great diversity of motor and cognitive skills. The school teaches at different levels of education such as primary, secondary, postsecondary transition and work insertion. The classroom gathered 3-4 pupils who are grouped according to their age, skills and behaviour.

First, the researchers contacted the executive team of the school to start a new collaboration. We presented our motivation and objective which was to explore the possibilities of integrating an educational tool that uses Natural User Interfaces (NUIs) at school. Previous to the meeting, the researchers had developed a prototype that exploited the main features proposed by the SDK (Software Development Kit) of the Microsoft® Kinect. This demo was exposed during the meeting with the executive team members. The prototype consisted in painting with the hands with the projection of the users displayed onto the screen as a visual feedback. When users touched their head with one hand, the pencil was activated so that they could paint with the other hand. Several buttons were displayed on the borders so that the users could change the colour or the size of the pencil (Figure 1). Afterwards, the school proposed to organise one pilot study session with the pupils in order to observe their reaction. The session was video recorded (Andrés Muñoz experience, 2012).

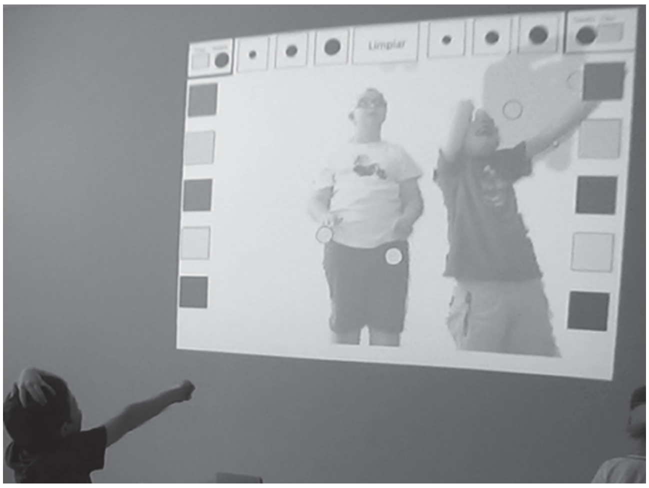

Figure 1: Pupils of Andrés Muñoz playing with the prototype of painting with hands

The objective of the second stage was to find out what added values the new technology could bring to the school. Thus, the school invited the lead researcher (first author) for one week where he could integrate several classes. This week was crucial in order to know better the pupils and discover what the specific interests of the different teachers were. Furthermore, the school provided its curricular project so that the researchers could select the topics which they considered relevant. Their educational programme was composed of 8 learning areas: *autonomy*, *sensory integration*, *participation with the environment*, *motors skills*, *language/audition*, *communication/expressive language*, *music* and *health*. From that list and the associated competences the researchers sorted out 2 main categories: *body skills* and *creativity*.

Finally, the researchers and executive team members met again in order to establish a common-ground between both entities. All the stakeholders agreed that the children with motor disabilities were usually limited in the use of applications despite the fact that different technologies such as multi-touch surfaces, tablets or adapted mice tend to solve this issue (Standen et al., 2006). Moreover, since the curricular project of the school also focused on working coordination, stabilization and knowledge of the body, the idea of using the Microsoft® Kinect was accepted by all the stakeholders. However, this raised both a contradiction and a real challenge because contrary to other technologies the Microsoft® Kinect is not directly designed for children with motor disabilities. Additionally, the school tends to adapt the content of its curricular programme to each of the children since each one requires a specific attention. Consequently, they expressed the need of an application which would not only aim at improving specific skills from their curricular project but also be adapted to the necessities of the children. Thus, the two learning areas "*creativity*" and "*body skills*" were validated.

During the development, the framework was set up at the school and regularly updated. For two months, three teachers tested the application with three children (1 male and 2 female). During this period, the teachers provided feedback and ideas to improve the use of the activities by adding new features or adjusting the detection of the gestures. Thus, the framework was iteratively updated until the teachers considered that the children were able to work with it. The activities and user's profile system are presented below.

3.2. USER'S PROFILE

The outcome of the brainstorming sessions with the school led to the need of a framework that would adapt itself to children's motor capacities. Thus, users would also be able to work other contents almost regardless of their motor skills.

In order to achieve such an objective a user's profile is compulsory. This latter allows the application to detect who the user is and as a result adapts the use of the activities. Thus, the configuration proposes several interaction techniques for a same action. Moreover, the user's profile takes also into account whether the user is left- or right-handed and seated or standing.

Communication between computer applications and humans are performed through interfaces. These interfaces, generally called Graphics User Interfaces (GUIs), are classified into 4 categories (Van Dam, 1997): windows, icons, menus and pointer (WIMP). Based on WIMP, we propose four specific actions such as scanning the screen (windows and pointer), activating a button (icons), activating a menu and navigating through it (menu). However, a fifth action is usually required in order to activate a state. When this state is activated activities will perform a specific action such as drawing.

3.2.1. SCANNING THE SCREEN:

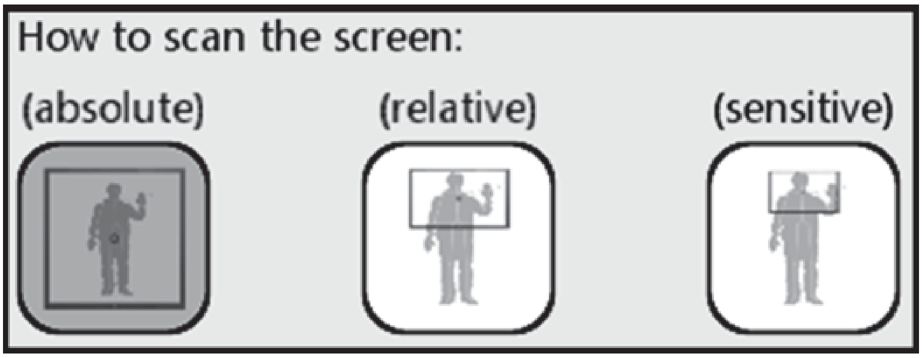

Figure2: The three options of user's profile for scanning the screen: absolute, relative and sensitive.

Activities tend to use the entire screen to place icons or simply to work. Thus, it is important that users can reach each area of the window. Unconsciously, pointing at the screen with the arm requires coordination and stabilization. However, not all children can move freely their arms. Consequently, we propose three ways to scan the screen (Figure 2). The first one is the absolute position. Users can see their own image displayed on the screen, thus they need to walk around and move the arm so that they can reach all areas with the hand. For children in wheelchair or with low stability, it is better to use relative position. We display virtual screens, one for each hand. Through a large movement of the arm, users can scan the whole screen. At the beginning, we used only one virtual screen for both hands centred on the body; however, it was difficult and unstable to reach the opposite side. It was difficult because the position of the arm was not comfortable and it was unstable due to the low accuracy of the skeleton recognition with the own occlusion of the body. Finally, we propose a third option which uses smaller virtual screens for children who cannot perform large movements. In this case, they lose in precision but they can reach all parts of the screen.

3.2.2. *ACTIVATING A BUTTON*

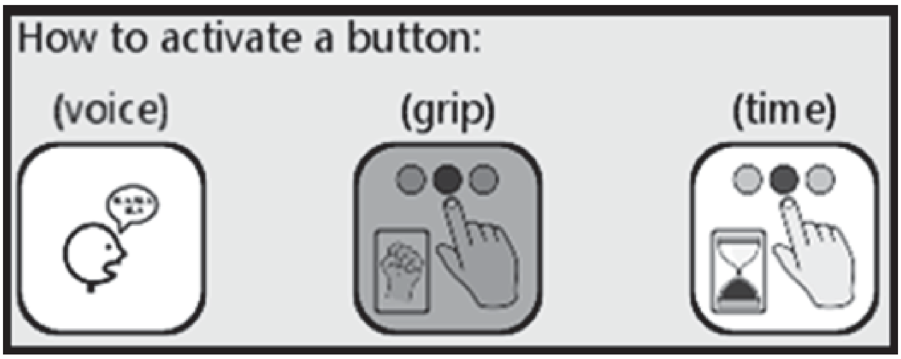

Figure 3: The three options of user's profile for activating a button: by voice, by closing the hand and with a timer.

Now that users are able to reach an icon displayed on the screen, they should be able to activate it (Figure 3). Based on pointing gestures we propose two options. By default, when users point over the button, they have to close their hand to activate it.

In that case, they are sure that they will not activate it unwillingly. However, some children cannot open and close their hands easily, thus we also propose a timer which starts when the cursor is over the button and activates this latter when the time is over. A third option is the activation by voice. All the buttons of the application have a keyword which defines them. For children who are not able to control their arm movements, they can still participate to some activities through this option.

3.2.3. ACTIVATING A MENU

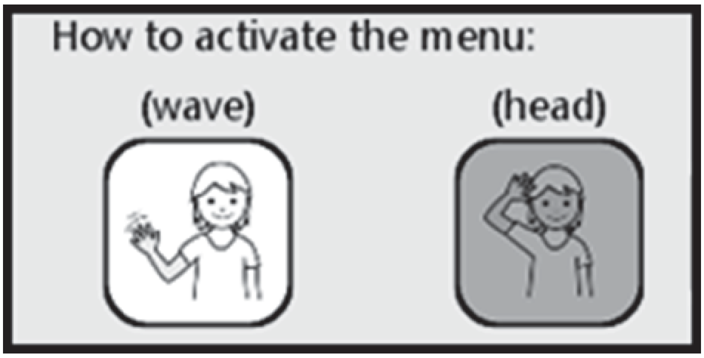

Figure 4: The two options of user's profile for activating the menu: by waving one hand and by touching the head with one hand.

Menus are one of the most important GUI elements. They allow users to choose between different commands in order to access all the functionalities provided by the application. The menu should be activated by a unique trigger. The most common trigger is a specific key of the keyboard. However, in remote interaction it should be a specific gesture that is not usually performed. Consequently, we propose two options (Figure 4). The first one is waving the hand. It is a natural movement and generally not used by an application. Nevertheless, this gesture should be performed quickly with at least two 2-ways in order to make that gesture unique. For children who cannot perform this quick gesture, we also propose touching the head with one hand. This gesture does not require such dynamism but furthers the knowledge of the body.

3.2.4. NAVIGATING THROUGH THE MENU

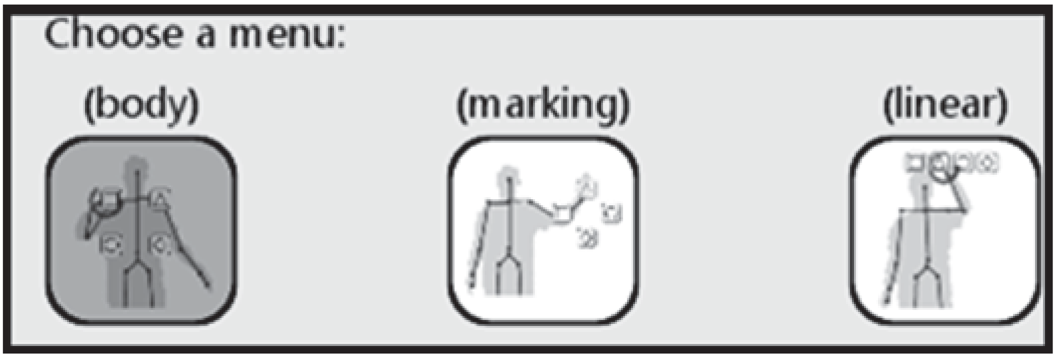

Figure 5: The three options of user's profile for navigating through the menu: *Body Menu*, Marking Menu and Linear Menu.

Several kinds of menus exist in the literature. In remote interaction we have decided to use the three menus (Figure 5) proposed by Bossavit et al. (2014) (see further details in Chapter I). The first one is called *Body Menu* and associates items to parts of the body. To activate these items users have to touch the corresponding part of their own body. This technique requires coordination, stabilization and knowledge of the body. The second option is the *Marking Menu*. Items are displayed in circle around the hand and users have to move it in the plane to reach the item for selection and moving back to the centre for validation. This type of menu is fast and accurate. The last menu is the *Linear Menu*. It is the classic one, items are displayed in row and users have to point at the screen to activate them.

3.2.5. ACTIVATING A STATE

Activities usually require a specific state to perform an action such as drawing. Therefore, we propose three options for the state activation (Figure 6). The first one consists in moving one leg ahead. We also propose to close or open the hand to activate or release the state, respectively. However, for children who find these interaction techniques difficult or impossible to perform, we also propose a button that teachers can activate with the mouse.

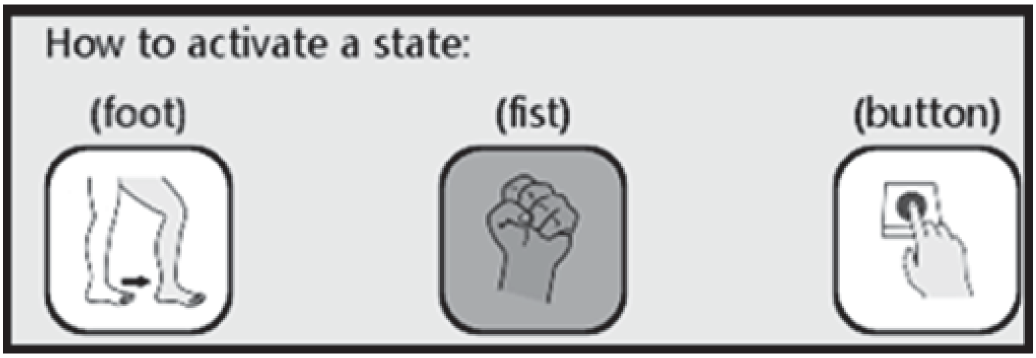

Figure 6: The three options of user's profile for activating a state: moving one leg ahead, closing one hand and activating a button.

3.2.6. CONFIGURATION

Sometimes it is difficult to know which technique is the most appropriate for the child. Consequently, for each option suggested in the user's profile we developed an exercise in which children have to reproduce the corresponding action. They are given 5 opportunities to do it, and to be sure they are able to control the technique they are asked to reproduce the gesture 3 times. In the end, the result is easily observed on the main page (Figure 7).

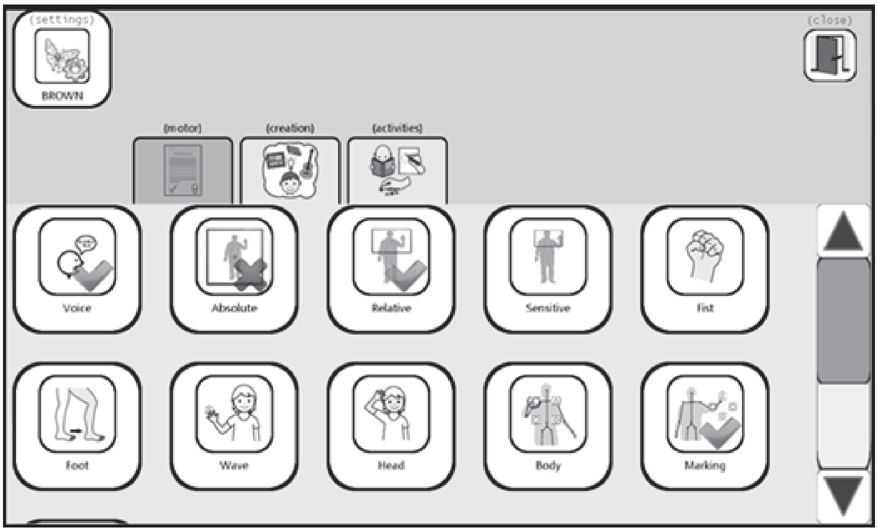

Figure 7: List of exercises based on user's profile options. It can help to choose the most appropriate techniques beyond all of them.

