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Natural User Interfaces and Smart Devices for the Assessment of Spatial Memory Using Auditory Stimuli

Author

Mauricio Loachamín Valencia

Advisors

Prof. M. Carmen Juan Lizandra

Dr. Elena Pérez Hernández

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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Author:
Mauricio Renán Loachamín Valencia

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Mauricio Loachamín Valencia

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This work is dedicated to my dear wife Sonia and to darling daughter Doménica.
The two are my inspiration!

Abstract

Natural User Interfaces (NUI) allow users to be the controller itself. These interfaces change completely how the user interacts with a system. The user does not have to use any wearable device. These interfaces can help in the assessment of cognitive processes in an ecological way, among many other applications. Nowadays, we can find suitable devices for the development of this type of interfaces (e.g., Kinet^{TM} or Leap Motion). Smart devices (e.g., Karotz rabbit) are also suitable devices for the development of applications for different fields. Psychology and neuropsychology are fields of research in which NUI and smart devices have not been exploited.

Considering the current situation, in this thesis, the main objective was to design and develop a new task that combines NUI and smart devices for assessing spatial memory using auditory stimuli, and its validation in both children and adults. The new task tests the ability of participants to detect and localize auditory stimuli that are emitted in different positions of the task area. The task recognizes the movements of the arms of the user using Kinect^{TM}. Smart devices (Karotz rabbits) are used for emitting auditory stimuli and also as visual cues (e.g., movement of the ears). Therefore, the task combines auditory stimuli with real visual cues for the assessment of spatial memory. The task includes a total of 45 acoustic stimuli, which should be randomly emitted in different locations. The task is composed of five different levels. Each level is defined to relate to a specific theme. Each level consists of 3 trials. The difference between levels lies in the number of sounds to be used in each trial, which will increase by 1 at each subsequent level. To our knowledge, our task is the first work that combines NUI and smart devices for the assessment of spatial memory. Similarly, our task is the first work that uses auditory stimuli to assess the spatial memory.

For the validation, three studies were carried out to determine the efficacy and utility of our task with regard to the performance outcomes, usability, fun, perception and overall satisfaction. The performance of our task was compared with traditional methods. The first study involved children with and without symptoms of inattention. A total of 34 children participated. There were 17 children with inattention and 17 children without inattention. The results showed that the children with inattention showed statistically worse performance in the task. These children with inattention also showed statistically worse performance in the traditional method for testing the learning of verbal sounds. There were no statistically significant differences in the time spent by each group to complete the task. The results suggest that the task is a good tool for distinguishing spatial memory difficulties in children with inattention.

The second study compared the performance in the task between older children and adults. A total of 70 participants were involved in this study. There were 32 healthy children from 9 to 10 years old, and 38 healthy adults from 18 to 28 years old. The performance outcomes with the task were significantly lower for the older children. Correlations were found between our task and traditional methods, indicating that our task has proven to be a valid tool for assessing spatial memory by using auditory stimuli for both older children and adults. From the analysis, we can conclude that the older children were significantly more satisfied with the task than the adults.

In the third study, a total of 148 participants were involved. They were distributed in three groups (younger children, older children and adults). A total of 100 children from 5 to 10 years old and 48 adults from 18 to 28 years participated in this study. The results are in line with the second study. The task performance was significantly incrementally and directly related to the age group (younger children $<$older children $<$adults). The results were better for adults and older children; this is consistent with the idea that adults can store more elements in short-term memory than children.

The following general conclusions were extracted from the development and the three studies:

- Natural user interfaces and smart devices are appropriated for developing tasks for the assessment of spatial memory.

- As a computer-based game, our task facilitates the control of the presentation of stimuli and the recording of responses.
- Our task and similar tasks could be used for assessment and training of spatial memory in children and adults.
- The task could be an alternative tool to assess spatial memory in children with symptoms of inattention.
- The task promotes engagement and allows the assessment in an ecological way.
- The task could help in the identification of alterations in spatial memory in both children and adults.

Resumen

Las interfaces de usuario naturales (NUI) permiten que el usuario sea el propio mando. Estas interfaces cambian completamente la forma en que el usuario interactúa con un sistema. El usuario no tiene que llevar consigo ningún dispositivo. Estas interfaces pueden ayudar en la evaluación de procesos cognitivos de una manera ecológica, entre otras muchas aplicaciones. Hoy en día, se dispone de dispositivos adecuados para el desarrollo de este tipo de interfaces (p. ej., Kinect^{TM} o Leap Motion). Los dispositivos inteligentes (p. ej., conejos Karotz) también son dispositivos adecuados para el desarrollo de aplicaciones para diferentes campos. La psicología y la neuropsicología son campos de investigación en los que las NUI y los dispositivos inteligentes no se han explotado.

Considerando la situación actual, en esta tesis, el objetivo principal fue diseñar y desarrollar una nueva tarea que combinara NUI y dispositivos inteligentes para evaluar la memoria espacial utilizando estímulos auditivos, y su validación tanto en niños, como en adultos. La nueva tarea evalúa la capacidad de los participantes para detectar y localizar estímulos auditivos que se emiten en diferentes posiciones del área de trabajo. La tarea reconoce los movimientos de los brazos del usuario, utilizando para ello Kinect^{TM}. Los dispositivos inteligentes (conejos Karotz) se utilizan para emitir estímulos auditivos y, también, como señales visuales (por ejemplo, movimiento de las orejas). Por lo tanto, la tarea combina estímulos auditivos con claves visuales reales para la evaluación de la memoria espacial. La tarea incluye un total de 45 estímulos acústicos, que deben emitirse al azar en diferentes posiciones. La tarea se compone de cinco niveles diferentes. Cada nivel está relacionado con un tema específico. Cada nivel consta de 3 ensayos. La diferencia entre los niveles radica en el número

de sonidos que se utilizan en cada ensayo, que aumenta 1 en cada nivel. Por lo que sabemos, nuestra tarea es el primer trabajo que combina NUI y dispositivos inteligentes para la evaluación de la memoria espacial. Del mismo modo, nuestra tarea es el primer trabajo que utiliza estímulos auditivos para evaluar la memoria espacial.

Para la validación, se llevaron a cabo tres estudios para determinar la eficacia y la utilidad de nuestra tarea con respecto a rendimiento, usabilidad, diversión, percepción y satisfacción general. El rendimiento de nuestra tarea se comparó con métodos tradicionales. El primer estudio involucró niños con y sin síntomas de inatención. Participaron un total de 34 niños. Participaron 17 niños con inatención y 17 niños sin inatención. Los resultados demostraron que los niños con inatención mostraron un rendimiento estadísticamente peor en la tarea. Estos niños con inatención también mostraron un rendimiento estadísticamente peor con el método tradicional para evaluar el aprendizaje de sonidos verbales. No se encontraron diferencias estadísticamente significativas en el tiempo dedicado por cada grupo para completar la tarea. Los resultados sugieren que la tarea es una buena herramienta para distinguir las dificultades de memoria espacial en niños con dificultades de atención.

El segundo estudio comparó el rendimiento en la tarea entre niños mayores y adultos. Un total de 70 participantes estuvieron involucrados en este estudio. Participaron 32 niños sanos de 9 a 10 años y 38 adultos sanos de 18 a 28 años. Los resultados de rendimiento con la tarea fueron significativamente más bajos para los niños mayores. Se encontraron correlaciones entre nuestra tarea y los métodos tradicionales, lo que indica que nuestra tarea ha demostrado ser una herramienta válida para evaluar la memoria espacial mediante el uso de estímulos auditivos tanto para niños mayores, como para adultos. A partir del análisis, podemos concluir que la satisfacción con la tarea de los niños mayores fue significativamente mayor que la de los adultos.

El tercer estudio incluyó un total de 148 participantes. Se distribuyeron en tres grupos (niños más pequeños, niños mayores y adultos). Un total de 100 niños de 5 a 10 años y 48 adultos de 18 a 28 años participaron en este estudio. Los resultados están en línea con el segundo estudio. El rendimiento de la tarea se relacionó significativamente, de forma incremental y directa con el grupo de edad (niños más pequeños $<$niños mayores $<$adultos). Los resultados fueron mejores para adultos y niños mayores; resultado que es consistente con la idea de que los adultos pueden almacenar más elementos en la memoria a corto plazo que los niños.

Las siguientes conclusiones generales se han extraído del desarrollo y los tres estudios:

- Las NUI y los dispositivos inteligentes son apropiados para desarrollar tareas para la evaluación de la memoria espacial.
- Como juego de ordenador, nuestra tarea facilita el control de la presentación de estímulos y el almacenamiento de las respuestas.
- Nuestra tarea, y tareas similares, podrían usarse para la evaluación y el entrenamiento de la memoria espacial en niños y adultos.
- La tarea podría ser una herramienta alternativa para evaluar la memoria espacial en niños con problemas de inatención.
- La tarea promueve interés y permite la evaluación de una manera ecológica.
- La tarea podría ayudar a identificar alteraciones en la memoria espacial tanto en niños, como en adultos.

Resum

Les interfícies d'usuari naturals (NUI) permeten que l'usuari siga el propi comandament. Aquestes interfícies canvien completament la forma en què l'usuari interactua amb un sistema. L'usuari no ha de portar amb si cap dispositiu. Aquestes interfícies poden ajudar en l'avaluació de processos cognitius d'una manera ecològica, entre altres moltes aplicacions. Avui dia, es disposa de dispositius adequats per al desenvolupament d'aquest tipus d'interfícies (p. ex., Kinect™ o Leap Motion). Els dispositius intel·ligents (p. ex., conills Karotz) també són dispositius adequats per al desenvolupament d'aplicacions per a diferents camps. La psicologia i la neuropsicologia són camps de recerca en els quals les NUI i els dispositius intel·ligents no s'han explotat.