3.3. ACTIVITIES

According to the curricular project of the school, we propose three activities in order to increase the motivation in using the application, and thus, validate the system of user's profile. The activities do not require a high cognitive level since we want all the children to be able to interact with them. As a result we have decided to develop activities based on creativity and imagination.

The first activity consists in painting with the hands (Figure 8). When the (drawing) state is activated a coloured point is drawn under the virtual hand. Then, through the menu, children can change the size and the colour of the pencil for each hand. In addition, a song can be played according to the movement of the hands in order to promote the cause and effect reaction. This option is editable in the user's profile. Finally, a *Linear Menu* for the supervisor is available in order to draw an image on the background or to save the result.

Figure 8: "Painting" activity. The user draws by closing the hands and moving them inside the virtual screens.

With the second activity, children are asked to discover a blurred image by clearing the screen with their hands (Figure 9). A song can be played according to the movement of the hands like in the “painting” activity. Moreover, the supervisor can add and change the image displayed on the background.

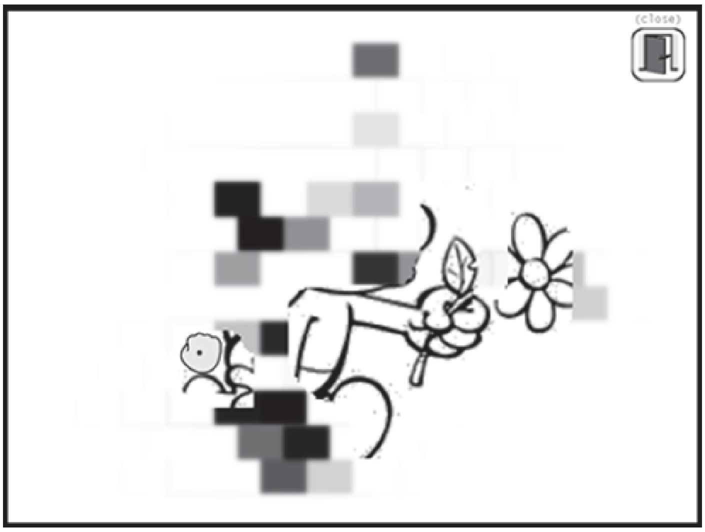

Figure 9: “Discovering an image” activity. The user clears the screen by closing the hands and moving them.

Finally, we propose an activity to create music (Figure 10). This activity is exclusively based on menu navigation. Through the menu, children can choose a musical instrument and notes. When a note is selected, an icon is drawn on the bottom of the screen with the rest of the composition. Users can also reproduce their creation.

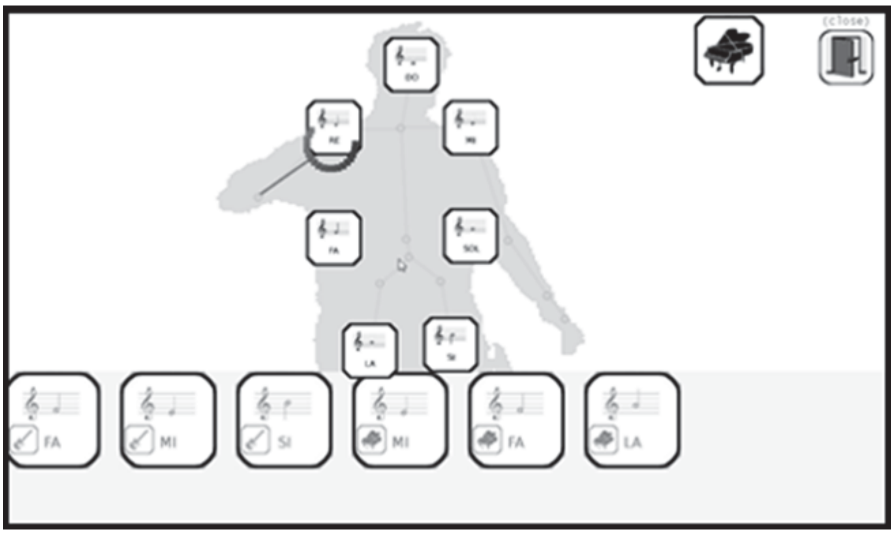

Figure 10: “Creating music” activity. The user plays musical notes by selecting them from the menu.

4. USER CASES

Once the teachers considered that the framework was operational, three more children were recruited to test the activities. Thus, a total of six children (4 male and 2 female) played with the framework during 3 controlled sessions, one per week. The children were separated in three groups. Children of a same group belong to the same class and during the sessions they observed the other members of their group interacting with the application. Mr. Brown, Mr. White and Mr. Orange belong to the same class while Ms. Blonde and Ms. Pink belong to another class. Mr. Blue was alone during the sessions. A profile for each child was created and their configurations are stated in Table I.

Table I: User's profile for each child

Child	Scanning the screen			Activating a button			Activating a menu		Navigating through the menu			Activating a state		
	Absolute	**Relative**	**Sensitive**	**Voice**	**Grip**	**Time**	**Wave**	**Head**	**Body**	**Marking**	**Linear**	**Foot**	**Fist**	**Button**
Mr. Brown	X					X		X	X				X	
Mr. White		X				X		X			X		X	
Mr. Orange		X				X		X			X		X	
Ms. Blonde	X					X		X			X		X	
Ms. Pink		X				X		X			X		X	
Mr. Blue			X			X		X			X			X

Then, for each child, specific objectives were defined by the teachers. During these sessions, we measured specific criteria in order to check whether children fulfilled the corresponding objectives. There were 3 possible states for each criterion: starting (S) when the child did not know how to execute the criterion, in development (D) when the child understood how to execute the criterion but still needed help and achieved (A) when the child could execute the criterion on his/her own (Table II and

Table III). Objectives and criteria were chosen according to the official assessment of the curricular project of the school.

Videos were recorded for the analysis of the behaviour and motivation. However, for confidential reason these were exclusively used for internal purposes. For the same reasons, the complete diagnostic of the children could not be revealed. However, a description of their motor and cognitive skills is given below. According to the differences between children, it was impossible to compare their performance. As a result, we present six study cases in which the teachers had decided the activities that each child would perform according to their capacity and their preference.

Figure 11: Apparatus composed of a projected surface, a Microsoft Kinect and a user interacting

For the experiment, we used a computer running Windows® 7, which belongs to the school, and a Microsoft® Kinect placed under a projected surface with a resolution of 1280 x 768. Users were located in front of the Microsoft® Kinect at a distance of 2 m approximately although they were free to move (Figure 11).

Table II: Common objectives (highlighted in grey) and criteria for Mr. Brown, Mr. White and Mr. Orange (S for Starting, D for Development and A for Achieved).

Criteria	Session 1			Session 2			Session 3		
	S	*D*	*A*	*S*	*D*	*A*	*S*	*D*	*A*
Expression of the emotions									
Express emotions with gestures or facial expression			Mr. Brown Mr. White Mr. Orange			Mr. Brown Mr. White Mr. Orange			Mr. Brown Mr. White Mr. Orange
Express emotions verbally			Mr. Brown Mr. White Mr. Orange			Mr. Brown Mr. White Mr. Orange			Mr. Brown Mr. White Mr. Orange
Experimentation of the possibilities of the body to interact with the application									
Coordinate the arms in order to use the application freely	Mr. White	Mr. Orange	Mr. Brown		Mr. White Mr. Orange	Mr. Brown		Mr. White Mr. Orange	Mr. Brown
Coordinate the arms with precision in order to execute a specific task	Mr. White	Mr. Orange	Mr. Brown		Mr. White Mr. Orange	Mr. Brown		Mr. White Mr. Orange	Mr. Brown
Understand and execute a specific gesture		Mr. Brown Mr. Orange				Mr. Brown Mr. Orange			Mr. Brown Mr. Orange
Understanding and execution of an order given by the teacher									
Complete correctly a single order		Mr. Orang	Mr. Brown			Mr. Brown Mr. Orange			Mr. Brown Mr. Orange
Complete correctly two consecutive orders		Mr. Brown Mr. Orange			Mr. Orange	Mr. Brown		Mr. Orange	Mr. Brown
Encouraging the use of technologies									
Use correctly the application according the corresponding level		Mr. White Mr. Orange	Mr. Brown			Mr. Brown Mr. White Mr. Orange			Mr. Brown Mr. White Mr. Orange

Table III: Common objectives (highlighted in grey) and criteria for Ms. Blonde and Ms. Pink (S for Starting, D for Development and A for Achieved)

Criteria	Session 1			Session 2			Session 3		
	S	*D*	*A*	*S*	*D*	*A*	*S*	*D*	*A*
Show interest									
Stare at the screen		Ms. Blonde	Ms. Pink		Ms. Blonde	Ms. Pink			Ms. Blonde Ms. Pink
Point at the screen		Ms. Blonde	Ms. Pink		Ms. Blonde	Ms. Pink			Ms. Blonde Ms. Pink
Move	Ms. Pink		Ms. Blonde	Ms. Pink		Ms. Blonde	Ms. Pink		Ms. Blonde
Use significant gestures (applause, "give me five"…)		Ms. Pink	Ms. Blonde		Ms. Pink	Ms. Blonde		Ms. Pink	Ms. Blonde
Show self esteem									
Accept help from the teacher			Ms. Blonde Ms. Pink			Ms. Blonde Ms. Pink			Ms. Blonde Ms. Pink
Ask for help		Ms. Blonde	Ms. Pink		Ms. Blonde	Ms. Pink		Ms. Blonde	Ms. Pink
Ask for activities		Ms. Blonde Ms. Pink			Ms. Blonde Ms. Pink			Ms. Blonde Ms. Pink	
Encouraging the use of technologies									
Accept to use technologies	Ms. Pink	Ms. Blonde		Ms. Pink	Ms. Blonde		Ms. Pink	Ms. Blonde	
Enjoy playing with the application	Ms. Pink	Ms. Blonde		Ms. Pink	Ms. Blonde			Ms. Blonde Ms. Pink	

4.1. MR BROWN

Mr. Brown is a 15-year-old boy with intellectual disabilities and oppositional defiant disorder. His global cognitive development is equivalent to an 8-9 year-old typical development child. Mr. Brown does not show any motor impairment.

For the three sessions and during 20 minutes each, Mr. Brown worked with the "painting" activity in which he was given two different tasks to perform. The first one consisted in drawing a "house" which is composed of a square and a triangle above in the same colour. Then, he was asked to draw the square with one colour and the triangle with another one. He had to change the colour through the menu. Moreover, Mr. Brown interacted with the "creating music" activity. He was asked to choose a specific musical instrument and then to play a specific sequence of notes.

The teacher was interested in the use of the application for several reasons. The first objective was the regulation of his conduct. To fulfil this goal, we observed three criteria. The first one was his acceptance of receiving orders and comments given by the teacher. The second one was his tolerance of the delay of his own wishes. Then, the last one was his respect of the order of the players. For the first session, the three criteria were checked as *in development (D)*, then for the two last sessions they were checked as *achieved (A)*.

The other objectives and criteria are stated in Table II since they are common with some of the other children.

Overall, for the last session, Mr. Brown achieved all the objectives set by his teacher. Moreover, we could observe a slight improvement in the regulation of his conduct and in the understanding and execution of orders. Mr. Brown was willing to play and although he complained when he failed he persevered in executing the orders.

4.2. MR WHITE

Mr. White is a 15-year-old boy with cerebral palsy and intellectual disabilities. His global cognitive development is equivalent to a 7-8 year-old typical development child. Mr. White presents tetra paresis and consequently uses a wheelchair.

For the three sessions and during 15 minutes each, Mr. White was asked to discover the content of blurred images. The hidden content was directly linked with the thematic of the class. He had to clear partially the image and try to discover what the content was. Once he had discovered it, the teacher asked him several questions about it.

The first objective was to work the current topic taught in the class. We observed whether he was able to deduce the content of the image and if he could answer correctly the questions asked by the teacher. For the three sessions, Mr. White achieved these two criteria.

The other objectives and criteria are stated in Table II since they are common with some of the other children.

Overall, we could observe an improvement in the interaction with the application. The slower the movement of the arm was, the better the image was cleared. Consequently, Mr. White was forced to control his movement in order to fulfil efficiently the objective. Thus, he was asked to reduce the speed when he was performing fast gestures.

4.3. MR ORANGE

Mr. Orange is a 14-year-old boy with intellectual disabilities. His global cognitive development is equivalent to a 7-8 year-old typical development child. Mr. Orange presents a degenerative muscular dystrophy. He is not using a wheelchair.

For the three sessions and during 15 minutes each, Mr. Orange was asked to choose different musical instruments and play a specific sequence of musical notes.

The objectives and criteria are stated in Table II since they are common with some of the other children.

Overall, Mr. Orange achieved all the objectives set by his teacher. We could observe an improvement in the execution of one order, but he still had difficulties to execute two consecutive orders. Although he has a low balance, Mr. Orange moved consequently in order to select items of the menu. However, he quickly felt tired and used the back of a chair to support himself.

4.4. MS BLONDE

Ms. Blonde is an 18-year-old girl with psychic and intellectual disabilities and difficulties with attention. Her global cognitive development is equivalent to a 4-5 year-old typical development child. She does not show any motor impairment.

For the three sessions and during 20 minutes each, Ms. Blonde was asked to paint circles with one hand, with the other one and with both hands symmetrically. She was also asked to clear the screen in order to discover hidden images. The picture represented a classmate or an event in which she had participated.

The first objective was to evaluate her capacity and knowledge in plastic art. The first criterion that we observed was the use of the arms to draw accurately. Then, while she was painting circles, the teachers asked her the current colour in order to know whether she distinguished primary colours. These two criteria were checked in development for the three sessions. The two last criteria for this objective were whether she could draw something to express feelings/emotions and whether she could draw concrete objects. She could not complete any of these criteria.

The other objectives and criteria are stated in Table III since they are common with some of the other children.

Overall, Ms. Blonde did not show any improvement across the three sessions. She could perform circles with both hands separately. Nevertheless, she was not able to perform the gesture with both hands at the same time. According to the second activity, she cleared the image without any difficulty. However, she did not show a lot of interest when the image corresponded to a classmate. Her teacher says that she is very obedient, and sometimes it is difficult to know if she does things willingly.

4.5. MS PINK

Ms. Pink is a 20-year-old girl with cerebral palsy and psychic and intellectual disabilities. Her global cognitive development is equivalent to a 6-7 year-old typical development child. She presents difficulties to execute voluntary movements and uses a wheelchair.

For the three sessions and during 10 minutes each, Ms. Pink was asked to clear the screen in order to discover hidden images. The picture represented a classmate or an event in which she had participated.

The objectives and criteria are stated in Table III since they are common with some of the other children.