Considerant la situació actual, en aquesta tesi, l'objectiu principal va ser dissenyar i desenvolupar una nova tasca que combinés NUI i dispositius intel·ligents per a avaluar la memòria espacial utilitzant estímuls auditius, i la seua validació tant en xiquets, com en adults. La nova tasca avalua la capacitat dels participants per a detectar i localitzar estímuls auditius que s'emeten en diferents posicions de l'àrea de treball. La tasca reconeix els moviments dels braços de l'usuari, utilitzant per a açò Kinect™. Els dispositius intel·ligents (conills Karotz) s'utilitzen per a emetre estímuls auditius i, també, com a senyals visuals (per exemple, moviment de les orelles). Per tant, la tasca combina estímuls auditius amb claus visuals reals per a l'avaluació de la memòria espacial. La tasca inclou un total de 45 estímuls acústics, que s'han d'emetre a l'atzar en diferents posicions. La tasca es compon de cinc nivells diferents. Cada nivell està relacionat amb un tema específic. Cada nivell consta de 3 assajos. La diferència entre els nivells radica en el nombre de sons que s'utilitzen en cada

assaig, que augmenta en 1 en cada nivell. Pel que sabem, la nostra tasca és el primer treball que combina NUI i dispositius intel·ligents per a l'avaluació de la memòria espacial. De la mateixa manera, la nostra tasca és el primer treball que utilitza estímuls auditius per a avaluar la memòria espacial.

Per a la validació, es van dur a terme tres estudis per a determinar l'eficàcia i la utilitat de la nostra tasca pel que fa a rendiment, usabilitat, diversió, percepció i satisfacció general. El rendiment de la nostra tasca es va comparar amb mètodes tradicionals. El primer estudi va involucrar xiquets amb i sense símptomes de inatenció. Van participar un total de 34 xiquets . Van participar 17 xiquets amb inatenció i 17 xiquets sense inatenció. Els resultats van demostrar que els xiquets amb inatenció van mostrar un rendiment estadísticament pitjor en la tasca. Aquests xiquets amb inatenció també van mostrar un rendiment estadísticament pitjor amb el mètode tradicional per a avaluar l'aprenentatge de sons verbals. No es van trobar diferències estadísticament significatives en el temps dedicat per cada grup per a completar la tasca. Els resultats suggereixen que la tasca és una bona ferramenta per a distingir les dificultats de memòria espacial en xiquets amb dificultats d'atenció.

El segon estudi va comparar el rendiment en la tasca entre xiquets majors i adults. Un total de 70 participants van estar involucrats en aquest estudi. Van participar 32 xiquets sans de 9 a 10 anys i 38 adults sans de 18 a 28 anys. Els resultats de rendiment amb la tasca van ser significativament més baixos per als xiquets majors. Es van trobar correlacions entre la nostra tasca i els mètodes tradicionals, la qual cosa indica que la nostra tasca ha demostrat ser una ferramenta vàlida per a avaluar la memòria espacial mitjançant l'ús d'estímuls auditius tant per a xiquets majors, com per a adults. A partir de l'anàlisi, podem concloure que la satisfacció amb la tasca dels xiquets majors va ser significativament major que la dels adults.

El tercer estudi va incloure un total de 148 participants. Es van distribuir en tres grups (xiquets més xicotets, xiquets majors i adults). Un total de 100 xiquets de 5 a 10 anys i 48 adults de 18 a 28 anys van participar en aquest estudi. Els resultats estan en línia amb el segon estudi. El rendiment de la tasca es va relacionar significativament, de forma incremental i directa amb el grup d'edat (xiquets més xicotets $<$ xiquets majors $<$ adults). Els resultats van ser millors per a adults i xiquets majors; resultat que és consistent amb la idea que els adults poden emmagatzemar més elements en la memòria a curt termini que els xiquets.

Las següents conclusions generals s'han extret del desenvolupament i els tres estudis:

- Les NUI i els dispositius intel·ligents són apropiats per a desenvolupar tasques per a l'avaluació de la memòria espacial.
- Com a joc d'ordinador, la nostra tasca facilita el control de la presentació d'estímuls i l'emmagatzematge de les respostes.
- La nostra tasca, i tasques similars, podrien usar-se per a l'avaluació i l'entrenament de la memòria espacial en xiquets i adults.
- La tasca podria ser una ferramenta alternativa per a avaluar la memòria espacial en xiquets amb problemes de inatenció.
- La tasca promou interès i permet l'avaluació d'una manera ecològica.
- La tasca podria ajudar a identificar alteracions en la memòria espacial tant en xiquets, com en adults.

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I am eternally grateful!


shortterm
Karotz
sensory
Devices
Using
Learning
five
device
environment
Microsoft
ergonomics
memory
information
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cognitive
design
smart
Auditory
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iconic
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psychology
Spatial

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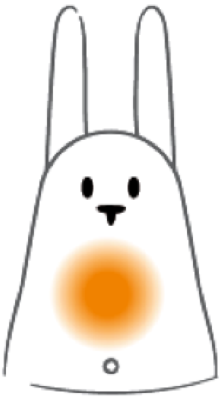


Chapter 1

Introduction

"Great works are performed not by strength, but by perseverance"

Samuel Johnson

Contents

1.1 Motivation

The current situation of ICT (Information and Communication Technology) is a key factor for achieving scientific, technological and innovative advances in many sectors. Specifically, both the current software and hardware allow achievements that were unimaginable only 2 years ago. This evolution increases the opportunities for the development of tools and technologies, as well as the manufacture of new smart devices and new natural user interfaces (NUI). Smart devices are technological resources that are capable of communicating, share and interact with the users and help them in daily activities. This communication can be between similar devices through a communication protocol or with humans through a user interface. The appearance of smart devices can help to focus and maintain users' attention. One of their features is their ability to connect to a network to share and interact remotely. Smart devices, especially those with human appearance (robots) or animal (pets), have contributed to the development of several applications. For example, Moriguchi et al. (2011) used Robovie for children between 4 and 6 years old could learn words. In other study presented by de Graaf et al. (2016), a Karotz rabbit was used. They installed the Karotz in the home of elderly people. The goal was to improve their health. The Karotz are rabbit-shaped smart devices that interact with the subject by moving their ears, emitting sounds/messages and illuminating LED lights in their bellies (Kozima, Michalowski, and Nakagawa 2009). In this thesis, we used Karotz rabbits. According to a market research report (Markets & Markets 2017), the humanoid robot market is expected to grow from USD 320.3 Million in 2017 to USD 3,962.5 Million by 2023, at a CAGR of 52.1% between 2017 and 2023. This report indicates that humanoid robot market is mainly driven by factors such as the introduction of advanced features in humanoid robots, the increasing use of humanoids as educational robots, and growing demand from the retail industry for personal assistance.

Natural user interfaces allow natural interaction, in which the body itself is responsible for transmitting instructions to the applications, without using controls or input devices. NUI use devices with sensors to capture the movement of the body (e.g., arms, hands, legs or head), allowing the user to interact without needing to have physical contact with other control devices. The appearance of depth sensors (e.g., Kinect™ or Leap Motion) allowed the developers to use them as input devices for natural user interfaces. These sensors have been used for different purposes and for a wide variety of applications, such as rehabilitation (Chang, Chen, and Huang 2011), learning (Martín-SanJosé et al. 2015), recognition of sign language (Cheng, Yang, and Liu 2016) or diagnosis of facial paralysis (Carro et al. 2016), among others. However, NUI have not been exploited for creating interactive environments for assessing cognitive processes in an engaging and ecological way.

The spatial ability of a person refers to the ability to solve spatial problems, how to perceive distances and directional relationships, transform mentally objects with respect to their position in space, locate elements in space, etc. It is important to know how the person is spatially oriented and what are the factors that influence this ability for their implications on daily activities. Human beings put into practice the spatial ability in a large number of times each day, when they are oriented in both familiar and unknown environments. In addition, this ability is also essential to perform certain professional roles that require designing and planning in the space in two or three dimensions, as well as navigate in complex and extensive environments with few references of support. One of the most critical cognitive skills in human beings is to store the memory of stimuli that have been experienced in the past. The field of psychology is interested in investigating the ability to learn spatial and auditory information. The reason for this interest is that they are significant processes in daily activities. Memory can be divided into short-term and long-term memory (Burgess and Hitch 2005). The short-term memory can be defined as the capacity for holding a small amount of information in mind in an active, readily available state for a short period of time. By contrast, in the long-term memory, the information to be memorized is relevant to be stored in a stable manner for any future need. Spatial memory has the capacity to store representations of spatial stimuli. Spatial memory allows us to find a place that was visited previously, remember the place where we left our belongings or follow a route after consulting a map (Burgess et al. 2001). Spatial learning is associated with academic outcomes (Rourke 1993). Auditory memory involves being able to take information that is received by the auditory system, to process that information, store it and, then, recall it. For example, auditory learning facilitates taking notes while listening, written expression and oral expression (Dehn 2008). Some learning and behavior problems are related to impairments in these processes (Graham and Heywood 1975; Rauscher, Krauss, and Chen 1996). Many learning experiences require simultaneously considering auditory and spatial information. One example is the identification of people or objects. Since there are no procedures to assess spatial orientation with auditory stimuli, their implications for different types of disabilities remain uncertain. In addition, it can be an alternative to assess spatial ability in people with visual impairment.

Tools related to spatial memory can be for assessment or training. The tools for assessment allow to determine if the person presents an adequate performance of this skill or has difficulties that may affect his/her independence (Cimadevilla et al. 2014; Negut et al. 2016). The results of this assessment could allow the early identification of atypical development in children, or if an adult has alterations in his/her memory. These difficulties in orientation usually occur in disorders or diseases as is the case of Alzheimer's patients (Monacelli et al. 2003); after suffering a cerebrovascular accident Barret and Muzaffar (2014) or a head trauma (Skelton et al. 2006); large prematures (Pérez-Hernández et al. 2015); patients with epilepsy (Cimadevilla et al. 2014) or major depressive disorder (Cornwell et al. 2010). As a training tool, can help in improving the performance in situations of spatial orientation by practicing help strategies (Caffò et al. 2014). It has been demonstrated that improving spatial capabilities not only benefits orientation behavior, but also has a positive impact on the recovery of other areas, such as motor, mood and social relationships (Barrett and Muzaffar 2014; Faria et al. 2016).

The applications of Virtual Reality (VR) or Augmented Reality (AR) allow to obtain objective indicators of the person's spatial memory through a presentation of stimuli (varied and diverse) and the record of responses (reaction times, successes-failures, distance traveled, speed, etc.) (e.g., Picucci, Caffò, and Bosco 2011; Juan et al. 2014). This type of applications suppose an advantage with respect to the assessment and training of the person in a natural environment (temporary, economic cost, etc.). Therefore, the use of VR/AR in the study of human spatial ability is becoming more frequent. However, the VR applications are used in procedures developed in simple natural environments (rooms, laboratories, etc.), where the person interacts in the virtual environment, more or less complex, without physical displacement. For example, rooms where the person is sitting in front of a PC screen and performs a task exploring a VR environment (e.g., Cimadevilla et al. 2014; Picucci, Caffò, and Bosco 2011; Walkowiak, Foulsham, and Eardley 2015). However, it has been shown that the physical displacement component is important in spatial ability (Ruddle and Lessels 2006; Ruddle and Lessels 2009). In this sense, the National Spanish Project "CHILDMNEMOS" developed systems to assess the memory involving movement and using different types of technology and devices. This thesis is part of this project and its contribution focuses on the use of auditory stimuli.

In the CHILDMNEMOS project, Handheld Augmented Reality involving only visual stimuli was used for developing the ARSM task (Juan et al. 2014; Méndez-López, Pérez-Hernández, and Juan 2016). The basic principle of the ARSM task was to show objects in a physical location and had the children remember where they were. The number of objects/locations to be retained increased throughout the task depending on the performance in previous trials. The ARSM task consisted of seven different levels and each level contained a maximum of seven trials. The physical place for testing was a square of about 5 meters on each side. It was surrounded by light brown paper to a height of 1.5 meters. This height was considered to be enough for an egocentric reference. The objects appeared inside boxes that were placed in the real environment. The size of the boxes used was: 26x35x25 cm. To distribute the boxes, a circle with a radius of 1.85 meters was used. The center of the circle was the position of the user. The angle between boxes was defined by the number of boxes and was the same for all of them. To run the ARSM task, a tablet (Motorola Xoom 2 Media Edition) was used. In another work, a VR task that used only visual cues was developed, the MnemoCity task (Rodríguez-Andrés et al. 2015; Rodríguez-Andrés et al. 2018). The VR environment consisted of a city square that was surrounded by several buildings and three tables on which the objects to be remembered appeared. The main objective of the user in the MnemoCity task was to search for objects and remember their location in the VR environment. The MnemoCity task had six levels: an interaction adaptation level, a habituation level, and four levels for the main task. The MnemoCity task incorporated two types of interaction: 1) Based on standard interaction that did not required physical movement. It used a gamepad (B-Move Gamepad BG Revenge); 2) Based on natural interaction involving physical movement. It used a Wii Balance Board and a Wii Mote with the wheel accessory. The user moved in the virtual environment by physically walking on a Wii Balance Board. A change in direction was achieved by turning a wireless steering wheel. The task was displayed on a large screen with 120 inches. Passive 3D was used for the visualization. The user had to wear linear polarized glasses to perceive the 3D sensation. In another work, a Virtual Maze Task was also developed (Cárdenas-Delgado et al. 2017a). As in the previous work, the VR task used only visual cues. This task also incorporated two types of interaction: 1) Inactive condition, with no physical movement. As in previous work, a gamepad was used (B-Move Gamepad BG Revenge); 2) Active condition, involving physical movement. The task used a real bicycle (GT mountain bike). The participant controlled the navigation and the 3D bicycle (avatar) by using the physical bicycle. When he/she pedaled the physical bicycle, he/she moved forward in the virtual maze. The participant was also able to control the turns by using the handlebar. For visualization, the task used a VR HMD (Oculus Rift). The maze had nine intersections, a wall of hedges that were two meters high and pathways of grass that were two meters wide. Different animals were placed on the route. They worked as visual cues for facilitating the learning of the route. The task had three stages: habituation, learning, and testing. The habituation stage trained participants to handle the system properly. In the learning stage, the participants should learn the path. In the testing stage, the participant should remember and follow the same route that was followed in the learning stage.

As far as we know, the combination of NUI and smart devices has not been exploited to assess cognitive processes, and in particular, for the assessment of spatial memory using auditory stimuli in a wireless and attractive way. From our point of view, this technology is on the right track for being a good complement of the traditional assessment processes in the field of neuropsychology. The development of new systems for neuropsychological assessment represents an important tool for the assessment of memory as a cognitive function that is linked to various intellectual and social activities, and also, as mentioned, for the identification of impairments in it. Tools of this type could contribute to a better understanding of the influence of different variables on cognitive function.

1.2 Scientific goals and research hypotheses

The main objective of this thesis was to develop and validate an interactive game for assessing spatial memory using auditory stimuli. The game incorporated Natural User Interfaces in combination with smart devices. For the validation, three studies were carried out to determine how auditory stimuli and physical movement contribute for the assessment of spatial memory in children and adults. Furthermore, this thesis focused on studying and comparing different factors and performance measures between data collected with the interactive game and traditional tools. We also assessed other aspects such as usability, fun, and overall satisfaction.

To achieve the main objective a task was designed and developed, and three different studies were carried out.

1.2.1 Design and development of a new task that combines NUI and smart devices:

A task that combines NUI and smart devices for interaction was developed from scratch. The task is played in a physical real environment. The task uses gesture interaction to recognize movements (Kinect^{TM}) and smart devices with auditory stimuli (Karotz rabbits) as the visual/auditory interface. The task tests the child's ability to detect and localize auditory stimuli that are emitted in different positions of the task area. The task consists of 5 levels. Each level consists of 3 trials. The difference between levels lies in the number of sounds to be used in each trial, which increases by 1 at each subsequent level. Each level is related to a specific theme. The chosen themes were: nature, a party, a farm, a house, and a big city.

Three studies were carried out:

Study 1. Inattentive children vs. control group

In this study, two groups of children were considered.

- The group of children with symptoms of inattention (inattentive group). This group scored within the clinically significant range in the Attention Problems subscale of the Behavioral Assessment Scale for Children - Parent Report form (BASC) (Reynolds and Kamphaus 1992).
- The participants of the control group were children who scored within the range of normality in the BASC.

The goals of the study were:

- To obtain indicators of the participating children with the task and traditional methods for the assessment of spatial and auditory memory.
- To compare the performance obtained by using the task and the traditional methods between the two groups of the study (i.e., the inattentive group and the control group).
- To compare the outcomes obtained on a questionnaire about satisfaction and interaction between the two groups.

The first of our hypothesis (H1) was that there would be statistically significant differences for the outcomes obtained in the task and the traditional tools between the children with symptoms of inattention and the children without symptoms of inattention in favor of the control group. The second hypothesis (H2) was that there would not be statistically significant differences in the outcomes for satisfaction and interaction with the task between the children with symptoms of inattention and the children without symptoms of inattention.

Study 2. Older children vs. adults

In this study, two groups were considered.

- Healthy children, with ages ranging from 9 to 10 years old (older children group, for differentiating from younger children that participate in the third study).
- Healthy adults, ranging in age between 18 and 28 years old.

The objective of this study was to test the capability of the task to assess spatial memory in older children and adults. The participants' performance on the task and traditional methods were evaluated and compared. We also compare the outcomes obtained on the questionnaire about perceptions and satisfaction between the two groups of participants.

The third hypothesis (H3) was that there would be statistically significant differences for the performance outcomes obtained with the task between older children and adults in favor of the adults. The fourth hypothesis (H4) was that there would be statistically significant differences in the level of satisfaction with the task between older children and adults in favor of the older children.

Study 3. Small children vs. older children vs. adults

In this study, three groups were considered.

- Healthy children, with ages ranging from 5 to 7 years old (younger children).
- Healthy children, with ages ranging from 8 to 10 years old (older children group).
- Healthy adults, ranging in age between 18 and 28 years old.

The objective of this study was to test the capability of the task to assess spatial memory in younger children, older children and adults. The participants' performance on the task and traditional methods were evaluated and compared. We also compare the outcomes obtained on the questionnaire about perceptions and satisfaction between the three groups of participants.