Overall, Ms. Pink did not show much interest in the application. During the two first sessions, she worked with images of her classmate and she was not willing to clear a new photo. Although she presents difficulties to execute voluntary movements, she was able to clear almost all the image without any help. However, movements were not accurate. For the last session, we added pictures of events in which she had participated and she showed more interest. For this last session she was willing to clear a new photo.

4.6. MR BLUE

Mr. Blue is an 8-year-old boy with multiple disabilities including cerebral palsy and intellectual disabilities. His global cognitive development is equivalent to a 0-6 month-old typical development baby. He pays attention to lights and sounds. He presents a partial control of his arms and uses a wheelchair.

For the three sessions and during 30 minutes each, he was asked to clear the screen in order to discover the hidden image. The picture represented a classmate.

The first objective was the motivation in using his arms. We were interested in the voluntary movements of the right and left arm. For the three sessions, we could not observe voluntary movements. In order to help him in connecting his movements with the result into the application as a cause effect reaction, a song was played only when he performed a movement. However, he did not show any sign of establishing this connection.

The second objective was the recognition of the person on the photo. In order to be sure that he recognized the person, when the image was cleared two real photos were presented to him. However, he did not show any sign of recognition. In addition, we observed his reaction when the image was cleared. Although he did not show any reaction when he discovered the picture for the two first sessions, for the last one he smiled.

The last objective was the motivation in using technology. For the second session, Mr. Blue entered the room smiling and according to the teacher he was happy to use the application. He did not show emotions for the first and third sessions. Mr. Blue mainly pays attention to lights and sounds. Although we used the cause-effect reaction with the music, it did not show insights of motivation. Although sometimes he was smiling and showing interest, results were not significant as they depended of the mood Mr. Blue had that day.

5. DISCUSSION

Our objective was two-fold. On the one hand, we wanted to provoke interest and motivation to children in working educational aspects, including the body. On the other hand, we wanted that almost all children would be able to interact with activities regardless their motor skills.

According to the first objective, we have implemented three activities which consist in painting with the arms, discovering an image and creating music. These activities used simple interface and various feedbacks in order to motivate the exploration of the different features and to ease the adoption of the technology (Keay-Bright & Howarth, 2012). Results showed that almost all the children were willing to participate to the activities and followed the orders without complaining. Mr. Blue's teacher said "when he entered the room and saw the screen he started to smile and paid attention to it". In fact, virtual environments and technologies can enhance the participation of the children with which they can learn information and transfer it to the real life (Parsons and Cobb, 2011). Teachers commented that they were happy with the application and more precisely with the "discovering an image" activity as they could adapt it easily to their own interests.

Regarding our second objective, we argue that devices which offer natural interaction can be used as an adaptive assistive technology like the Nintendo® Wii Remote (Battersby, 2008). Our framework was used by six children with different motor skills for the three sessions. Five out of six children could interact without great difficulties. Although it is almost impossible to find a device that fits the needs of everybody (Standen et al., 2011), its use can enhance the experience of the users. In the case of Mr. White we could notice some improvement and effort in reducing the speed of the movement of his arms. Mr. Blue did not really interact autonomously. His teacher used to help him in moving the arms as it seemed that he was not able to correlate the movement of his arms with the song and the image clearing.

Nevertheless, the teacher thought that Mr. Blue was attracted by the screen and seemed happy to participate.

6. CONCLUSIONS

In this work, we presented a user's profile system for applications which use remote interaction devices such as Microsoft® Kinect. Children with motor disabilities are usually hindered in the use of computer applications. Thus, applications should adapt themselves to the needs of each child. In addition, one important part of the curricular project of a specialized school is working with the body. As a result, our interest, apart from working other educational aspects, is working the stabilization, coordination and knowledge of the own body.

The users' study gave some insights that the interaction techniques are numerous enough and their implementation with the Kinect can be a powerful tool for improving specific skills and motivation. However, with the limited number of sessions we only could measure qualitative data. It would be interesting to perform an evaluation during a longer period of time and measuring quantitative data in order to observe learning effect and persistence.

Our framework can adapt itself to different motor disabilities. Thus, the next step would be the integration of new activities which require higher cognitive skills. In fact, these would cover a broader spectrum of educational skills.

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CHAPTER IV

SPECIAL SCHOOL: COLLABORATION WITH TEENAGERS WITH HIGH FUNCTIONING AUTISM

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Bossavit, Benoit and Parsons, Sarah (2016) This is how i want to learn: high functioning autistic teens co-designing a serious game. In, *CHI '16; Conference on Human Factors in Computing Systems,* San Jose, CA, US, 07 - 12 May 2016. New York, US, ACM, 1294-1299. Doi:10.1145/2858036.2858322

Bossavit, B., & Parsons, S. (2016). Designing an Educational Game for and with Teenagers with High Functioning Autism. *En Proceedings of the 14th Participatory Design Conference: Full Papers - Volume 1* (pp. 11-20). New York, NY, USA: ACM. Doi:10.1145/2940299.2940313

ABSTRACT

This study describes a Participatory Design approach which involved teenagers with High functioning Autism in the design of an educational game to learn about Geography via the use of Natural User Interfaces. The project took place in highly specialized schools for young people with Special Educational Needs. Design sessions were conducted with specific activities, which were guided by the interaction between the teachers and students on the day. The corresponding activities implicitly shaped the roles that each stakeholder undertook such as user, informant, tester, co-designer, motivator or facilitator. As a result, adults and young people together designed and then evaluated a digital educational game based on their expertise as programmers, teachers, and video gamers, respectively. This work contributes by highlighting the importance of supporting students to participate on their own terms, which led to an academic tool. The serious game consists in obtaining European countries by answering questions. Several strategic features were added so that users could collaborate against the computer or compete against each other. The results showed that the participants learnt Geography content although the difference in level of competitiveness created tensions within the peer teams, which led to a decrease of engagement towards the task.

CHAPTER V

MAINSTREAM SCHOOL: COLLABORATION WITH THE DIDACTICS SECTION OF A MUSEUM

ABSTRACT

Museums usually look for new educational tools to enhance their exhibition. The Oteiza's museum in Navarre (Spain) especially gives importance to the dissemination of Jorge Oteiza's work to children. Consequently, a didactics section was created with the objective of developing activities and relationship with schools. Jorge Oteiza represents one of the most important artists in the Spanish modern art and his sculptures stem from his proper philosophical concepts such as negative aesthetics via addition and subtraction, or activation of space and time. Such notions make the learning process at school complex. Thus, this study proposes a framework that aims to enhance the visit to the museum through a series of mini-games that shed light on these abstract concepts. Representative sculptures were selected and the corresponding activities were designed and developed in collaboration with the didactics section of the museum following a Co-Design approach. Then, the framework was tested by pupils from primary and secondary schools and students from educational practice. The analysis of the results showed that the participants did understand the artistic concepts among which the girls were more engaged and increased the most their knowledge.

1. INTRODUCTION

"A museum is a non-profit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment". This definition of the International Council of Museums (ICOM, 2007) defines the main objectives of museums, which are exhibition and education towards a targeted audience, which are mostly specialists, students and tourists (Bowen & Filippini-Fantoni, 2004). Thus, museums usually look forward to engaging their public in new types of displays in order to understand and appreciate the cultural heritage (Petridis et al., 2013).

Thus, museums tend to integrate new educational tools to their exhibitions. Some evidence suggests that game-based learning environments can be effective (Clark et al., 2014) due to the use of cognitive skills such as memory or construction of knowledge (Sylaiou et al., 2009). These educational games, also known as serious games, adapt specific features of entertaining video games such as storyline or direct goals (Kapp, 2012). These components are important to make the experience enjoyable (Salen & Zimmerman, 2004). For instance, the MuseUs project (Coenen et al., 2013) removed all competitive aspects in their game in order to lower discomfort towards the other visitors but the feedback was confusing because, indeed, the users were expecting a level of progression with a system of score.

Prensky (2005) classified educational games into mini- and complex-type with different objectives. Indeed, their complexity will influence the expected experience. For instance, complex games are usually long and combine various game mechanisms such as storyline, level of difficulty or rewards. These latter are interesting for a deep and long-term learning process (Prensky, 2005). This is in line with a museum context where the longer the users interact with an exhibit, the more likely they are to learn (Serrell, 1997). On the other hand, mini-games are usually short and do not require elaborated or evolutionary rules (Prensky, 2005). The choice among these two types of games would depend mostly on the targeted audience, the place and the time allowed (Rivera-Gutierrez et al., 2014; Pescarin et al., 2013). For instance, visitors would sometimes prefer being engaged in the "experience" of learning rather than learning content by itself (Packer, 2006).

Museums do not limit their interests to indoor exhibits since communication and dissemination are also important criteria (Paliokas & Kekkeris, 2008). Thus, several strategies have been developed. For instance, Research has focused on Virtual Museum (VM) applications (Sylaiou et al., 2009) which widen the gallery access to visitors at different physical places through web technology (Kuo et al., 2009) or Virtual Reality (Anderson et al., 2010). It has been shown that a clear learning strategy between schools and museums reinforce students' learning experience (Griffin, 2004). Consequently, some projects have focused on the design of virtual museum applications specifically to be used at school (Paliokas & Kekkeris, 2008) while others have been oriented to the creation of teamwork (students, educators, museum staff and researchers) to collaborate on the conception of museum activities (Wishart & Triggs, 2010). Although such projects have shown interesting results, it is important to warn against the difficulties that can be encountered such as the cost for a school or the stakeholders' time schedule which might invade their personal time (Vavoula et al., 2009).

The Oteiza's museum in Navarre, Spain, made a call for a project which objective was the dissemination of Jorge Oteiza's work. This project, "*Oteiza para tod@s*" (literally, *Oteiza for all*), answered this call by proposing a framework that integrates the three following components: Art, Education and Technology. Jorge Oteiza represents one of the most important artists in the Spanish modern art (Alvarez-Martinez, 2003; Pelay, 1978). His sculptures move from at the vanguard art such as cubism or constructivism to his proper mathematical / philosophical concepts such as negative aesthetics (Alvarez-Martinez, 2003; Echeverria-Plazaola, 2012). Such concepts make the learning process at school complex and this is what motivates the didactics section of Oteiza's museum to look for new educational tools (Urtasun, 2006).

Therefore, we hypothesised that the design of educational mini-games would help students and visitors understand such abstract concepts. Regarding the technology, current paradigms in Human-Computer Interaction (HCI) look for new technology means that propose intuitive interfaces via motion-based touchless interactions, also known as Natural User Interfaces (NUIs). Some evidence showed that these new interfaces are engaging and may also support learning (Hsu, 2011; Lee et al., 2012). One of the most common device that implements NUI is the Kinect, which is a device developed by Microsoft that detects 3D positioning and orientation of users' skeleton. The Kinect is affordable, compact and easy to use. Thus, this technology would allow the use of the application either at the museum or at schools. Furthermore, there are few evidences that explore the use of NUIs in school settings.

The following section surveys the existent projects that use NUIs in VM applications. Then, the educational tool is described as well as its design process. The framework is composed of four activities related to three sculptures / concepts of the artist. The digital tool was evaluated at three levels of education: primary school, secondary school and educational practice at University. Finally, the results are detailed and discussed. Thus, this study aims to evaluate the impact of an educational tool that can be used at schools to enhance the visit of the museum.

2. RELATED WORK

Virtual Museum applications have been widely researched. A recent review (Sylaiou et al., 2009) analysed an extensive list of VM regarding their technology (Web, Virtual / Augmented / Mixed Reality, haptic devices). Besides, Yiannoutsou et al. (2009) outlined three categories of VM that use mobile technology: (i) applications that only deliver information to the visitors (Kuflik et al., 2011); (ii) applications that enrich the interaction between users and exhibits (Chen & Huang, 2012; Coenen et al., 2013); and (iii) applications that are designed around a pedagogical task (Petridis et al., 2013). Since the release of the Kinect in 2011, research in HCI has actively looked for the use of body gestures to interact with virtual museum content. Contrasting with the above classification (Yiannatsou et al., 2009), VM applications that use NUIs mostly aimed at either (i) improving the interaction between users and exhibits or (ii) teaching educational content at museums.

Regarding the first category, the applications provided experience to visitors by observing and discovering ancient sites or relics. For instance, Hsieh et al. (2014) proposed an interaction with the past via the control of users' breathing. In fact, their system was able to recognize when users inhaled or exhaled by focusing on the chest. Thus, participants could play with the evolution of the Mao-Kung Cauldron by moving the timeline, and thus, helped them appreciate the value of the object. Schieck and Moutinho (2012) presented a new way to engage the visitors with museums by manipulating 3D sculptures. The interaction involved the whole body by projecting users' body movements to the virtual object, which extended the conventional ways of how people used to engage with existing museum settings. Şen et al. (2012) offered re-discovering the Vrouw Maria wreck to the visitors via a virtual environment which reconstructed the ship based on historical documents. The users were able to explore the scene by moving one arm. With the same idea, Pescarin et al. (2013) proposed an extended grammar of gestures to explore cultural heritage within virtual environments such as an Etruscan's tomb.

However, such virtual museum exhibitions do not fulfil all their potential by simply presenting virtual objects and descriptions (Petridis et al., 2013). For instance, Rivera-Gutierrez et al. (2014) exposed in a museum of science a physical exhibit where visitors were able to learn about public health via mini educational games. Yoshida et al. (2015) proposed a pedagogical mini game designed for children (10-12 years old) to support learning about paleontological era. Although the project is in its early stage, the preliminary study showed positive insights of enhancing the interests of the learners. Mora-Guiard and Pares (2014) taught the concept of nanoscale to children (11-13 years old) via an exhibit that 'miniaturises' the body over a huge surface of 10x4.5m. They showed that full-body experiences provided a better sense of scales to children. Targeting at a younger public (4-7 years old), Paul et al. (2015) focused on promoting creativity and collaboration. The exhibition consisted on matching alphabet letters displayed on the screen with the projection of the body. Although no formal evaluation was led, users' participation and involvement revealed an interesting potential.

3. VIRTUAL MUSEUM APPLICATION: OTEIZA IN MOTION

3.1. DESIGN PROCESS

The Oteiza's museum especially gives importance to the dissemination of J. Oteiza's work to children. Consequently, the museum created a didactics section which is in charge of developing activities and relationship with schools. This project "*Oteiza para tod@s*" aimed to disseminate J. Oteiza's work by combining Art, Education and Technology. Thus, to carry out such a multidisciplinary project several sessions were designed with stakeholders from different background: two researchers in Computer Science, one researcher in Art and Education, and the head of the didactics section of the Oteiza's museum.

First, the researchers visited the museum and were guided by the head of the didactics section. The tour was directed according to the different periods of the artist's life. Thus, the most representative sculptures of each artistic movement were thoroughly explained with their corresponding artistic style as well as the messages that J. Oteiza wanted to transmit. The visit lasted approximately two hours. At the end of the session, each stakeholder was asked to list a number of sculptures that had aroused their interests.

Therefore, the objective of the second session was to select which sculptures and concepts would be digitalised. The session took place in the museum where the stakeholders shared their corresponding list with the reasons why they chose these sculptures. The head of the didactics section confirmed and corrected the researchers' interpretation of the artist's concepts. The selection of the final sculptures was decided by the common stakeholders' interests, the technical feasibility estimated by the researchers' point of view, and the potential added-value that VR can provide regarding the classic activities organised by the didactics section. Thus, the final selection was reduced to three sculptures described in the following section.

Finally, the last session aimed to describe activities related to the corresponding concept of the sculptures. In order to optimise the session, the lead researcher (first author) proposed a scenario for each of the activities as a starting point. Each scenario defined a specific task to complete and elements of interaction. Then, for each activity, the ideas were discussed and adapted until all the stakeholders agreed on the main plot and features. The activities are described in the following section.

The software was developed using C#, the Microsoft Kinect SDK and GoblinXNA as rendering engine. It was decided that the games would not diffuse any sound because it can be disruptive in both school and museum environment (Economou, 1999).

3.2. MINI GAMES

3.2.1. NEGATIVE AESTHETIC VIA SUBTRACTION

The first activity was inspired of a permanent exhibit which is exposed in Pamplona, Spain. The sculpture had been built by removing spherical matters which resulted in a two-column shape (see Figure 1). The concept behind this sculpture, however, is the negative aesthetic. Therefore, it is important to focus the attention not only on the sculpture but also on the invisible matter generated by this latter. In order to explain this first concept, the mini game moves the users' point of view around a virtual reproduction of the sculpture (not strictly identical to the original one). Then, the objective is to find out of four possibilities the empty space that fills the invisible matter (see Figure 1). To select an option, the users should point at the screen and move the projection of the hand towards the corresponding icon at the top of the screen. Once the solution has been found, the invisible matter is highlighted.

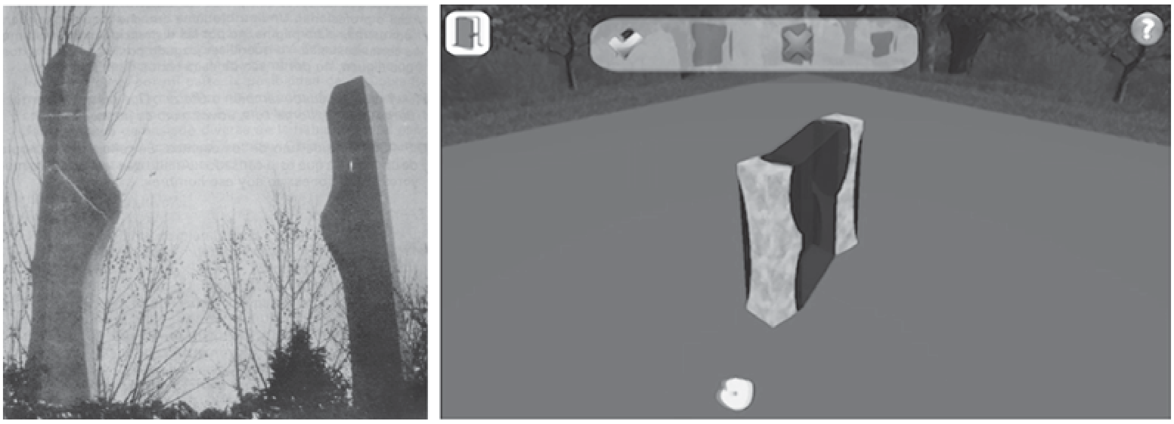

Figure 1: On the left, picture of the real sculpture. On the right, screenshot of the corresponding activity

3.2.2. *NEGATIVE AESTHETIC VIA ADDITION*

The second activity was based on a sculpture created by addition of matter (see Figure 2). The concept behind this work is also negative aesthetic, although this time the invisible matter is not spherical but cubic. Since this sculpture was built by addition, the mini game offers similar mechanisms. The position and orientation of half of the piece is set in the scene with its invisible matter highlighted in green. The user manipulates the second part of the sculpture by using the *Crank Handle* technique, which is described in Chapter I (Bossavit et al., 2014). The corresponding invisible matter of this second piece is highlighted in blue to its final position within the final sculpture (see Figure 2). Thus, the user has to position and orientate this second half of the sculpture in order to encapsulate its corresponding invisible matter (highlighted in blue) while being in direct contact with the static bit. This final position will shape one and unique sculpture. Several sculptures are designed so that users will not perform the same one twice in a row. The task should be completed within a time range limit (40 seconds) otherwise the solution would be displayed once the time is over.

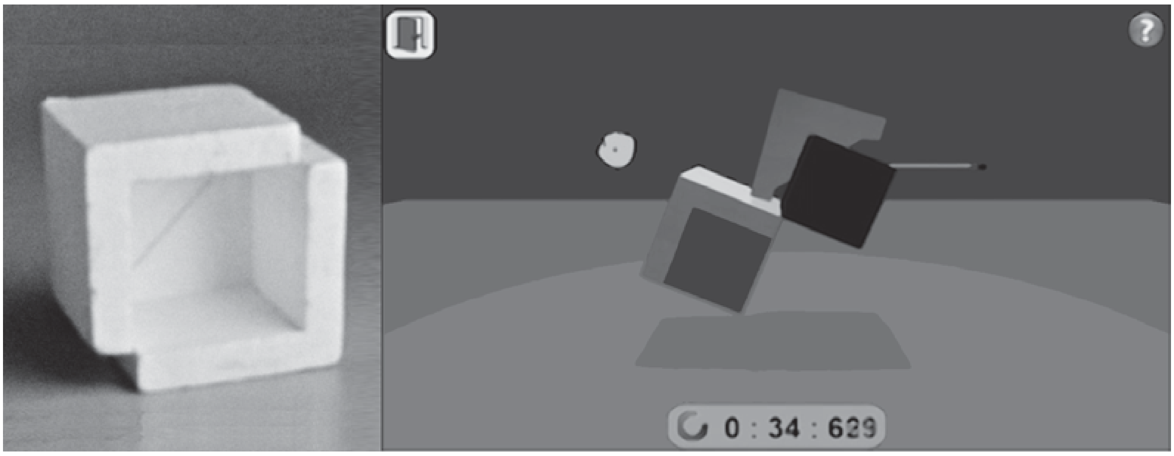

Figure 2: On the left, picture of the real sculpture. On the right, screenshot of the corresponding activity

3.2.3. *ACTIVATION OF SPACE AND TIME*

The third activity was based on a sculpture for which J. Oteiza had found inspiration in Pieter Mondrian's work. J. Oteiza represented the activation of the space by curving Mondrian's parallel and perpendicular lines which resulted in an opened spherical shape (see Figure 3). It is important to state that the sphere is only defined by its negative aesthetic. Furthermore, the concept behind this work remains somehow open to interpretation because, and in accordance with the didactics section of the Oteiza's museum, the strips would not only represent the surface of the negative sphere. Indeed, each strip would also stand for a 'negative' sphere at one specific time. As a result, the mini game was designed with two stages. During the first phase, the user is presented several 'flat' patterns and has to find which one fits the model (see Figure 3). The user can manipulate a virtual ray, which is the extension of the arm, by pointing at the screen. Once the virtual ray intersects a starting point of a strip, which is represented by a small sphere, the user can activate the concept of space by closing the hand. Thus, an animation, which shows how the 'flat' pattern converts into the final sculpture, would be launched. At the end of this first stage, the strips are animated around the negative sphere. Each strip moves independently at different speeds. Then, the user has to reconstruct the original sculpture by rotating the strips one by one using the *Crank Handle* technique (Bossavit et al., 2014).

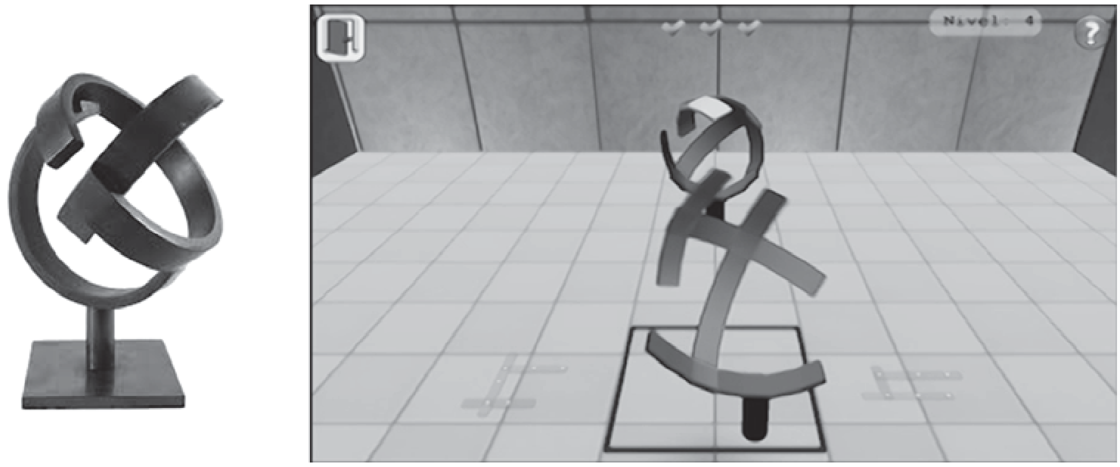

Figure 3: On the left, picture of the real sculpture. On the right, screenshot of the corresponding activity

3.3. EXTERNAL VALIDATION

Once the three activities were implemented, a session was set in the Oteiza's museum with the vice director of Oteiza's museum and three professors in art history (two from the University of Barcelona in Spain and one from the Public University of Navarre in Spain). The session was organized in three stages. First, all the stakeholders visited the museum (approximatively one hour). Then, the researchers explained the different activities and how to interact. The stakeholders were given the possibility to interact as well (about one hour). Finally, the participants provided feedback in order to improve the activities in terms of usability and pedagogy.

Overall, all the stakeholders agreed that the activities did explain J. Oteiza's abstract concepts. However, they felt like the objective of the game was to replace the visit of the museum. As a result, they accentuated that this digital tool should be a complement to the visits, as it was also suggested by Sylaiou et al. (2009).

Regarding usability, the stakeholders considered that the tutorials, which explained how to interact with the software, embedded too much text. Instead, they suggested replacing the text by simple animations. This was also highlighted by Antoniou et al. (2013). Furthermore, a professor commented that apart from being more visual, this would definitely separate interactions from pedagogical aspects.

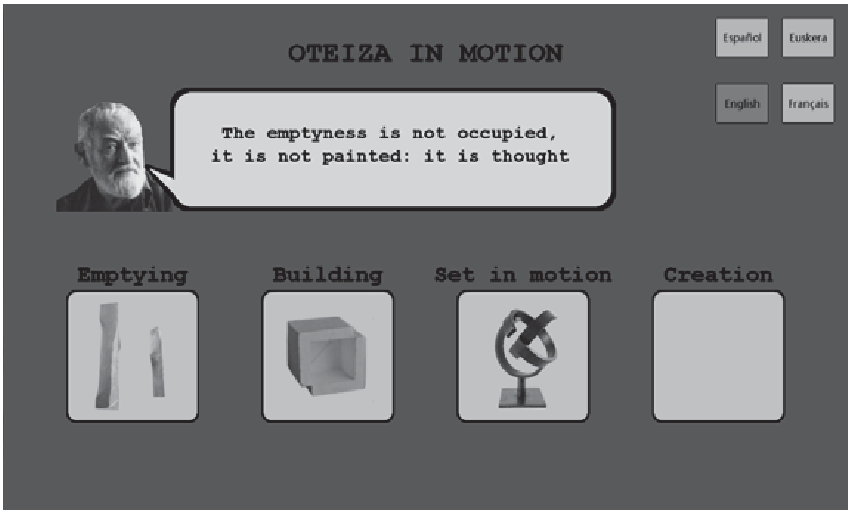

Figure 4: Main screen of the application with J. Oteiza's quotations and access to the different activities.

In terms of pedagogical improvements, all the stakeholders agreed that it would be interesting to integrate more of Oteiza's personality within the software. Thus, we decided to add a new quotation of J. Oteiza every time the users enter main screen (see Figure 4). Regarding the first activity, they thought that the representation of the invisible matter between the two columns was too linear instead of being composed of spherical shapes. Consequently, we added a short animation that transforms the linear space between the two columns into spherical shapes, which would be the real representation of the invisible matter. Finally, the activities all lacked the presence of creativity. This was also suggested by Kuo & Yang (2009) who called for adding artistic teaching materials into E-learning programs. Thus, they suggested that users should be able to create their own sculpture based on the concept outlined by the software. Consequently, we added a new activity which is described below.

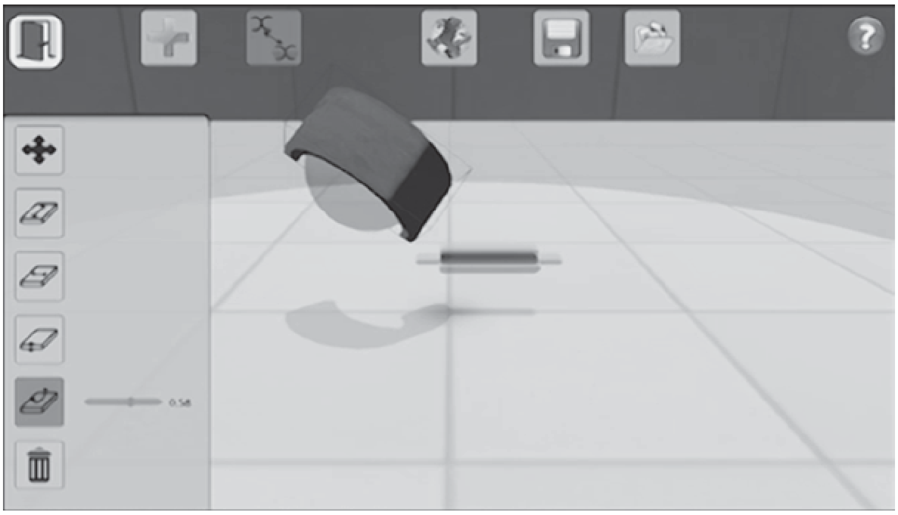

Figure 5: Screenshot of the last activity which focuses on the creation of a sculpture that is based on the concepts learnt from the other three activities.

Thus, the last activity allows users to add and edit pieces by changing their size (length, width and thickness), their curvature and their position / orientation. Users can manipulate the pieces separately or together. They are also offered the possibility to observe the invisible matter that the sculpture creates (see Figure 5). The 3D manipulation is done via the *Crank Handle* technique (Bossavit et al., 2014) and the parameters that change the shape of the piece are controlled by sliders. We proposed two techniques to manipulate the sliders: (i) via a constant step by touching the shoulders with the hand; (ii) via an interpolated value. For this second technique, an unfolded user's arm stands for the slider while the other hand represents the tick between the hand and the shoulder (Shoemaker et al., 2010).

4. EVALUATION AT SCHOOLS

This evaluation study seeks for the impact of technological input on the illustration of artistic concepts at schools. However, the design and development of this educational tool does not intend to replace the visit of the museum but to enhance it. Consequently, comparing the impact of this tool as an alternative to the visit at the museum is beyond the scope of this evaluation.

4.1. PARTICIPANTS

Schools usually organise field trips to museums from primary to University. Therefore, participants from different ages and educational stages had been recruited for this study.