The fifth hypothesis (H5) was that the results of the task will reflect the capacity of the task to assess short-term spatial memory for both children and adults, offering significant correlations with respect to traditional procedures.

1.3 Thesis structure

The thesis document is structured as follows:

Part I. This part introduces the thesis, including the motivation, the scientific goals, the research hypotheses, the studies carried out, the organization of the document and enumerates the publications derived from this thesis.

Part II. This part presents a selection of the most representative papers supporting this thesis which were published in conferences and journals. Specifically, it includes three papers.

Paper 1. It describes the first study of the thesis. It deals with the assessment of spatial memory using auditory stimuli with inattentive children and a control group. The performance in the task and traditional methods were considered for both groups.

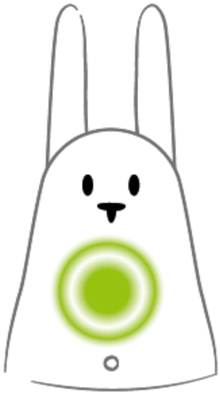
Paper 2. It describes the second study of the thesis, which consists of the assessment of our task with older children and adults. The performance in the task and traditional methods were considered for both groups.

Paper 3. It describes the third study of the thesis, which consists of the assessment of our task with younger children, older children and adults. The performance in the task and traditional methods were considered for the three groups.

Part III. This part discusses the results of the thesis, summarizes the work with the general conclusions and future works.

Part II

Selected Papers



Chapter 2

Auditory and Spatial Assessment in Inattentive Children Using Smart Devices and Gesture Interaction

"Our greatest glory is not in never having fallen, but in getting up every time we fall"

Oliver Goldsmith

Contents

Mauricio Loachamín-Valencia, M.-Carmen Juan, Magdalena Méndez-López, Elena Pérez-Hernández. "Auditory and Spatial Assessment in Inattentive Children Using Smart Devices and Gesture Interaction", In: IEEE 17^{th} *International Conference on Advanced Learning Technologies (ICALT 2017). pp. 106 - 110. DOI:* https://doi.org/10.1109/ICALT.2017.28

Abstract

We present an interactive game for assessing auditory and spatial memory. We compared the performance of children with and without inattention using the game and using a variety of classical tools for assessment of auditory and spatial memory. The children with inattention showed statistically worse performance in the game. There were no statistically significant differences between the two groups for the satisfaction and interaction outcomes. Therefore, our game could be a good tool for distinguishing performances of children with and without inattention.

2.1 Introduction

Classical methods for testing cognitive skills are sometimes not exciting, especially for children. However, they are of interest for the psychological assessment of children's cognitive profile, especially in the field of cognitive disabilities. Beside this, one of the most frequent behaviors of children is inattention (Williams, Wright, and Partridge 1999). The symptoms of inattention represent a problem when children participate in different learning contexts that require substantial amounts of attention. Therefore, we need to develop assessment tools that facilitate keeping children's attention focused on the task while they are learning. In this regard, computer technology has been incorporated in psychology to improve the engagement of children during learning or assessment experiences. Computer-based, Kinect-based, and videogame tasks have shown positive results even in children with attention difficulties (Drigas et al. 2014; Altanis et al. 2013). We suggest that they could be good options for testing spatial assessment for auditory stimuli of children with symptoms of inattention. Knowing more about how inattentive children learn this type of information is of great interest. The classical psychological assessment tools have shown spatial-related deficits on a variety of specialized tests (Rourke 1993). These deficits have implications for daily life and academic outcomes

(Rourke 1993). However, to our knowledge, no work has yet been conducted to test auditory spatial memory in children with attention difficulties using a game based on smart devices and gesture interaction. We suggest that this game might be useful in this population for several reasons: it reduces the efforts of attention required by the user to interact with the system; it allows the creation of an attractive environment; it facilitates motivation in players; and it allows the stimuli presentation and the objective registration of the performance variables to be controlled.

The goals of the study are: (1) to develop an assessment game that is able to recognize gestures and integrate gesture recognition with smart devices; (2) to obtain indicators of the participating children on traditional tools for the assessment of spatial memory and auditory memory; (3) to compare the performance obtained by using the game and the traditional tools between the two groups of the study (i.e., the inattentive group and the control group); (4) to compare the outcomes obtained on a questionnaire about satisfaction and interaction between the two groups.

Our main hypotheses are: (1) there would be statistically significant differences for the outcomes obtained in the game and the traditional tools between the children with symptoms of inattention and the children without symptoms of inattention; (2) there would not be statistically significant differences in the outcomes for satisfaction and interaction with the game between the children with symptoms of inattention and the children without symptoms of inattention.

2.2 Methodology

2.2.1 General Description of the Game

The game uses gesture interaction to recognize movements (Kinect^{TM}) and smart devices with auditory stimuli (Karotz rabbits) as the visual interface. The game is a serious game. The game tests the child's ability to detect and localize auditory stimuli that are emitted in different positions of a game area (see Figure 2.1). The walls were covered with wrapping paper to eliminate any spatial cues. From the player's perspective, the game consisted of guessing the rabbit that emitted a sound. The rabbits were identical, so the only difference among them was their placement in the room. The advice to the player is to concentrate on the rabbits' locations and memorize them. Kinect was used to detect that the players raise their arms in front of a Karotz rabbit. This action indicates that the player has selected the Karotz rabbit that is in front of him or her (see Figure 2.2).

Figure 2.1: Game area.

Figure 2.2: Child rasing her arms in front of a Karotz rabbit.

Each Karotz rabbit emitted its assigned sound. The game included a total of 45 acoustic stimuli, which were randomly emitted in different locations to avoid repetitions or established sequences. The game is composed of five different levels based on the number of stimuli presented in each trial. Each level is related to a specific theme which includes: nature, a party, a farm, a house, and a big city. The acoustic stimuli were distributed as follows: Level I (1 acoustic stimulus for each trial, 3 stimuli in total); Level II (2 acoustic stimuli for each trial, 6 stimuli in total); Level III (3 acoustic stimuli for each trial, 9 stimuli in total); Level IV (4 acoustic stimuli for each trial, 12 stimuli in total); and Level V (5 acoustic stimuli for each trial, 15 stimuli in total).

The game had two phases: the detection phase and the location phase. In the detection phase, the children first listened to instructions through the loudspeakers. Then, they listened to the stimulus that the Karotz rabbit emitted and learned its location. The stimuli were emitted constantly. Then, the children moved to the location and raise their arms in front of the Karotz rabbit in order to select it (detection). In the location phase, the children first listened to instructions through the loudspeakers and the stimulus that had to be located. In the detection phase, the children had to remember the location from where the stimulus was emitted (sound). The stimuli were only emitted once. Then, the children had to move to the correct location and raise their arms in front of the Karotz rabbit in order to select it. Afterwards, they returned to the initial position. Their answers were recorded as successes or failures. In order to test a child's ability to recall a higher number of stimuli and locations, the number of stimuli and locations increased based on the progress at each level. The number of chances for completing a level was determined by the number of successes and/or failures. If all of the stimuli of a given trial were located correctly, then the trial was successful. However, if a stimulus of the trial was not correctly located, then the trial was a failure. If there was at least one successful trial within the three trials of a given level, the children could advance to the next level. In any case, the children have to perform the three trials. However, if they failed the three trials at any of the levels, the game ended. This was to keep the child from becoming frustrated with a higher number of incorrect responses that would impact subsequent performance on the game. Also, the game ended when the participant completed Level V.

2.2.2 Hardware and Software

We used five Karotz rabbits and two Microsoft Kinect V_1 devices for our game. The Karotz rabbits are shaped like a rabbit and are 30 cm tall (Figure 2.1). They can connect to the Internet through a wireless access point. They have loudspeakers, a webcam, an LED-light (in their bellies), and they can move their ears. The Microsoft Kinect v1 devices include a RGB camera with a resolution of 640x480 pixels, an infrared camera, an infrared projector, and a multiarray microphone.

We used an HP computer with an Intel i5 processor and Windows 7 operating system. This computer had USB ports connected to a separate USB host controller. This allowed two Kinect to be used simultaneously. Additionally, this computer was used as the server. We used a wireless-G Router with WAN port for networking and accessing to Internet. This Internet access was required by the five Karotz rabbits and the computer. Two conventional loudspeakers were used to give instructions during the game (see Figure 2.1).

The system that manages the procedure during the game and the graphical interface for the supervisor was developed with VisualBasic 2008 Express Edition. To program the Kinect device, we used Visual C++ 2010 Express Edition, Kinect SDK 1.8, OpenNI 2.0 SDK, and Nite. The system has three modules: one to configure and manage the Karotz rabbits, their IPs, and the IP of the sounds server; one to register the participant's information and for the evaluation process; one to manage the communication among the Karotz rabbits and the Kinect devices.

When the communication module is executed, the system receives data from the two Kinect devices, and the information of the Karotz rabbit chosen. After receiving this information, a function sends an activation message to the selected Karotz rabbit. This selected Karotz rabbit executes the function for emitting the message to the player, turning on lights, and moving its ears. The lights can be of different colors. The color green in the belly of a Karotz rabbit indicates that the system is ready to start. The color blue indicates success. The color orange indicates failures. The color white indicates that the Karotz rabbit is expecting the player's response. The color red indicates missed communication with the server.

The rest of the Karotz rabbits enter in a waiting process. Then, the selected Karotz rabbit sends a message to the system for the rest of the Karotz rabbits to end the waiting process and to execute the reset function to reset and start the next communication loop.

The management module of the Karotz rabbits contains a function that runs the services that were developed for each Karotz rabbit. These services allow the recognition of the IP of the selected Karotz rabbit, assign the auditory stimulus that must be emitted, and decide whether the Karotz rabbit must enter in the waiting process, the emission state, or the reset process.

The system has a graphical interface that allows the supervisor to introduce the player's information and observe the performance carried out by the player (i.e., trials, successes, and failures). The database of the system recorded successes or failures in the detection and location of stimuli.

2.2.3 Study Sample

A total of 34 children participated in the study. The group with symptoms of inattention (the IN Group) was comprised of 17 children (boys = 9, girls = 8). This group scored within the clinically significant range in the Attention Problems subscale of the *Behavioral Assessment Scale for Children* - Parent Report form (BASC) (Reynolds and Kamphaus 1992). The participants of the control group (the C Group) were 17 children who scored within the range of normality in the BASC (boys = 9, girls = 8). The IN Group and the C Group were matched by age and gender: 6-year-olds (one boy and four girls); 8-year-olds (three boys and one girl); 10-year-olds (five boys and three girls). The children's *Intelligence Quotient* (IQ) was similar for the two groups (IN Group IQ score (mean ± standard deviation) = 103.65 ± 11.66, C Group IQ score (mean ± standard deviation) = 107.47 ± 11.82, ($F_{[1,32]} = 0.901$, $p = 0.35$)). The IQ score was calculated using the RIST (Reynolds and Kamphaus 2009).

2.2.4 Measures Used in the Study

We assessed the children's memory ability during the game by considering the following variables: *Percentage of Correct Trials* (PCT), *Percentage of Correct Stimuli* (PCS), *Number of Correct Levels* (NCL), *Time* (T), *Number of Errors* (E) and *Approximation-Errors* (AE). PCT was the percentage of trials that a player could successfully complete. PCS was the percentage of stimuli that a player could successfully locate. NCL was the sum of the number of levels correctly performed. T was the total time in seconds that a player spent to complete the game. E was the sum of the number of errors that a player could commit. Finally, AE was the sum of the number of errors committed by pointing to a spatial location that was placed adjacent to the correct location.

2.2.5 Assessment with Traditional Methods

For the assessment of visuospatial memory, we selected the TOMAL (Reynolds and Bigler 2001) subtest: *Memory for Location* (ML). This subtest consists of a spatial recall task of one or more dots that appear within a grid printed on paper. In order to assess immediate retrieval of auditory items, we used two verbal span subtests of the TOMAL: *Digits Forward* (DF) and *Digits Backward* (DB). The DF is a number recall task that measures low-level rote recall of a sequence of numbers. The DB task (a variation of the DF task) consists of a recall of a sequence of numbers but in reverse order. For the assessment of auditory and phonological discrimination, we selected the EDAF (Brancal et al. 2009) subtests: *Auditory Sequential Memory* (ASM), *Environmental Sound Discrimination* (ESD), and *Auditory Figure-Ground Discrimination* (AFGD). The ASM is a word repetition task. The ESD is a discrimination task about sounds of the environment that are played on a CD. Finally, the AFGD is a discrimination task in which the participant listens to two sounds simultaneously for a few seconds and must point to the two pictures that correspond to the sounds.

2.2.6 Satisfaction and Interaction with the Game

We designed a Satisfaction and Interaction Questionnaire (SIQ). The SIQ included questions about satisfaction (SQ), and questions about the interaction with the game (IQ) (Table 2.1). The questions used a Likert scale with values (1–5) ($1 \rightarrow$ *low* and $5 \rightarrow$ *high*).

2.2.7 Procedure of the Study

The parents of all the potential participants completed the Parent Report form of BASC (Reynolds and Kamphaus 1992). Afterwards, the children completed the RIST (Reynolds and Kamphaus 2009). Participants were tested individually in two sessions, which were conducted on a classroom. In the first session, each participant did the activities using the traditional methods. The sequence was as follows: DF, ML, DB, ASM, ESD, and AFGD. In the second session, each participant interacted with the game. Once the participant had completed this game, he/she answered the SIQ. The participants were accompanied by a supervisor. The supervisor administered the activities and questionnaires. The study was conducted in accordance with the European Directive 2001/20/EC and the Helsinki Declaration for biomedical research involving humans. The research protocol was approved by the Ethics Committee of the Universitat Politècnica de València (Spain).

Table 2.1: Satisfaction and interaction questionnaire (SIQ).

Q	Questions
SQ1	How much fun did you have ?
SQ2	Would you recommend this game to your friends ?
SQ3	Would you like to use this game on another occasion ?
SQ4	Score the game from 1 to 5
IQ1	How easy was the game to use ?
IQ2	Did you understand the rules of the game ?
IQ3	Was it easy to select the sounds by raising your arms ?
IQ4	Did you like the interaction with the rabbits ?

2.2.8 Statistical Analysis

Levene's test was applied to check the assumption of homogeneity variance for all of the measures. The E and AE variables did not fit the normal distribution, so we conducted the Mann-Whitney U test for unpaired data. For the remaining variables, a one-way ANOVA was conducted to evaluate differences between the IN Group and the C Group. Mann-Whitney U tests were performed and r effect sizes were calculated for the SIQ data. In all instances, significance was accepted when $p < 0.05$.

2.3 Results

2.3.1 Outcomes Using the Game

The IN Group performed worse in the game than the C Group (see Table 2.2). The results of the comparisons indicated statistically significant differences for the variables related to successes (PCT, PCS, and NCL). Also, the IN Group committed a significantly higher number of errors (E and AE). There were no statistically significant differences in the time spent by each group to complete the game.

Table 2.2: One-Way ANOVA and Mann-Whitney U test for the outcomes obtained using the game.

	C	**IN**	***d.f.***	***F***	***p***
PCT	84.60 ± 4.40	61.34 ± 4.83	$1,32$	12.64	0.001*
PCS	88.43 ± 4.42	66.73 ± 4.79	$1,32$	11.06	0.002*
NCL	3.47 ± 0.35	1.94 ± 0.29	$1,32$	11.13	0.002*
T	582.0 ± 47.0	540.0 ± 53.0	$1,32$	0.36	0.550
	C	**IN**	***U***	***Z***	***p***
E	2.29 ± 0.61	14.35 ± 0.15	40.50	-3.61	< 0.001*
AE	1.58 ± 0.36	5.35 ± 0.14	46.00	-3.43	0.001*

Data represent Mean ± SEM values on the C Group and IN Group. * indicates significant differences. C = Control group, IN = Inattention group, PCT = Percentage of Correct Trials, PCS = Percentage of Correct Stimuli, NCL = Number of Correct Levels, T = Time, E = Number of Errors, AE = Number of Approximation-Errors.

2.3.2 Outcomes Using Traditional Methods

Table 2.3 shows the results and statistics. The performance scores on the subtest ML did not show significant differences between the two groups. Based on this subtest, both groups had similar visuo-spatial memory. Similarly, there were no statistically significant differences between the two groups in the performance scores indicating the participant's ability to discriminate sounds (ASM, ESD and AFGD). Both groups had similar auditory and phonological discriminations skills. The scores of the two verbal span subtests (DF and DB) showed that the two groups had similar ability to recall a sequence of numbers in reverse order (DB), but the IN Group did worse than the C Group on the forward version (DF).

2.3.3 Satisfaction and Interaction Outcomes

There were no statistically significant differences between the C Group and the IN Group. The children's satisfaction was favorable, as shown in Table 2.4. In addition, the scores related to usability were very high.

Table 2.3: One-Way ANOVA for the outcomes obtained using the traditional methods.

	C	**IN**	***d.f.***	***F***	***p***
ML	13.06 ± 0.89	11.00 ± 1.07	$1, 32$	2.17	0.150
DF	8.70 ± 0.61	6.52 ± 0.47	$1, 32$	7.96	0.008*
DB	11.05 ± 0.59	10.64 ± 0.75	$1, 32$	0.18	0.670
ASM	9.70 ± 0.49	9.41 ± 0.49	$1, 32$	0.18	0.675
ESD	14.17 ± 0.23	14.35 ± 0.15	$1, 32$	0.41	0.523
AFDG	5.29 ± 0.19	5.35 ± 0.14	$1, 32$	0.06	0.806

Data represent Mean ± SEM values on the C Group and IN Group. * indicates significant differences. C = Control group, IN = Inattention group, ML = Memory for Location, DF = Digits Forward, DB = Digits Backward, ASM = Auditory Sequential Memory, ESD = Environmental Sound Discrimination, AFDG = Sound Discrimination and Pointing task.

2.4 Discussion and Conclusions

To our knowledge, no study has tested this type of assessment using the technology proposed by us. Similarly, there are no published tools that focus on the assessment of auditory-spatial memory in children with symptoms of inattention.

The outcomes of children with symptoms of inattention were not as good as the outcomes obtained by children without these symptoms for the game or for the traditional method of testing the memory of verbal sounds. However, they had no difficulties for auditory discrimination of verbal and environmental sounds. We believe that our game promoted greater cognitive effort. Therefore, we suggest that the cognitive effort needed to solve this game plays a crucial role in the detection of the difficulties presented by children with symptoms of inattention. The game requires constant attention and concentration. Children with inattention have difficulty sustaining attention over time (Williams, Wright, and Partridge 1999). Besides these problems, there is also impaired performance on tasks of spatial memory (Arai et al. 2016).