- The first group was composed of 57 primary pupils from a state school of Pamplona, Spain. Participants' mean age was 7.14 (SD=0.43) which included 21 male and 36 female. 28 participants played with the software (active) and 29 just watched (passive).

- The second group was composed of 60 secondary pupils from another state school of Pamplona, Spain. Participants' age was 14.55 (SD=0.58) which included 24 male and 36 female. 19 participants played with the software (active) and 41 just watched (passive).

- The last group was composed of 21 students in educational practice at the Public University of Navarre, Spain. Participants' mean age was 22.1 (SD=2.67) which included 2 male and 19 female. 13 participants played with the software (active) and 8 just watched (passive).

4.2. PROCEDURE

Each group followed the same procedure. None of the educational institutions teaches content about J. Oteiza in their programme, thus, according to the teachers, the class before the visit to the museum was an introductory session about the artist. At the end of this introductory session, the teachers gave out a pre-test questionnaire (see further details in the next section)

Afterwards, the schools visited the Oteiza's museum during approximatively one hour each. The visit was guided by the head of the didactics section of the museum. The tour started with a presentation of J. Oteiza who is a reference as artist and intellectual of the twentieth century. Then, the visit continued on the permanent exhibits with the most representative sculptures. Not only does Oteiza's work open to concepts such as figurative/abstract art, movement/space, or visible/non-visible matter, but it also refers to social art and sculpture-architecture relationship.

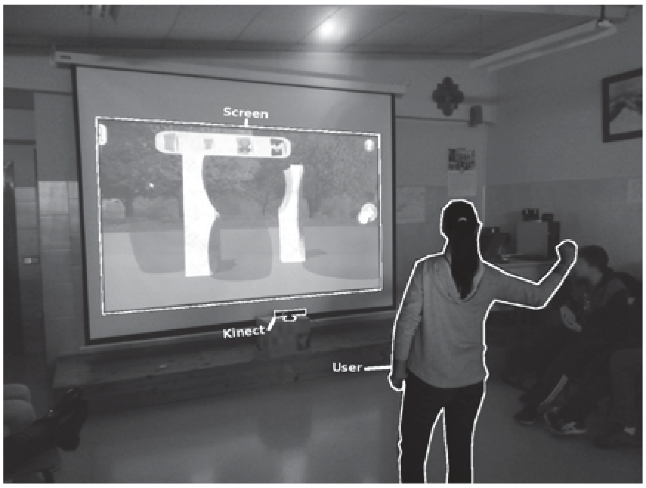

Figure 6: Overview of the apparatus with all the elements outlined (screen, Kinect and user).

Later, within a range of one to four weeks after the visit of the museum (according to the availability of the schools), the researchers were contacted to evaluate the use of the software with the students during one of the mainstream teaching session at the school. Thus, we setup two installations in the same room so that participants had more opportunities to play. The game was projected onto a wall with the Kinect under it and the interacting student was placed at about 2 meters from the screen (see Figure 6). The session lasted 50 minutes during which the students could voluntarily test one out of the four activities for about 40 minutes in total. The researchers were there to help the users interact if required.

For the last 10 minutes, the participants were asked to fill a post-test, which was the same as the pre-test although the answers were inverted, plus a small questionnaire about their experience (see further details below).

4.3. RESULTS

This user study aimed to validate the impact of the educational tool on the learning process either on the *micro level* and the *meso level* (Vavoula et al., 2009).

4.3.1. MICRO-LEVEL

The *micro-level* surveys the participants' experience mostly towards the technology via a usability and utility questionnaire. Thus, we provided a 5-Likert scale questionnaire with 12 questions (see Appendix IX). Four questions were related to motivation (1-4), four about usability (5-8) and four about utility (9-12). The questionnaire was given out after testing the mini-games.

Table I: Statistic results of the *Micro-level* (significant differences are highlighted in bold)

Dependent variable	Independent variable	Mean	SD	Result	Sig
Motivation	**Male**	**13.91**	**3.18**	**T(134) = -3.66**	**p < 0.05**
	Female	**15.77**	**2.6**		
	Active	**15.81**	**2.68**	**T(134) = 2.4**	**p < 0.05**
	Passive	**14.61**	**3.03**		
	Primary	**16.5***	**2.98**	**F(2,133) = 15.42**	**p < 0.001**
	Secondary	**13.76***	**2.52**		
	Educational practice	15.31	2.05		
Usability	Male	12.04	3	T(134) = -0.63	p > 0.05
	Female	12.38	2.97		
	Active	12.57	3.28	T(134) = 1.06	p > 0.05
	Passive	12.02	2.71		
	Primary	12.12	3.31	F(2,133) = 0.87	p > 0.05
	Secondary	12.6	2.68		
	Educational practice	11.63	2.79		
Utility	**Male**	**13.55**	**2.95**	**T(134) = -2.28**	**p < 0.05**
	Female	**14.7**	**2.72**		
	Active	**14.88**	**2.1**	**T(134) = 2.07**	**p < 0.05**
	Passive	**13.87**	**3.25**		
	Primary	**14.98***	**2.39**	**F(2,133) = 3.31**	**p < 0.05**
	Secondary	**13.65***	**3.19**		
	Educational practice	14.36	2.56		

The analysis of internal consistency reliability of the questionnaire revealed a Cronbach's alpha coefficient at 0.695. The Cronbach's alpha coefficient ranges between 0 and 1 and an acceptable minimal reliability value is 0.7 (Nunnaly, 1978).

Table I shows the results of the *two-tailed independent samples t-tests* performed on the participants' score about *Motivation*, *Usability* and *Utility* regarding their gender (Male or Female) or the fact they had interacted with the software (Active or Passive). Moreover, a *one-way ANOVA* was performed to compare these three dependent variables between the three groups of participants (independent variables: *primary*, *secondary* and *educational_practice*). A pairwise comparison adjusted by a Bonferroni correction was applied when a significant difference appeared (see Table I).

4.3.2. MESO-LEVEL

The *meso-level* examines the learning experience. Therefore, a multiple choice questionnaire composed of ten questions with four possible answers each (see Appendix X) was provided. The first fifth questions (*partI*) were related to the author himself and the second half (*partII*) quizzed about the Oteiza's concepts treated by the software. The questionnaire was given out at the pre-visit session and after testing the mini-games.

Thus, a *paired t-test* was performed on the results of the pre- and post-tests for each group of participants in order to indicate whether the learners showed significant gains. Then, three dependent variables were defined, which represent the percentage of increased knowledge:

i. *Learning = ((post-test – pre-test) / 10) * 100*

ii. *Learning_Oteiza = ((post-test_partI – pre-test_partI) / 5) * 100*

iii. *Learning_Concepts = ((post-test_partII – pre-test_partII) / 5) * 100*

Table II: Statistic results of the *Meso-level* (significant differences are highlighted in bold)

Group	Dependent variable	Independent variable	Mean	SD	Result	Sig
Primary	Questionnaire	**Pre-test**	**2.57** (/10)	**1.55**	**T(56) = 8.8**	**p < 0.001**
		Post-test	**4.49** (/10)	**1.96**		
	Learning	Male	16.6 (%)	17.12	T(55) = -0.862	p > 0.05
		Female	20.5 (%)	16.02		
		Active	**14.6** (%)	**13.7**	**T(55) = 2.08**	**p < 0.05**
		Passive	**23.4** (%)	**17.7**		
	Learning_Oteiza	Active	17.14 (%)	22.25	T(55) = 0.76	p > 0.05
		Passive	22.06 (%)	26.37		
	Learning_Concepts	**Active**	**12.14** (%)	**19.88**	**T(55) = 2.29**	**p < 0.05**
		Passive	**24.82** (%)	**21.81**		
Secondary	Questionnaire	**Pre-test**	**4.88** (/10)	**1.51**	**T(59) = -9.71**	**p < 0.001**
		Post-test	**6.98** (/10)	**1.38**		
	Learning	**Male**	**14.58** (%)	**16.14**	**T(58) = 2.53**	**p < 0.05**
		Female	**25.27** (%)	**15.94**		
		Active	18.42 (%)	18.63	T(58) = 0.81	p > 0.05
		Passive	22.19 (%)	15.89		
	Learning_Oteiza	Male	19.16 (%)	16.12	T(58) = 1.35	p > 0.05
		Female	25.55 (%)	18.88		
	Learning_Concepts	**Male**	**10** (%)	**26.34**	**T(58) = 2.22**	**p < 0.05**
		Female	**25** (%)	**24.31**		
Educational Practice	Questionnaire	**Pre-test**	**7.00** (/10)	**1.51**	**T(20) = 3.11**	**p < 0.01**
		Post-test	**8.19** (/10)	**1.28**		
	Learning	Male	10 (%)	14.14	T(19) = -0.15	p > 0.05
		Female	12.1 (%)	18.12		
		Active	11.53 (%)	18.63	T(19) = -0.11	p > 0.05
		Passive	12.5 (%)	16.69		
Inter groups	Learning_Oteiza	Primary	19.64 (%)	24.34	F(2,135) = 0.4	p > 0.05
		Secondary	23 (%)	17.97		
		Educational practice	20 (%)	20		
	Learning_Concepts	Primary	18.59 (%)	21.66	**F(2,135) = 3.38**	**p < 0.05**
		Secondary*	19 (%)	**26.4**		
		Educational practice*	**3.8** (%)	**24.99**		
	Learning	**Active**	**15.16** (%)	**16.41**	**T(136) = 2.27**	**p < 0.05**
		Passive	**21.66** (%)	**16.78**		
		Male	15.31 (%)	16.26	T(136) = -1.77	p > 0.05
		Female	20.65 (%)	16.98		

Therefore, a *two-tailed independent samples t-test* was also completed in order to reveal a significant effect on these dependent variables according to the participants' gender (Male or Female) or the fact of they had interacted with the software (Active or Passive). Furthermore, a *one-way ANOVA* was performed to compare these three dependent variables between the three groups of participants (independent variables:

primary, secondary and *educational_practice*). A pairwise comparison adjusted by a Bonferroni correction was applied when a significant difference appeared (see Table II).

5. FINDINGS AND DISCUSSION

This study explores the use of technological input to support museums for shedding light on artistic concepts at schools. People's behaviour and expectation regarding digital exhibits might vary from the environment. For instance, in museums visitors tend to understand and learn through active participation (Kampouropoulou et al., 2013). However, in this study, students who did not interact directly with the software learnt significantly more (see Table II). This might be explained by humans' social boundaries. Indeed, the students interacted in front of their colleagues, which might be a very stressful experience due to the importance we give to the judgment of people that surround us (Feinstein, 2004). Thus, most of the students' attention might have focused on the way they behaved instead of the task by itself. Furthermore, the stress is higher when people are socially closer. In museums, this pressure is lowered and some people manage to negotiate these social boundaries (Schieck & Moutinho, 2012; Paul et al., 2015). Another reason that could explain why the students learnt more when they were not active is the cognitive load that was required by the interface. Indeed, all the participants did not score high usability of the system (see Table I), which means that they found it relatively difficult. The activities were designed with the *Crank Handle* technique (Bossavit et al., 2014), which allows manipulation of six degrees of freedom (three for translation and three for rotation). Although the technique is easily understandable because it is based on a common metaphor, which is rotating a crank handle, the accuracy of the Kinect requires users to perform clear gestures. Thus, this technique does entail some training that the children did not have. Consequently, it might be judicious to provide more assistance to the users by limiting the complexity of the gestures

(Pescarin et al., 2013; Yoshida et al., 2015) as well as the amount of actions (Hsieh et al., 2014; Mora-Guiard & Pares, 2014).

Despite the fact that passive students learnt more than the active ones, all the groups increased their knowledge significantly (see Table II). An interesting outcome is that female participants were the most engaged, they found the experience useful and they learnt the most. This might be explained by the fact that girls tend to prefer games that require cognitive skills instead of destruction-like games (Pasek, 2008; Pelletier, 2008). The overall experience aimed to provide information about the artist as well as his artistic concepts. Concerning content about J. Oteiza, all the participants improved similarly (see Table II). However, the concepts of invisible matter and spatiotemporal dimensions may be already assimilated by adults. Indeed, students from educational practice showed a very small progression (see Table II). The pupils from secondary school learnt the most. Surprisingly, the teenagers revealed the least motivation and just found the experience somehow useful (see Table I). It has already been observed that enjoyable experiences with museums and the amount of cognitive learning might vary regarding the group of participants (Griffin, 2004). On the other hand, not only did the pupils from primary school reveal the highest rate of motivation (see Table I) but they also improved significantly their understanding of these notions (see Table II). This puts forward the fact that children from 7-8 years are, indeed, able to learn complex concepts as suggested by Antoniou et al. (2013). Thereafter, the primary school teacher commented that the session had motivated her and she organised a workshop where children could sculpt and collage works related to J. Oteiza's concepts (See Figure 7).

6. CONCLUSIONS AND FUTURE WORK

A series of mini games that shed light on Jorge Oteiza's artistic concepts to children have been co-designed with the didactics section of a museum. The framework was evaluated by children from primary and secondary schools and students from educational practice. Overall, participants did learn more about Jorge Oteiza as well as his artistic concepts, including children from primary school. Furthermore, the study showed that girls were more engaged and learnt the most. Contrary to visits at museums, participants who did not interact were more likely to understand and increase their knowledge. This might be a consequence of using Natural User Interfaces at school. Indeed, participants had to interact alone in front of all their friends, which obliged them to negotiate their social boundaries beyond shyness and stress. Moreover, the interaction techniques should be limited to simple gestures so that participants can focus more on the educational content. Finally, this study looked at the *micro-* and *meso-level*, which examines respectively the users' experience towards the technology and their learning experience. It would also be interesting to analyse the *macro-level* by involving teachers in order to examine the longer term impact of the project.

Figure 7: Pictures of the workshop of the pupils from primary school

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GENERAL DISCUSSION

This thesis looks at the intersection of two important research fields, Human-Computer Interaction (HCI) and Special Education. Although important progress has been made in both areas respectively, the integration of HCI outcomes to educational contexts remains at an early stage. The original research presented in this thesis is based on the hypothesis that Natural User Interfaces (NUIs) support engagement and motivation in learning via the use of the body (Hsu, 2011; Latham & Stockman, 2014). In line with this, new interaction techniques have been designed, implemented and evaluated in order to explore the potential of NUIs (see Chapter I and II). These techniques have been embedded in the design and development of three different educational tools which have been evaluated within different educational contexts (see Chapter III-V). Therefore, this section discusses the hypothesis and objectives of this thesis by following a transversal reading.

<u>*NUIs to support children with SEN*</u>

The first key point to take into consideration is the usability of NUIs. Indeed, NUIs are recognised to be more ergonomic than traditional interfaces (Grandhi et al., 2011; O'Hara et al., 2013). This might be explained by the concepts of intuitiveness and transparency that are embedded within the etiquette 'NUI'. The concept of intuitiveness implies that rational thoughts are not involved when performing an action. Humans have an inherent ability to determine the relative position, the applied strength and the velocity of their own body, which is called proprioception (Boff et al., 1986). Furthermore, humans' brain has a separate mechanism that automatically guides the person to touch different parts of the body (Cocchini et al., 2001). As a result, the proprioception might be considered as one of the reasons that explain the intuitiveness of NUIs since the whole body is involved. The results obtained in the study with the *Body Menu* (see Chapter I) supports this idea. Three techniques that implemented three different level of involvement of the body were compared. The results showed that the interaction with the two techniques that required proprioception the most (*Body Menu* and *Marking Menu*) was faster and more accurate than the technique which did not (*Linear Menu*). It is important to emphasize that the *Linear Menu* remains the most common available interface, which means that the participants were expected to interact better. This makes the findings in the opposite direction even more compelling. In addition, the concept of transparency refers to the capacity of forgetting that the interaction technique exists. This means that an action should be familiar enough to become automatic (Shank & Gebler, 2002). In HCI, the mechanism of metaphors is generally used to translate an unfamiliar domain to common gestures (Bowman et al., 2012) which are part of our daily routine (Grandhi et al., 2011). Thus, it can be considered that the use of metaphors might increase the transparency of NUIs since in the study of the three manipulation techniques (see Chapter II), which implemented three common metaphors (crank handle, handle bar and grasping an object), all the participants understood quickly the use of the techniques and interacted without any difficulty. In conclusion, I argue that NUIs are more ergonomic than classical interfaces because of the transparency and intuitiveness that are implemented by the use of metaphor and proprioception respectively.

The second key aspect to take into consideration about NUIs is their accessibility. Children with special educational needs present a great diversity of motor and cognitive disabilities and thus, different support needs. Beyond the physical interaction, motor disabilities may hinder the use of applications (Bryanton et al., 2006) so the interfaces should take into account children's motor skills. Establishing specific guidelines would eventually help with the design (Maike et al., 2015). Nonetheless, there is still a gap between the theory behind NUIs and their implementation. This thesis implements the NUIs with the Microsoft® Kinect which is, to date, the most affordable and compact device that entirely detects the users' skeleton. The Kinect is built with low-resolution cameras which have an effect on the accuracy of the skeleton detection. Therefore, it is important to highlight that the discussion around accessibility is limited to the implementation of NUIs via the

Microsoft® Kinect. Among the limited evidence that the Kinect can be adapted to motor skills, Gerling et al. (2016) proposed a set of gestures to enable children in wheelchairs to play videogames and argued that the Kinect was an accessible device. We also support this idea with the results of the study on the adaptive framework (see Chapter III). The evaluation of the application, which has been tested by six children with different motor and cognitive skills, showed that a set of interaction techniques for a same action would allow more children to play with activities. This leads to the conclusion that with a proper implementation of the interfaces, the frameworks implemented with the use of the Microsoft® Kinect can be considered as adaptive assistive technologies.

Finally, this thesis is based on the hypothesis that NUIs support learning experiences. Indeed, studies conducted with typically developing students showed that the action-centred mechanics of NUIs are engaging (Kynigos et al., 2010) and improve students' interaction in classroom settings (Lee et al., 2012), which may support learning (Hsu, 2011). Unfortunately, there are limited studies that involved participants with SEN and these few mostly focused on the autistic spectrum (Bartoli et al., 2013; Saiano et al., 2015). Latham & Stockman (2014) showed that 'hands-on' kinaesthetic approaches do support learning effects for children with ASD. This latter, indeed, provides good insights; however, the evidence is not strong enough to be generalised to the use of NUIs which have no haptic feedback. For instance, the use of the *Body Menu* did not help the teenagers with high functioning autism learn more Geography-specific content than the use of the mouse (see Chapter IV). Thus, stronger evidence is still required to argue that NUIs might support learning to children with special needs. Nevertheless, in the study with the *adaptive framework* (see Chapter III), it was observed that the use of NUIs did increase the motivation of the participants; especially when one of them improved the speed control of his arms in order to interact better. Therefore, this gives good insights to deepen this field since motivation and engagement has a demonstrated relationship to learning (Keen, 2009; Sheldon & Biddle, 1998).

Designing educational tools regarding the educational context

In this thesis, three technology-enhanced learning frameworks have been developed within three different contexts following distinct design approaches. Although research in the Education field outlines several and varied design approaches to support the creation of new technology-based projects (Benton & Johnson, 2015), their implementation is typically sensitive and closely related to the context in which these are undertaken. Educational projects typically aim to improve some specific skills that belong, at least, to one of the four learning domains: (i) *Cognitive* which develops the capacity of memorising, understanding, analysing, applying knowledge, etc. (Bloom et al., 1956); (ii) *Affective* which consists in receiving and responding to stimuli, valuing, organising and internalising values, etc. (Bloom et al., 1956); (iii) *Psychomotor* which involves the perception, origination, adaptation, mechanisation, etc. of motor skills (Simpson, 1972); and (iv) *Interpersonal* which promotes relationship with others by seeking and giving information, building and supporting relations, etc. (Perencevich et al., 2007). Thus, this section discusses the methodology and impact of the educational outcomes regarding the end-users (*Who*), the educational context (*Where, When*), the design approach (*How*) and the outcome (*What*) (Mazzone et al., 2011).

The first scenario addressed in this thesis involves children with severe cognitive and motor disabilities. This is a very challenging, and often under-researched, domain where the role of children is usually limited to the use of educational tools rather than being drawn into their design. This can be explained by the fact that most of these children are non-verbal, which makes their participation as co-designers very difficult. Consequently, in order to carry out educational projects, researchers usually consider in the design decisions the point of view of carers, teachers (Lopez-Mencia et al., 2010; Zarin & Fallman, 2011) and parents (Sampath et al., 2013; van Rijn & Stappers, 2008). Regarding the methodology used in this context, the stakeholders are involved either in an Iterative Design approach (Lopez-Mencia et al., 2010; Zarin & Fallman, 2011) which mostly concerns carers and teachers, or in a Participatory Design approach (Sampath et al., 2013; van Rijn & Stappers, 2008), usually involving parents. In the first study of this thesis (see Chapter III), an Iterative Design approach was followed with the teachers who guided and improved the functionalities of the technology through their knowledge about their pupils' needs. Due to the severe level of disabilities in this educational context, the learning objectives typically concern *affective* and *psychomotor* skills. Indeed, most of the activities are grounded in cause-effect reactions after a physical stimulus (Larsen & Hedvall, 2012; Sampath et al., 2013; Zarin & Fallman, 2011). This is also the case with the *adaptive framework* where the educational content was extracted from the curricular project of the special school based on the body and creativity (see Chapter III).

The second scenario involves youth with high functioning autism. This is a very different setting where children have sometimes been involved in the design of the educational tools through Participatory Design approaches (Benton & Johnson, 2015). Thus, children can undertake up to four roles: *user, informant, tester* and *co-designer* (Druin, 2002) in order to explore, understand and elaborate new ideas (Benton et al., 2012; Frauenberger et al., 2012; Malinverni et al., 2014; Parsons & Cobb, 2014). Researchers typically recommend the use of sensitive and creative tools to support the design sessions with children (Malinverni et al., 2014; Millen et al., 2011). However, in the second study of this thesis (see Chapter IV), the teenagers, who were involved, did not require such elaborated tools, though this was a finding that emerged through the study rather than something that was planned *a priori*. Indeed, the approach was more informal owing to the support of the teachers who knew the pupils very well. This highlights the importance of the role of adults (teachers, carers, eventually parents), which is barely discussed in the literature (Benton & Johnson, 2015). This is surprising given that their participation is crucial to facilitate, motivate and support the young stakeholders. The fact that children with high functioning autism have an average or above-average IQ widens the potential learning outcomes to the four learning domains outlined above: *cognitive*, *affective*, *psychomotor* and *interpersonal*. Indeed, most of the projects focused on social interaction which is one of the impairments of the autism spectrum disorder (American Psychiatric Association, 2013). Regarding the *cognitive* aspect, the development of academic skills is still underexplored and should not be limited to Mathematics (Benton et al., 2012), English and literacy (Pennington, 2010). For instance, learning about Geography was decided by one of the participants since it is a subject that he was struggling with.

The last scenario expands the context of enquiry of this thesis since it targeted children from mainstream schools and collaborated with a museum, which is an informal learning context. Museums are usually looking forward to engaging their public with new ways of exhibitions and typically engage different stakeholders in the design of these new activities. In this informal learning context, previous research shows that the selection of the stakeholders and type of collaboration depends mostly on the specific objectives of the project. For instance, when museums want to create new physical exhibits (Axelsen et al., 2015; Dindler et al., 2010) or digital ones (Culén et al., 2013; Roussou & Ave, 2007), the research projects engage typically developing children in Participatory Design (PD) approaches. The PD sessions typically consist of an introduction to the corresponding museum field, followed by physical activities to elaborate ideas such as handicrafts (Culén et al., 2013; Taxén, 2004) or Lego plastic building blocks (Axelsen et al., 2015). Moreover, when museums want to transfer knowledge (Dubois et al., 2011; Şen et al., 2012) or enrich the interaction between users and exhibits (Ciolfi et al., 2016; Coenen et al., 2013; Wishart & Triggs, 2010), the involvement of curators and ergonomists in User-Centred or Co-Design approaches shows good results. The third study of this thesis (see Chapter V) was in line with these good practices by engaging the head of the didactics section of the museum in a Co-design approach with several brainstorming sessions (Dubois et al., 2011; Ciolfi et al., 2016) in order to convey and explain Jorge Oteiza's artistic concepts. Indeed, the outcome of such collaboration helped the participants, including children from primary schools, increase their understanding about abstract concepts such as the negative aesthetic.

Overall, in this research, collaboration with stakeholders from these three different educational settings has been crucial in the design and development of educational tools that are adapted to the needs and skills of children. It is important to bear in mind that, whatever the type of collaboration, equity in partnership is not about all partners sharing all decisions, but about respectfully managing the different expertise that each partner can bring (Parsons & Cobb, 2014). Moreover, the role of teachers / parents / carers remains essential in terms of facilitation, motivation and support of the youth stakeholders (Benton & Johnson, 2015). Finally, being flexible in terms of time, resources, expectations, progression, etc. is the key message when working in a multidisciplinary field with different stakeholders (Davis et al., 2010; Frauenberger et al. 2012). This thesis provides rich insights into these processes and highlights the valuable contributions that different stakeholders can make within a range of contexts, utilising different technologies. By providing such detail about methods, roles, and outcomes of these projects, this thesis contributes original knowledge to the field of HCI that can be applied, extended, and critiqued in further research.

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CONCLUSIONS / CONCLUSIONES / CONCLUSION

CONCLUSIONS

The works compiled in this thesis have focused on the design, implementation and evaluation of educational tools using Natural User Interfaces (NUIs). From the results presented, the following conclusions are drawn:

Exploration of the potential of Natural User Interfaces

1. The *Body Menu* competes with the *Marking Menu* and the *Linear Menu* in terms of task completion time, accuracy and usability.

2. The *Crank Handle* overcomes the *Grasping Object* and competes with the *Handle Bar* in terms of time task completion time, accuracy and usability.

3. NUIs increase motivation and engagement of the participants. However, stronger evidence is still required to argue that NUIs might support learning of children with Special Educational Needs (SEN).

Design and implementation of educational tools

4. The collaboration with teachers who know their pupils very well allows a better adaptability of the educational tools regarding children's motor and cognitive needs / skills.

5. The collaboration with teenagers with high functioning autism can be informal and does not necessarily require the use of structured or visual methods.

Evaluation of the developed tools in their corresponding educational context

6. The results showed that the *Adaptive Framework* could adapt to the children's skills and improve their motivation. Thus, the outcome can be considered an adaptive assistive technology.

7. The serious game designed with the teenagers with high functioning autism increases knowledge in Geography. However, the difference in level of competitiveness created tensions within the peer teams, which led to a decrease of engagement towards the task.

8. The series of activities related to Jorge Oteiza's sculptures enhances the visit to the museum in order to understand the corresponding artistic concepts; the girls increased their knowledge the most.

Personal reflections

This section outlines three limiting factors that I encountered in each of the three educational studies of this thesis. These aspects are not often discussed in the literature and I consider that it is important to reflect upon them. Since these reflections are personal, I have decided to write them in the general conclusions of this thesis.

The development of research projects for and with people with SEN requires a strong collaboration with different partners (teachers, students, parents…). Such relationships are crucial to explore new content as well as to validate the potential outcomes. Paradoxically, besides being the main strength of a research project, it is also its main limitation. Indeed, factors such as duration, place, or number of participants depend mainly on the partners' availability. Therefore, such factors limit empirical evaluations to case studies, and thus narrow the potential generalisability of the outcomes. Only few studies were able to evaluate medium-long-term impacts of educational tools. Consequently, it would be interesting to look for new solutions in order to have access to larger groups of participants for a longer period of time.

In addition, although the question of sustainability is not commonly discussed in the literature, it should be considered as a limitation. While the research areas recycle and extend knowledge in terms of methodology and design guidelines, the educational tools are usually abandoned once these projects end. This is understandable due to the fact that the collaborating entities are subject to specific programmes or obligations which do not let much space to new tasks. However, stakeholders spend a lot of time and effort in the design of such educational tools. Consequently, it would be interesting and important to look at how these educational outcomes could be more sustainable so that educational institutions could have access and use these in real settings.

Finally, although interactions with NUIs offer great potential for many areas of interaction and learning (motivation, engagement, awareness of the body, development of motor skills…), the maximum number of users at the same time is basically limited, even individualized. This is, naturally, restrictive in a school setting where classrooms comprise many students. Besides, the interaction space is about two square metres and spectators should be placed at least three meters from the Microsoft® Kinect in order to be out of range. As a result, researchers and schools may need to plan creatively and carefully for how such technology could be incorporated into their daily practices.

Future work

We have seen that Participatory Design (PD) is a powerful methodology that can reveal interesting insights in terms of outcomes and experiences. One of its major strengths is that children are involved in the design of activities that focus on their own needs. In relation to such a methodology, there are some projects and ideas that would be worth deepening in a future.

First, projects with PD focus mostly on the design of activities. However, in order to play with an activity, the users require specific interaction techniques to turn their physical actions into events that can be interpreted by the software. These interfaces are usually planned and developed for adults or typically developing children, which may not fit the real needs of children with SEN or disabilities.

Consequently, an important extension to the current work would be a project that focuses on the design of new interaction techniques (e.g. navigating within a virtual environment) by directly involving children with SEN via PD. Such an approach could provide more creative techniques that may also be more inclusive as well.

Second, PD projects with children with SEN barely focus on the development of an activity. Indeed, the outcomes, which are planned and sought by the researchers, usually stray from children's expectation. Nowadays, there are several visual programming programs especially designed for children such as Microsoft® Kodu or Scratch from the MIT. Studies with typically developing children showed that programming might increase engagement, problem-solving and programming skills. Besides, several competences such as game design (scenario, characters…), programming, and level design are required to carry out video games. As a result, it would be interesting to take advantage of this variety of activities and promote collaboration between young people on the autism spectrum via PD to design and develop their own serious game.