The symptoms of inattention did not affect the time spent to complete the game. The features of our game resulted in an engaging activity. Several studies showed that inattentive children were good on computer-based tasks (Drigas et al. 2014). We suggest that our game can help to keep the participant's attention because he/she can move with some freedom in a new fun

Table 2.4: Satisfaction and Interaction outcomes.

	C	IN	*U*	*Z*	p	r
SQ1	[5]; [0]	[5]; [0]	161.5	1.049	0.601	0.180
SQ2	[4]; [1]	[4]; [1]	157.0	0.478	0.748	0.082
SQ3	[5]; [1]	[5]; [1]	130.0	-0.558	0.645	0.096
SQ4	[5]; [1]	[5]; [0]	138.5	-0.269	>0.99	0.046
IQ1	[4]; [1]	[4]; [1]	158.5	0.522	0.633	0.089
IQ2	[5]; [0]	[5]; [1]	179.5	1.634	0.178	0.280
IQ3	[5]; [1]	[5]; [1]	158.0	0.562	0.616	0.096
IQ4	[5]; [1]	[5]; [0]	125.0	-0.871	0.438	0.149

Mann-Whitney U test analysis and r effect size for the Satisfaction and Interaction Questionnaire, and C Group and IN Group. [ ];[ ] indicate [Medians];[Interquartile range].

environment. This is an advantage of our game, since most children who experience this disorder have a low level of motivation to complete demanding tasks (Holroyd et al. 2008). There seem to be several possible motivations for players: the physical immersion, the ability to move one's body, the ability to get feedback from the devices, and the perceptions of the game as a real experience.

The results indicate that our game was easy to use. Several authors argued that perceived ease of use is an important technical factor that affects educational effectiveness (Pei-Chen et al. 2008). The children with symptoms of inattention had fun while they interacted. This is a very important result as they have difficulty maintaining their commitment to the task or remaining motivated towards achieving a goal (Holroyd et al. 2008). The results indicate that the children liked interacting with their own body movements (Kinect), and they perceived the interaction with the Karotz rabbits as being easy and fun. The gesture detected by Kinect is understood as a magical way of communication with the rabbits, increasing the attractiveness of the game. These results are in line with a study showing that a Kinect-based game was interesting and an engaging activity for children (Homer et al. 2014).

Our results are also in line with a work suggesting that natural interaction with the user positively influences the perception of performance and quality of the interaction with the devices (Lim et al. 2011). This may also be due to the physical aspect of the Karotz, the movement of their ears, the messages emitted, and the bright colors on their bellies when the child gets a response. Our informal observations confirmed that most of the children were unaware of the supervisor and that sometimes they spoke to the rabbits. The possible influence of the novelty effect on the positive perception of the system should also be taken into account (Wells et al. 2010).

We conclude that our game offers a great opportunity to assess both auditory and spatial information in children. The game is a good tool for distinguishing these difficulties in children with symptoms of inattention. Knowledge about how they learn in different smart environments provides a basis for understanding their cognitive strengths and weaknesses, besides contributing to the development of new ways of learning. Other factors that could impair performance of the group with inattention (i.e., intelligence and sound discrimination) were controlled. In addition, the memory difficulties of the IN group did not compromise their favorable perception about the game. Our game facilitates the control of the presentation of stimuli and the recording of responses. We assume that a supervisor of the experience could make some mistakes due to distraction and/or tiredness, among other causes.

Nevertheless, our specific proposal has a drawback since the Karotz rabbits are no longer being manufactured. However, other types of affordable smart devices that allow interaction are available. Therefore, our idea could serve as a basis for the development of new systems.

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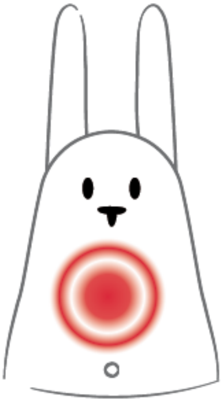

Chapter 3

Using a Serious Game to Assess Spatial Memory in Children and Adults

"You never fail until you stop trying"

Albert Einstein

Contents

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Abstract

Short-term spatial memory has traditionally been assessed using visual stimuli, but not auditory stimuli. In this paper, we design and test a serious game with auditory stimuli for assessing short-term spatial memory. The interaction is achieved by gestures (by raising your arms). The auditory stimuli are emitted by smart devices placed at different locations. A total of 70 participants (32 children and 38 adults) took part in the study. The outcomes obtained with our game were compared with traditional methods. The results indicated that the outcomes in the game for the adults were significantly greater than those obtained by the children. This result is consistent with the assumption that the ability of humans increases continuously during maturation. Correlations were found between our game and traditional methods, suggesting its validity for assessing spatial memory. The results indicate that both groups easily learn how to perform the task and are good at recalling the locations of sounds emitted from different positions. With regard to satisfaction with our game, the mean scores of the children were higher for nearly all of the questions. The mean scores for all of the questions, except one, were greater than 4 on a scale from 1 to 5. These results show the satisfaction of the participants with our game. The results suggest that our game promotes engagement and allows the assessment of spatial memory in an ecological way.

3.1 Introduction

The terms gamification or serious games are commonly used interchangeably to refer to the use of games in non-game contexts. According to Deterding et al. (2011), gamification refers to the use of design element characteristics for games in non-game contexts. The underlying idea of serious games is to combine game playing with a serious purpose (i.e., cognitive testing) (Wiemeyer and Kliem 2012). Several works have suggested that serious games help in the learning process when they are used in relevant contexts that engage learners (e.g., (Catalano, Luccini, and Mortara 2014)). For example, serious games have also been previously used for individuals with autism for learning purposes (Whyte, Smyth, and Scherf 2015); as an assessment tool for cognition and performance in an activity of daily living (in their case, cooking); or for training of cognitive functions in older adults (Kim et al. 2015).

Psychological science is interested in the assessment of a human's ability to learn about spatial and auditory information in different situations and contexts. Memory can be divided into short-term memory and long-term memory, depending on whether the information to be stored is useful for a limited period of time or is relevant to be stored stably for any future need (Lezak 1995). Spatial and auditory memories have the capacity to store representations of spatial and auditory stimuli, respectively. Spatial memory allows us to find a place that we have visited before, follow a route after consulting a map, or remember where we left our belongings, among other examples. The assessment of spatial memory contributes to the understanding of individual differences in behavior and helps to prevent and detect pathology (Lezak 1995). From a psychological perspective, there has been research interest in the ability to learn spatial and auditory information. The reason is that they are significant processes in daily life. Spatial learning is associated with academic outcomes (Rourke 1993) and with the functional maturation of the frontal pole (Arai et al. 2016). Auditory learning facilitates taking notes while listening, written expression, and oral expression (Dehn 2008). Some learning and behavioral problems are related to impairments in these processes (Graham and Heywood 1975; Rauscher, Krauss, and Chen 1996). Also, many learning experiences require considering auditory and spatial information simultaneously. Some examples are orientation in space and identification of people or objects. Since there are no procedures for assessing spatial learning for auditory stimuli, its implications for different types of learning remain unclear.

To our knowledge, the combination of Natural User Interfaces (NUI) and smart devices has not been explored for the assessment of cognitive processes, and especially for the assessment of spatial memory using auditory stimuli. We believe this combination promotes engagement and allows assessment in an ecological way. The development of new games for neuropsychological assessment represents an alternative for the evaluation of memory. These tools can be used for assessment as well as for training.

The objectives of our work are the following: to develop a game that is able to recognize gestures and integrate gesture recognition with smart devices; to obtain indicators of the participants' performance; to compare the performance obtained by using the game between the two groups of the study (i.e., children and adults); to compare the outcomes obtained on a questionnaire about perceptions and satisfaction and between the two groups.

A sample composed of adult participants is considered to determine the maximum performance with the game. We compare the performance between adults and children in order to determine whether or not the children achieve full competence in the game. Therefore, our research questions are the following: (RQ1) Is the new game a valid tool for assessing spatial memory? (RQ2) Are the performance outcomes obtained with the game between children and adults different? (RQ3) Is the level of satisfaction with the game between children and adults different?

In order to answer the research questions we proceed as follows: (RQ1) We observe the correlations between the outcomes obtained in the game and traditional tools; (RQ2) We check if there are statistically significant differences in the performance outcomes obtained with the game between children and adults; (RQ3) We check if there are statistically significant differences in the level of satisfaction between children and adults.