Finally, virtual reality (VR) environments have shown potential to support individuals with autism. Most of the projects in the field stemmed from the concept of veridicality and the medical model of disability which mainly concentrated the research on fitting the virtual world to the real one. However, decoupling the virtual from the reality to enable and empower features specific to VR remains underexplored. New spaces or scenarios in which children with autism feel more comfortable could be designed from their own perspective. Consequently, this would open interesting questions and help researchers understand better how the strengths and preferences of people with autism could be more effectively represented and supported (Parsons & Bossavit, 2016)*.

* Parsons S., Bossavit B. (2016). Virtual Reality for Autism: The Ethics of Positive Computing and the Design Potential of Representational Decoupling. [CHI'16 Workshop: Autism & Technology]

CONCLUSIONES

Los trabajos realizados en esta tesis se han centrado en el diseño, el desarrollo y la evaluación de herramientas educativas por medio del uso de Interfaces Naturales de Usuario (NUIs). De los resultados se han obtenido las siguientes conclusiones:

Exploración del potencial de las Interfaces Naturales de Usuario

1. La técnica de interacción *Body Menu* es capaz de competir con el *Marking Menu*, y el *Linear Menu* en lo referente al tiempo de realización de la actividad, precisión y facilidad de uso.

2. La técnica de interacción *Crank Handle* supera a la *Grasping Object* y está al nivel de la *Handle Bar* en cuanto a tiempo para la realización de la tarea, precisión y facilidad de uso.

3. Las NUIs aumentan la motivación y la implicación de los participantes, sin embargo siguen faltando evidencias para confirmar su apoyo al aprendizaje.

Diseño e implementación de herramientas educativas

4. La colaboración con docentes que conocen bien a sus alumnos permite que la herramienta educativa desarrollada se adaptase mejor a las necesidades y habilidades tanto cognitivas como motrices de los niños.

5. La colaboración con adolescentes con autismo de alto funcionamiento cognitivo se puede llevar de manera informal sin necesariamente utilizar métodos creativos y sensibles

Evaluación de las herramientas desarrolladas dentro de sus correspondientes contextos educativos

6. Los resultados mostraron que la aplicación *Adaptive framework* fue capaz de adaptarse a las dificultades de los niños y mejoró su motivación, por lo que puede ser considerada como tecnología adaptativa y de asistencia.

7. El juego serio colaborativo diseñado con adolescentes con autismo de alto funcionamiento mejora el conocimiento en Geografía. Sin embargo, la diferencia del nivel de competitividad generó tensiones entre las parejas, lo que llevó a una reducción del interés por la tarea.

8. La serie de actividades asociadas a esculturas de Jorge Oteiza sirve de complemento a la visita del museo para comprender los conceptos representados, siendo las chicas las que mayor aprendizaje mostraron.

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CONCLUSION

Les études réalisées dans cette thèse focalisent sur la conception, le développement et l'évaluation d'outils éducatifs utilisant les Interfaces Utilisateurs Naturelles (NUIs). Les résultats obtenus présentent les conclusions suivantes :

Exploration du potentiel de Interfaces Utilisateurs Naturelles

1. Le *Body Menu* est capable de converger avec le *Marking Menu* et le *Linear Menu* en temps de complétion de la tâche à réaliser, en précision et en facilité d'utilisation.

2. La technique d'interaction *Crank Handle* présente de meilleurs résultats que la technique *Grasping Object* et se trouve au même niveau que la *Handle Bar* en termes de temps de complétion de la tâche à réaliser, de précision et de facilité d'utilisation.

3. Les NUIs améliorent la motivation et l'engagement des participants. Cependant, il manque encore de fortes évidences pour confirmer le soutien à l'apprentissage des enfants aux besoins éducatifs spécialisés.

Conception et développement d'outils éducatifs

4. La collaboration avec les professeurs, qui connaissent très bien leurs élèves, permet que l'outil éducatif développé s'adapte mieux aux besoins et compétences des enfants, autant sur le plan cognitif que moteur.

5. La collaboration avec les adolescents avec autisme de haut niveau cognitif peut être menée de manière informelle sans avoir nécessairement besoin de méthodes visuelles et structurées.

Evaluation des outils développés dans leur contexte éducatif correspondant

6. Les résultats montrent que l'application *Adaptive Framework* peut s'adapter aux besoins des enfants et augmente leur motivation. Ainsi, l'application peut être considérée comme technologie adaptative et d'assistance.

7. Le jeu sérieux conçu par les adolescents avec autisme de haut niveau cognitif améliore la connaissance en Géographie. Cependant, la différence de niveau de compétitivité entre les joueurs créa des tensions, ce qui amena à une baisse d'intérêt envers la tâche à réaliser.

8. La série d'activités en relation avec les sculptures de Jorge Oteiza améliore la visite du musée pour comprendre les concepts représentés. Les filles présentèrent un meilleur apprentissage.

APPENDIX

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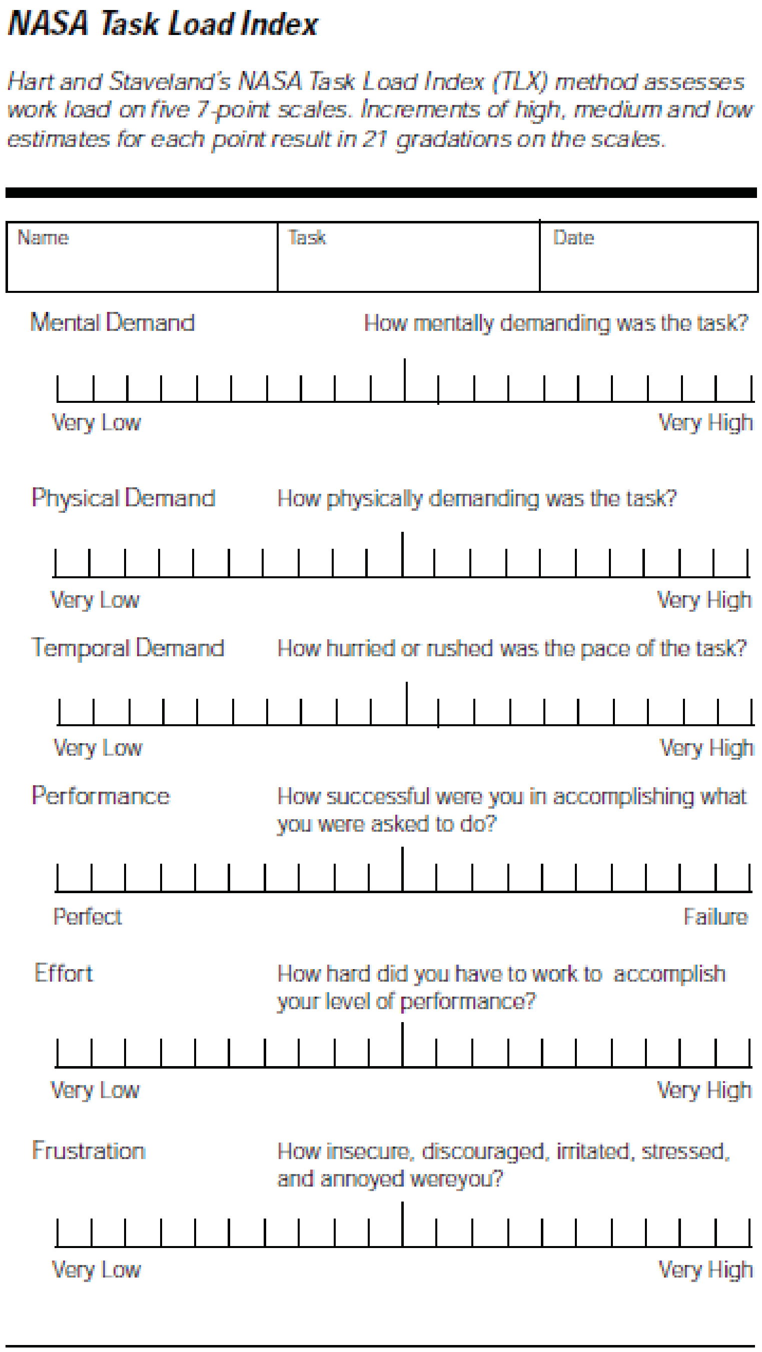
APPENDIX I: NASA - TASK LOAD INDEX



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Reference

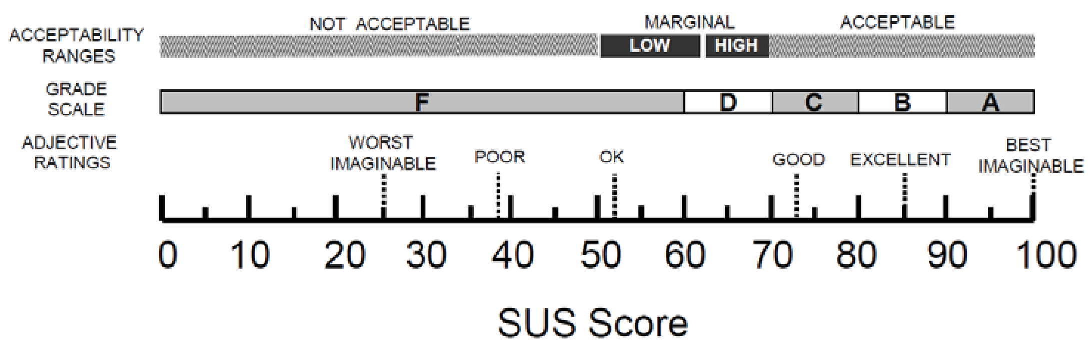
Hart, S. and Staveland, L. (1988) Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research. *Human Mental Workload*, pp. 139–183. Amsterdam: North Holland

APPENDIX II: SYSTEM USABILITY SCALE

The System Usability Scale (SUS) presented in Brooke (1996) is a short and quick survey scale that allow the usability practitioner to quickly and easily assess the usability of a given product or service. The SUS has been developed according to the three usability criteria defined by the ISO 9241-11: *effectiveness*, the ability of users to complete tasks using the system, and the quality of the output of those tasks; *efficiency,* the level of resource consumed in performing tasks; and *satisfaction* the users' subjective reactions using the system. It is composed of 10 statements (5 positive and 5 negative items) that are scored on a 5-point scale of strength of agreement subscale from strongly agree to strongly disagree (the (R) after an item number is a reminder that it is a reverse item).

Scoring information.

Each item's score contribution will range from 0 to 4. For items 1,3,5,7,and 9 (the positive items) the score contribution is the scale position minus 1. For items 2,4,6,8 and 10 (the negative items) the contribution is 5 minus the scale position. This sum is then multiply 2.5 to obtain the overall value of SU. Final scores for the SUS can range from 0 to 100, where higher scores indicate better usability.



Bangor and colleagues (2009) presented a comparison of the adjective ratings, acceptability scores, and school grading scales in relation to the average SUS score in a study with 964 participants. Their results suggested a set of acceptability ranges that help practitioners determine if a given SUS score indicated an acceptable interface or not.

Please circle the number that best reflects your response:					
	Not at all				**Very much**
1. I think that I would like to use this product frequently.	1	2	3	4	5
2. I found the product unnecessarily complex (R)	1	2	3	4	5
3. I thought the product was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this product (R)	1	2	3	4	5
5. I found the various functions in the product were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this product (R)	1	2	3	4	5
7. I imagine that most people would learn to use this product very quickly	1	2	3	4	5
8. I found the product very awkward to use (R)	1	2	3	4	5
9. I felt very confident using the product	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this product (R)	1	2	3	4	5

References

Bangor A., Kortum P. and Miller J. (2009) Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *Journal of Usability Studies* 4(3):114-123

Brooke, J. (1996). SUS: a „quick and dirty" usability scale. In P.W.Jordan, B. Thomas, B.A. Weerdmeester, and I.L. McClelland (Eds.) Usability Evaluation in Industry (189-194). London: Taylor and Francis.

APPENDIX III: DOCUMENT FOR TEACHERS

Co-design and evaluation of educational technology for pupils on the autism spectrum

Project partners

- Benoit Bossavit (University of Navarre, Spain)
- Sarah Parsons (University of Southampton, UK)
- New Forest Care.

Aims of the project

The project focuses on involving teachers and students from New Forest Care in the design and development of a new prototype interaction framework that uses the Microsoft Kinect. We are particularly interested in how technology can enable the use of the body for learning specific skills, especially skills that may be difficult or challenging to teach in other ways.

Purpose of today

We will show you the technology so far and really welcome any ideas you have about how it could be developed further for the children you work with. We are interested in two main questions:

1. In what ways could the application be used to support children with autism to interact with their own bodies?
2. In what ways can the application support collaboration in interactions between children?

Please note down any initial thoughts about the technology and how it might be used with the children you work with [e.g. are there things that the children find difficult that the technology could help with?]:

Any comments or ideas about how the technology could support children's interaction with their own bodies? [Is this relevant for the children you work with? Do you have any ideas about what might be helpful?]

Any comments or ideas about how the technology could support children to collaborate or interact with each other?

Thank you very much for your time and comments!

APPENDIX IV: VISUAL QUESTIONNAIRE

Questionnaire about videogames

This questionnaire will help us design and specify what kind of game we want to design and develop – thank you!

Question 1

What computer systems do you have at home? Tick all of the ones that you have.

 Computer or Laptop	 XBox	 Playstation	 Wii	 Nintendo DS	 PSP	Other (write the name)

Question 2

*Write down your 3 favourite computer **games**:*

1.
2.
3.

Question 3

*What is the **main feature** you like in these games?*

1.
2.
3.

Question 4

What kind of ***positive feedbacks*** *(when you do something good) do you like? For example sound, image, score multiplier...*

Question 5

What kind of ***negative feedbacks*** *(when you do something bad)do you like? For example sound, image, lose score...*

Question 6

What kind of ***rewards*** *do you like? For example, virtual money, medals, new skills, ...*

Question 7

*What kind of **penalties** do you like? (things that make the game more challenging)*

Game with Kinect and the Body Menu

The next step is to define the base of the game. In other word, what is the **objective** of the game? Remember that the game should have at least 3 modes: **single player, collaboration and competition**.

			*Observation*
Entertainment (such as story teller)			
Content of the classes (such as maths, geography, English...)			
Reflexion (such as jigsaw puzzle)			
Other: (define it)			

APPENDIX V: VISUAL SCHEDULE

Let start designing the game with Kinect!

	Do you want to create a game to learn geography?	
	If not: Brainstorm on idea of the game - Single Mode - Competition Mode - Collaboration Mode	
	If yes: Let's find an idea on a **competitive** and bring out the **main rules**	
	If we have no idea, let's watch a video! Let's think about some rules: - How to conquer an unoccupied country? - How to conquer an occupied country? - Defining bonus and penalties - Etc.	
	Sketch the **competitive** game with Kinect	
	Let's find an idea on a **collaborative game**	
	Sketch the **collaborative** game with Kinect	
	Let's find an idea on a **single player game**	
	Let's test the game!	

APPENDIX VI: SCENARIO EXPERIENCE FEEDBACK QUESTIONNAIRE

It consists of 14 items, rated with a 5 point scale, to query the children's enjoyment, understanding, ease of use, and other usability items while playing the games (maximum score = 70).