3.2 Background

3.2.1 Gesture Interaction

Human body motion and gesture recognition have received increasing attention (e.g., Khan and Ibraheem 2012; Pisharady and Saerbeck 2015). Since the arms and, in particular, the hands are used to gesture and are a natural means of communication among humans, they are also of importance in Human-Computer Interaction. Arm-motion recognition has been achieved through sensor-based and vision-based techniques. For sensor-based recognition, different sensors have been used to capture the position and orientation of the arms (e.g., accelerometer (Agrawal et al. 2011), or sensors worn on the body (Park et al. 2011)). The vision-based methods use images obtained through cameras/sensors, extract their characteristics, and analyze the actions performed by users. Recognition can be static or dynamic. Static gestures are time independent, whereas dynamic gestures are time dependent. The cameras/sensors can be of different types, color cameras (RGB), or color-depth cameras (RGB-D). Pisharady and Saerbeck (2015) reviewed conventional hand-gesture recognition using RGB cameras as well as recognition using RGB-D sensors. Pisharady and Saerbeck (2015) classified the techniques used for dynamic hand-gesture recognition as: (a) Hidde Markov Models (e.g., Beh et al. 2014) and other statistical methods (e.g., Suk, Sin, and Lee 2010); (b) Artificial Neural Networks (e.g., Yang, Ahuja, and Tabb 2002) and other learning based methods (e.g., Shen et al. 2012); (c) Eigenspace-based methods (e.g., Patwardhan and Roy 2007); (d) Curve fitting (Shin, Tsap, and Goldgof 2004); and (e) Dynamic programming (Kuremoto et al. 2013)/Dynamic time warping (e.g., Corradini 2001). Depth sensors have already been used in computer vision for many years both commercial and non-commercial (e.g., Breuer, Eckes, and Müller 2007). An example of a non-commercial depth sensor is an IR Time-of-Flight Range Camera (Breuer, Eckes, and Müller 2007). However, the appearance of low-cost, color-depth cameras/sensors led to a much more widespread use than their predecessors. Two of these sensors were Kinect™ (Zhang 2012; Shotton et al. 2011) by Microsoft, and Xtion PRO LIVE by ASUS. Sensors of this type provide reliable tracking of human body postures and obtain the coordinates of a skeletal model. These coordinates can be used for human body motion and gesture recognition.

Low-cost, color-depth sensors have been used extensively for gesture interaction, and they have contributed to different areas. One of these areas is serious games. For example, Martín-SanJosé et al. (2014) presented a game for learning historical ages. The researchers proposed a custom-built touch table and used the Microsoft Kinect™ sensor for hand-gesture recognition. They used this table to compare a personalized, free-learning itinerary with a linear learning itinerary. Their results showed that there were no statistically significant differences between the two learning itineraries. In another game for the same purpose (Martín-SanJosé et al. 2014; Martín-SanJosé et al. 2017), this same group used Kinect™ for gesture interaction and autostereoscopic display for 3D perception. The interaction of the children was similar to the interaction that is used in our game. In their game, the children had to raise their hands to select the elements that appeared on the screen. In our case, the children also have to raise their hands. The main difference is that, in our case, the children did not have to select elements, just raise both arms. A similar proposal was also used for dental learning (Rodríguez-Andrés et al. 2017). Homer et al. (2014) determined the effects of interactivity in a Kinect-based literacy game for beginning readers. Those authors concluded that the activities in the game were not distracting. They were interesting and engaging activities for children, and they could support children's acquisition of language and literacy. Lim et al. (2011) presented a game for a child to play blocks in a natural and intuitive way. They concluded that the users (children and adults) could fully immerse themselves in the game and construct a complicated structure easily. The game facilitated the learning experience.

With regard to how gesture interaction can assist in populations with special needs, one of the biggest contributions of low-cost, color-depth sensors is related to improvement in sign-language recognition. Sun et al. (2013) proposed a discriminative exemplar coding for American sign-language recognition. Lee, Yeh, and Hsiao (2016) also proposed a system for Taiwanese sign-language recognition that showed a good recognition rate. The proposals demonstrated feasibility and effectiveness. Armin, Mehrana, and Fatemeh (2013) reviewed the potential offered by low-cost, color-depth sensors in the context of educational methods for teaching children with sensory disabilities. For example, a Kinect-based game could help blind children to learn the name of objects by establishing links between tactile information and sound information. The authors highlighted the usefulness of low-cost, color-depth sensors as an attractive learning technology.

There are also games for the physical training of motor skills in children with a developmental disorder using color-depth sensors (e.g., autism, attention deficit/hyperactivity disorder, etc.), e.g., Altanis et al. (2013). One of these games consisted of moving a girl along a path by using the movement of a hand (Altanis et al. 2013). The girl was shown on a TV screen or projector. The game aimed to train children in an engaging way and tried to keep their attention during the session. The game was compared with a classical procedure. There were significant improvements in motor learning of students with motor difficulties when the developed game was used. Similarly, another game showed positive effects for motor rehabilitation of children with cerebral palsy (Luna-Oliva et al. 2013).

3.2.2 Smart Devices

Smart devices, especially those with a human appearance, have contributed to the study of human learning. One of the most interesting examples of their contributions is related to the field of autism. Adolescents with a diagnosis of autism played a face-match card game using a humanoid robot (Jordan et al. 2013). They played in pairs with a partner of a similar age who had a physical impairment. The game consisted of a face match. There were three playing conditions to establish comparisons: playing with the robot; playing with a computerized touch-screen whiteboard; and playing with conventional cards. Although the results were variable, they showed the feasibility of using robots in a school setting. Humanoid robots were also used for verbal learning. Children could learn words for several real objects in their first language after watching a video of a robot naming them (Moriguchi et al. 2011). Even toddlers aged 18-24 months could learn several words from a robot (Movellan et al. 2009). Robots have also been considered for learning about geometry in preschool education (Keren and Fridin 2014). Children interacted with a Linux-based robot in the context of an educational game. The results showed positive effects of the experience with the robot in the learning of geometry. In addition, the interaction with this robot contributed to the spatial learning of three-year-old children (Keren, Ben-David, and Fridin 2012). Timms (2016) emphasized the importance of the physical embodiment of the devices used. However, other types of devices showed interesting findings. For example, children learned about natural environments with a handheld device shaped like a horn that was used during the exploration of a woodland (Randell et al. 2004). The horn provided non-speech audio sounds related to ecological sounds and the children had to interpret their significance (e.g., a light sabre sound means photosynthesis). The learning experience stimulated creativity and imagination in the children.

To our knowledge, the only study that has used the Karotz robot was presented by de Graaf, Allouch, and Klamer (2015). De Graaf et al. (2015) installed Karotz robots in the home of older people. The goal was to improve their health. The role of the Karotz robot was to work as a *personal assistant* who was interested in their progress and gave recommendations, such as controlling their weight.

3.2.3 Assessment of Spatial Memory

The assessment of spatial memory using visual stimuli has been carried out using different types of applications. For example, ARSM Task (Juan et al. 2014; Méndez-López, Pérez-Hernández, and Juan 2016) is a mobile augmented reality game for assessing spatial memory in children. The game was tested in a room with a size of about 5 m^2. Real boxes were placed in the room. Inside the boxes were image targets and the virtual objects appeared on these image targets. The game consisted of 7 levels, in which the number of boxes and virtual objects to remember increased (in Level I, there were 2 boxes and 1 object to remember; in Level II, there were four boxes and 2 objects to remember, etc.). Juan et al. (2014) found similarities in the results using ARSM Task and traditional methods. MnemoCity Task (Rodríguez-Andrés et al. 2016) had a virtual reality environment, with passive stereoscopy and natural interaction to evaluate spatial memory in children. The study compared two types of interaction: 1) a gamepad; 2) a steering wheel (with a built-in Wii RemoteTM control) and Wii Balance BoardTM. The steering wheel was used to determine the user's turns. The Wii Balance BoardTM was used to determine the participant's speed. The virtual environment recreated a park in which some tables were placed. The elements that the user had to locate appeared on the tables. Rodríguez-Andrés et al. (2016) also obtained correlations between their MnemoCity Task and traditional methods. Cárdenas-Delgado et al. (2017b) developed a virtual labyrinth to assess spatial memory in adults. In this virtual labyrinth, the participant had to remember the route in order to find the exit. In their study, two types of interaction were compared: a gamepad and a bicycle. Pedaling on the bike indicated the speed. The handlebar turns indicated the turns that the avatar had to make in the virtual world. The performance of the participants that was obtained with the labyrinth correlated with traditional methods.

There are several reasons for researchers to use gamification in the field of psychological assessment. The review of Lumsden et al. (2016) described these reasons after considering empirical studies that tested the possibilities of games applied to the training or assessment of cognitive skills. These games were developed for processes such as executive functions and memory, combining different processes in certain cases. Lumsden et al. (2016) mentioned some of the positive aspects that are related to the purpose of the assessment which include the following: the active involvement of the user and motivation; clearly determined goals; and the reduction of anxiety suffered during a testing session. This last aspect is very important for assessment in psychology, both for clinical and non-clinical populations.

3.3 Design and Development of the Game

3.3.1 Design of the Game

The game was designed to use Natural User Interfaces (NUI) and smart devices for managing auditory stimuli. For the NUI, the proposal was to use a low-cost, color-depth sensor to capture movements. We used Microsoft Kinect™, but other sensors could also be used. Karotz rabbits were proposed as smart devices. Figure 3.1 shows an image of a Karotz rabbit. The game was designed to test the users' ability to detect and localize auditory stimuli that are emitted in different positions of a game area (Figure 3.2). The game consists of guessing the rabbit that emitted a sound. However, the rabbits are identical. The only difference is their performance (sounds and movements of their ears). Therefore, the player must concentrate on the rabbits' locations and memorize them. Some communication codes were identified and defined. When a player raises his/her arms in front of a rabbit, it means "Hello, I know you did it". The rabbits move their ears and turn on lights when they want to get the attention of the player (which means “Hello, I’m here.”) or when they have understood the player’s response (which means “Agreed!”). The children are told that they have to hear the response of the Karotz when they raise their arms in order to be sure that the Karotz has understood their action. If this response is not emitted, the children must repeat the action. Figure 3.3 shows a participant that is raising his arms in front of a Karotz rabbit.