Please circle the number that best reflects your response:					
	Not at all			Very much	
1. Did you enjoy the game?	1	2	3	4	5
2. Did you succeed in the game?	1	2	3	4	5
3. Was the game was easy for you?	1	2	3	4	5
4. Would you like to play the game again?	1	2	3	4	5
5. Did you feel you could control the game?	1	2	3	4	5
6. Did the game respond to you as you expected?	1	2	3	4	5
7. Did you have to wait too much time for the game to respond?	1	2	3	4	5
8. Did the game seem realistic to you?	1	2	3	4	5
9. How clear was the computer's response during the game?	1	2	3	4	5
10. Did you feel that you were an active player in the game?	1	2	3	4	5
11. How quickly did you get used to playing the game?	1	2	3	4	5
12. Did you feel comfortable during the game?	1	2	3	4	5
13. Did you like being with your partner during the game?	1	2	3	4	5
14. How much did the moving objects and sounds distract you during the game?	1	2	3	4	5

APPENDIX VII: INTRINSIC MOTIVATION INVENTORY

It consists of 22 items, rated on a 7 point scale, designed to assess a user's response to four components: interest in and enjoyment of the task, perceived competence, perceived choice and feelings of pressure or tension while doing the task.

Scoring information

Begin by reverse scoring items # 2, 9, 11, 14, 19, 21 (subtract the item response from 8). Thus a higher score will indicate more of the concept described in the subscale name. Then calculate subscale scores by averaging the items scores for the items on each subscale (the (R) after an item number is a reminder that it is a reverse item).

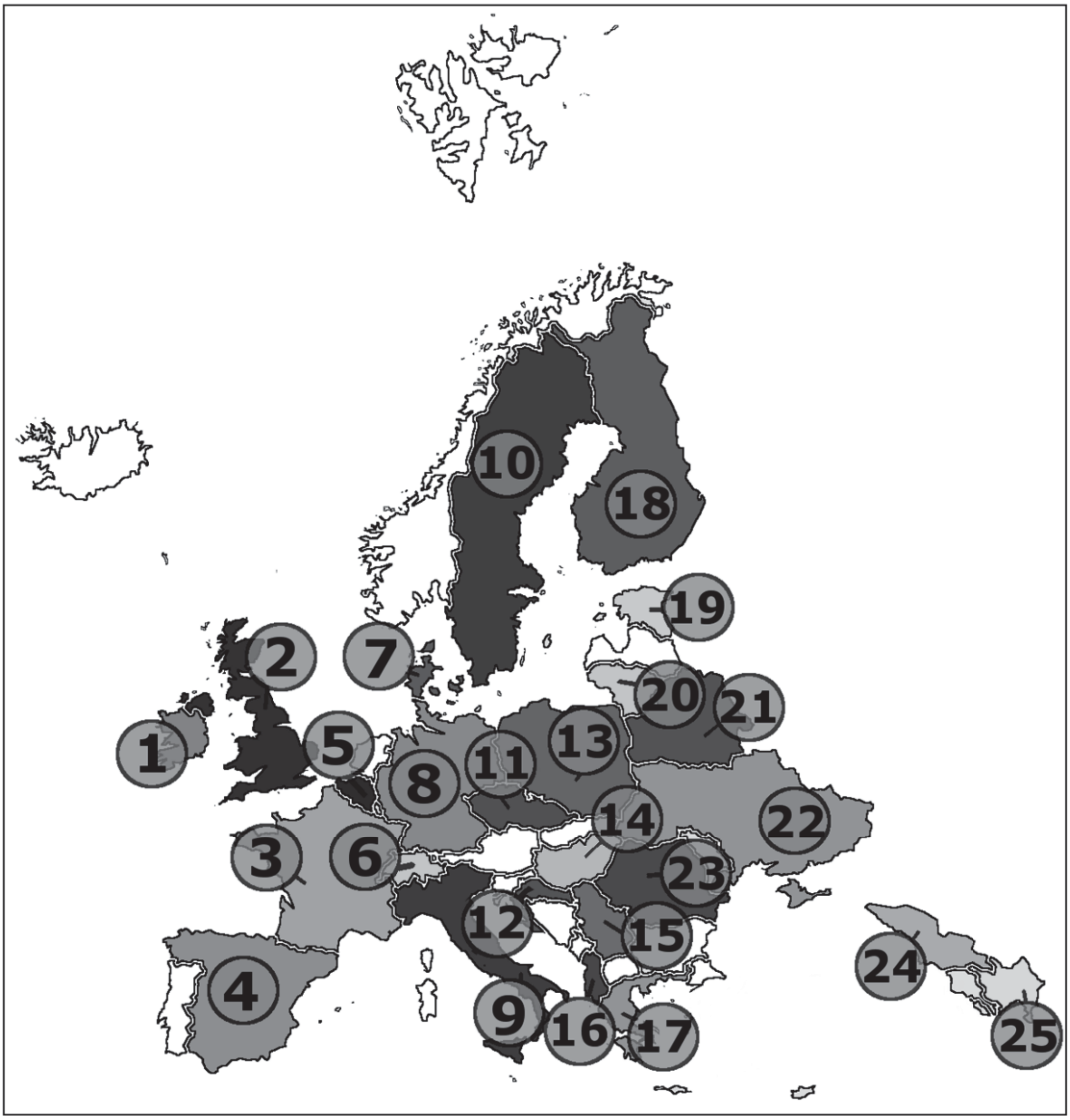
- *Interest/enjoyment*: 1, 5, 8, 10, 14(R), 17, 20
- *Perceived competence*: 4, 7, 12, 16, 22
- *Perceived choice*: 3, 11(R), 15, 19(R), 21(R)
- *Pressure/tension*: 2(R), 6, 9(R), 13, 18

Reference

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well being. American Psychologist, 55,68–78

Please circle the number that best reflects your response:							
	Not at all			Very much			
1. While I was working on the task I was thinking about how much I enjoyed it.	1	2	3	4	5	6	7
2. I did not feel at all nervous about doing the task.	1	2	3	4	5	6	7
3. I felt that it was my choice to do the task.	1	2	3	4	5	6	7
4. I think I am pretty good at this task.	1	2	3	4	5	6	7
5. I found the task very interesting.	1	2	3	4	5	6	7
6. I felt tense while doing the task.	1	2	3	4	5	6	7
7. I think I did pretty well at this activity, compared to other students.	1	2	3	4	5	6	7
8. Doing the task was fun.	1	2	3	4	5	6	7
9. I felt relaxed while doing the task.	1	2	3	4	5	6	7
10. I enjoyed doing the task very much.	1	2	3	4	5	6	7
11. I didn't really have a choice about doing the task.	1	2	3	4	5	6	7
12. I am satisfied with my performance at this task.	1	2	3	4	5	6	7
13. I was anxious while doing the task.	1	2	3	4	5	6	7
14. I thought the task was very boring.	1	2	3	4	5	6	7
15. I felt like I was doing what I wanted to do while I was working on the task.	1	2	3	4	5	6	7
16. I felt pretty skilled at this task.	1	2	3	4	5	6	7
17. I thought the task was very interesting.	1	2	3	4	5	6	7
18. I felt pressured while doing the task.	1	2	3	4	5	6	7
19. I felt like I had to do the task.	1	2	3	4	5	6	7
20. I would describe the task as very enjoyable.	1	2	3	4	5	6	7
21. I did the task because I had no choice.	1	2	3	4	5	6	7
22. After working at this task for a while, I felt pretty competent.	1	2	3	4	5	6	7

APPENDIX VIII: GEOGRAPHY QUESTIONNAIRE



1) Which of the following mountain range is situated in **country 1**?

a) Alps	b) Macgillycuddy's reeks	c) Skanderna

2) Which of the following rivers runs through **country 2**?

a) Humber	b) Shannon	c) Po

3) How many people live in **country 3**?

a) About 81 million	b) About 47 million	c) About 66,5 million

4) Which of the following mountain range is situated in **country 4**?

a) Alps	b) Halti	c) Sierra Nevada

5) Which is an official language of **country 5**?

a) Greek	b) French	c) Danish

6) What is the capital city of **country 6**?

a) Paris	b) Bern	c) Kiev

7) Which of the following seas/oceans belongs to **country 7**?

a) Azov sea	b) Baltic sea	c) Norwegian sea

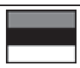
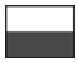
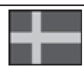
8) What is the capital city of **country 8**?

a) Berlin	b) Warsaw	c) Brussels

9) How tall is highest mountain of the *Alps* of **country 9**?

a) 4810 metres	b) 3478 metres	c) 2917 metres

10) What is the flag of **country 10**?

a) 	b) 	c) 

11) What is the capital city of **country 11**?

a) Athens	b) Budapest	c) Prague

12) What is the name of **country 12**?

a) Croatia	b) Montenegro	c) Latvia

13) Which is the official currency of **country 13**?

a) zloti	b) euro	c) ukranian hryvnia

14) Which of the following rivers runs through **country 14**?

a) Pedieos	b) Danube	c) Po

15) Which is the official currency of **country 15**?

a) romanian leu	b) euro	c) serbian dinar

16) Which is an official language of **country 16**?

a) Greek	b) Albanian	c) Italian

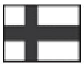
17) How many people live in **country 17**?

a) About 11 million	b) About 3 million	c) About 38 million

18) What is the name of **country 18**?

a) Finland	b) Sweden	c) Estonia

19) What is the flag of **country 19**?

a) 	b) 	c) 

20) Which of the following rivers runs through **country 20**?

a) Oder	b) Nemunas	c) Tagus

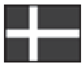
21) What is the capital city of **country 21**?

a) Kiev	b) Vilnius	c) Minsk

22) What is the name of **country 22**?

a) Ukraine	b) Azerbaijan	c) Denmark

23) What is the flag of **country 23**?

a) 	b) 	c) 

24) Which of the following seas/oceans belongs to **country 24**?

a) Black sea	b) Azov sea	c) Mediterranean sea

25) How tall is highest mountain of the *Greater Caucasus* of **country 25**?

a) 2925 metres	b) 2655 metres	c) 5642 metres

APPENDIX IX: QUESTIONNAIRE ABOUT OTEIZA'S EXPERIENCE

Pon un circulo sobre el número que corresponde a tu respuesta:
(*Please circle the number that best reflects your response:*)

	En desacuerdo (*Not at all*)				**De acuerdo (*Very much*)**
1. Me gusta ir a los museos (*I like going to museums*)	1	2	3	4	5
2. Cuando estoy en un museo paso mi tiempo observando las obras (*When I am in a museum I usually watch the exhibits*)	1	2	3	4	5
3. Cuando estoy en un museo me gusta además pasar el tiempo con las aplicaciones interactivas que proponen (*When I am in a museum I like spending time with the interactive exhibits*)	1	2	3	4	5
4. He disfrutado y he aprendido sobre la obra de J. Oteiza con esta experiencia (*I enjoyed the experience and learnt about Oteiza's work*)	1	2	3	4	5
5. Me ha parecido fácil la manera de usar la aplicación (*I found it easy using the application*)	1	2	3	4	5
6. Me ha parecido difícil entender lo que tenía que hacer (*I found it difficult understanding what I had to do*)	1	2	3	4	5
7. Podría usar la aplicación sin ayuda de un adulto (*I could use this application without the help of an adult*)	1	2	3	4	5
8. Me parece complicados de completar todos los ejercicios (*I found it difficult completing the activities*)	1	2	3	4	5
9. Creo que la aplicación me ayudo a entender mejor la obra de J. Oteiza (*I think the application helped me understand better J. Oteiza's work*)	1	2	3	4	5
10. Creo que la visita sola es suficiente para entender la obra de J. Oteiza (*I think the visit to the museum is enough to understand J. Oteiza's work*)	1	2	3	4	5
11. Me gustaría tener esta aplicación en el cole (*I would like such an application in my school*)	1	2	3	4	5
12. Iría más a los museos si tuvieran este tipo de aplicación instaladas (*I would go more often to museums if such kind of applications would be set up*)	1	2	3	4	5

APPENDIX X: TEST ABOUT OTEIZA AND HIS WORK

1) ¿En qué lugar nació Jorge Oteiza?

(Where is Jorge Oteiza born?)

a. San Sebastián	b. Pamplona	(c.) Orio	d. Bilbao

2) Dentro del mundo del arte Oteiza es conocido principalmente como:

(In the field of Art, Oteiza was well-known for:)

a. Cineasta (*Moviemaker*)	(b.) Escultor (*Sculptor*)	c. Pintor (*Painter*)	d. Arquitecto (*Architect*)

3) En 1935 el artista abandona España para trasladarse a otro país donde trabajará como profesor y artista, y donde vivirá hasta 1948. ¿Qué lugar es?

(*In 1935 the artist had left Spain for another country in which he had been working as teacher and artist until 1948. Where was it?*)

a. Francia (*France*)	b. Alemania (*Germany*)	(c.) Sudamérica (*South America*)	d. Italia (*Italy*)

4) ¿Cuál es la ciudad en la que más esculturas de Oteiza podemos encontrar en sus calles?

(*Which is the city that owns the most work of Oteiza within the streets?*)

(a.) Pamplona	b. San Sebastián	c. Biarritz	d. Madrid

5) La Fundación Museo Jorge Oteiza, que alberga la colección del artista, fue diseñada por un arquitecto navarro. ¿Quién fue?

(*The Oteiza's museum was designed by an architect from Navarre, Spain. Who was he?*)

(a.) Javier Sáenz de Oíza	b. Francisco Mangado	c. Rafael Moneo	d. Víctor Eusa

6) ¿Cuáles son las figuras geométricas utilizadas por Oteiza como base para sus esculturas? (*Which geometric shapes does Oteiza base his work on?*)

a. Cilindro, esfera y cubo (*Cylinder, sphere and cube*)	b. Círculo, cuadrado y trapecio (*Circle, square and trapeze*)	c. Esfera, cono y cubo (*Sphere, cone and cube*)	d. Cilindro y esfera (*Cylinder and sphere*)

7) ¿Que concepto es el más importante a la hora de estudiar las esculturas de Oteiza? (*Which context is the most important when one is studying Oteiza?*)

a. El movimiento (*Movement*)	b. La forma (*Shape*)	c. El vacío (*Empty space*)	d. El color (*Color*)

8) ¿Cuál consideras que es la principal relación de la escultura con el espacio según Oteiza? (*Which one is the most related to space according to Oteiza?*)

a. La escultura ocupa un espacio (*The sculpture fills a space*)	b. La escultura no tiene relación directa con el espacio (*There is no direct relationship between sculpture and space*)	c. El espacio vacío no representa nada en la escultura (*The empty space means nothing to the sculpture*)	d. El espacio vacío se puede convertir en escultura (*The empty space can become a sculpture*)

9) ¿En cuántas dimensiones podemos ver una escultura? (*How many dimensions can be observed in a sculpture?*)

a. En dos (*two*)	b. En una o dos (*one or two*)	c. En tres (*three*)	d. En dos o tres (*two or three*)

10) ¿Representa el color un elemento importante para la escultura? (*Does the color mean something to the sculpture?*)

a. Si, ya que modifica el aspecto de la misma (*Yes, since it changes its aspect*)	b. No, tan sólo es importante en la pintura (*No, it is only important in painting*)	c. No, tan sólo es importante en la pintura y el dibujo (*No, it is only important in painting and drawing*)	d. Sólo si la escultura es figurativa (*Only if the sculpture is figurative*)