Figure 3.1: Karotz rabbit

Our game is framed in the short-term type of memory. We are interested in the ability of the participants to retrieve a sequence of locations of the auditory stimuli emitted. This sequence is also called “memory span”, which represents the capacity of short-term storage to retain spatial items. We are interested in determining the maximum capacity of each participant in this type of memory span. A participant that did not retrieve a certain memory span in a certain number of attempts would not have been able to retrieve a longer memory span. Based on our experience, we have established that the number of attempts in our game in each level is 3.

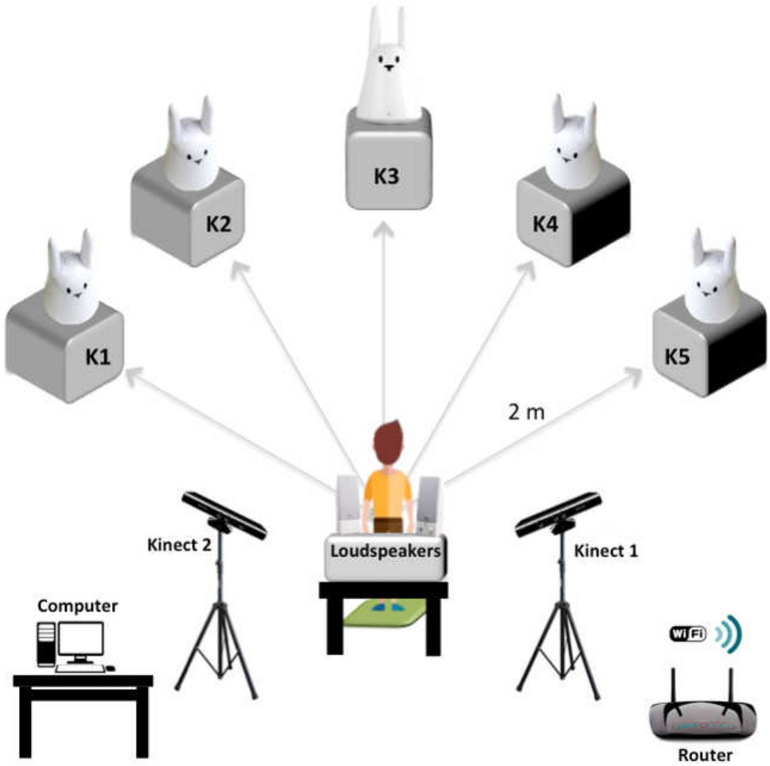

Figure 3.2: Diagram of the game area

Fifteen children participated in a preliminary study to determine which gestures were easier for Kinect^{TM} to recognize. It was determined that the most appropriate gesture for our game was to raise both arms at the same time in front of a Karotz. The identification was correct 95% of the time (when raising the arms and then lowering them immediately). To achieve 100% detection, the children were told to stand in front of a Karotz with their arms raised until they heard the message from the Karotz, which indicated that the Karotz had been selected ("Agreed!").

The area of the game for our study was defined to be around 5 m^2. Nevertheless, this area can be delimited within a room with larger dimensions. In our study, artificial turf was placed on the floor for guide paths, and a rug was used to indicate the initial position of the player. The walls were covered with wrapping paper to eliminate any spatial cues. The height of the Karotz rabbit

Figure 3.3: A participant raising his arms in front of a Karotz rabbit.

was adjusted by placing cardboard boxes on the tables. Five Karotz rabbits were placed on tables with the following locations (see Figure 3.2): Karotz rabbit 1 (−60°), Karotz rabbit 2 (−30°), Karotz rabbit 3 (0°), Karotz rabbit 4 (+30°), Karotz rabbit 5 (+60°). Each Karotz rabbit emits its assigned sound. The game included a total of 45 acoustic stimuli, which should be randomly emitted in different locations to avoid repetitions or established sequences. The game was defined to be composed of five different levels based on the number of stimuli presented in each trial (Figure 3.4). Each level was defined to relate to a specific theme. The chosen themes were: nature, a party, a farm, a house, and a big city. Each level consists of 3 trials. The difference between levels lies in the number of sounds to be used in each trial, which will increase by 1 at each subsequent level. Specifically, the acoustic stimuli were distributed as follows: Level I (1 acoustic stimulus for each trial, 3 stimuli in total); Level II (2 acoustic stimuli for each trial, 6 stimuli in total); Level III (3 acoustic stimuli for each trial, 9 stimuli in total); Level IV (4 acoustic stimuli for each trial, 12 stimuli in total); and Level V (5 acoustic stimuli for each trial, 15 stimuli in total).

Each level has two phases: the search phase and the location phase. In the search phase, the user learns the sounds and their location. First, the user listens to the instructions through the loudspeakers. Then, the user listens to the continuous sound emitted by a Karotz and memorizes its location. While the sound is playing, the participant moves to stand in front of the Karotz that emits the sound and raises his/her arms to make the selection. The Karotz emits a message to indicate that it has understood the gesture. The user is told that he/she must listen to the message of the Karotz after raising his/her arms. If the Karotz does not emit such a message, the user must repeat the action.

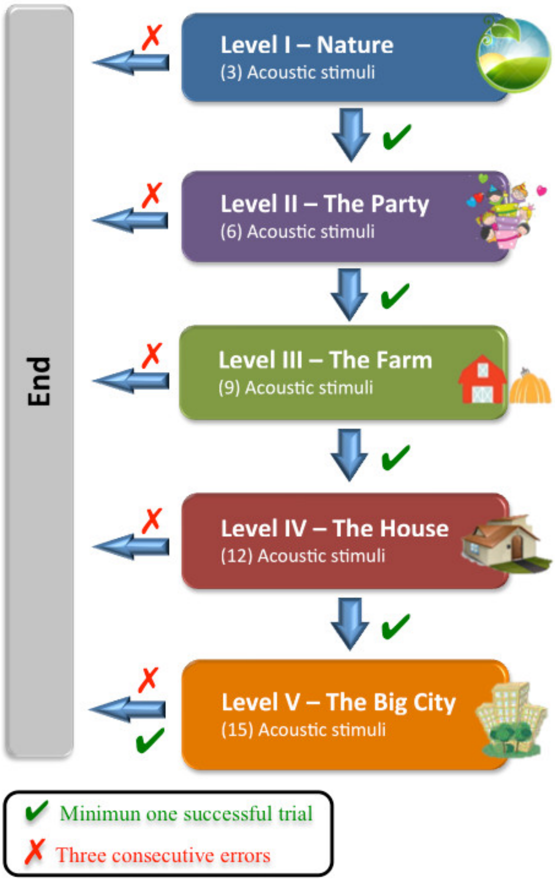

Figure 3.4: Levels of the game.

The participant's spatial memory is evaluated in the location phase. First, the user listens to the instructions through the loudspeakers and also the sound that has to be located. In this phase, the user has to remember the location of the Karotz that emitted the stimulus (sound). The stimuli are only emitted once. The user has to move to the correct location and raise his/her arms in front of the Karotz in order to select it. Then he/she must return to the starting position. The game stores all of the answers (successes or failures).

A trial is successfully passed if all of the sounds are correctly located. If a sound is not correctly located, the trial has not been passed. If there is at least one successful test of the 3 trials of a given level, the user has passed that level and advances to the next level. The participant must perform the 3 trials of one level, regardless of whether he/she has successfully passed all of the stimuli of the first trial. If the user fails in all 3 trials at any level, the game ends. The game also ends when the participant completes level V.

3.3.2 Hardware and Software

We used two Microsoft Kinect^{TM} v1 devices and five Karotz rabbits. The Kinect^{TM} v1 devices include a RGB camera with a resolution of 640x480 pixels, an infrared camera, an infrared projector, and a multiarray microphone. The Karotz rabbits are shaped like a rabbit and are 30 cm tall (see Figure 3.1). They can connect to the Internet through a wireless access point. They have loudspeakers, a webcam, an LED-light (in their bellies), and they can move their ears. Their technical specifications are: 400 MHz ARM-CPU, 64 MB-RAM, 256 MB of storage, and a Linux operating system.

An HP computer with an Intel i5 processor and Windows 7 operating system was used. This computer had USB ports connected to a separate USB host controller. This allowed two Kinect^{TM} devices to be used simultaneously. Additionally, this computer was used as the server. Two conventional loudspeakers were used to give instructions during the game. We used a wireless-G Router with WAN port for networking and accessing the Internet. This Internet access was required by the five Karotz rabbits and the computer.

The sounds were edited using Audacity 2.0.3 to ensure the loudness of 70 dB, frequency $>$ 3000 Hz, 4-s duration, and stereo format. For the voice of the messages, the audio clips were recorded using Audacity 2.0.3, and they had identical characteristics to the sounds, except that the duration varied depending on the specific instructions or message.

Visual Basic 2008 Express Edition was used for the development of the system that manages the procedure during the game and the graphical interface for the supervisor. To program the Kinect™ device, we used Visual C++ 2010 Express Edition, Kinect SDK 1.8, OpenNI 2.0 SDK, and Nite. The system has three modules: (a) one to configure and manage the Karotz rabbits, their IPs, and the IP of the sounds server; (b) one to register the participant's information and for the evaluation process; and (c) one to manage the communication among the Karotz rabbits and the Kinect™ devices.

The system has a graphical interface that allows the supervisor to introduce the player's code, date of birth, and gender. The role of the supervisor is to supervise the task by observing the supervisor's interface, which offers information about the participant's progress. The supervisor does not control the rabbits. The supervisor can observe the performance carried out by the player (i.e., trials, successes, and failures (Figure 3.5)).

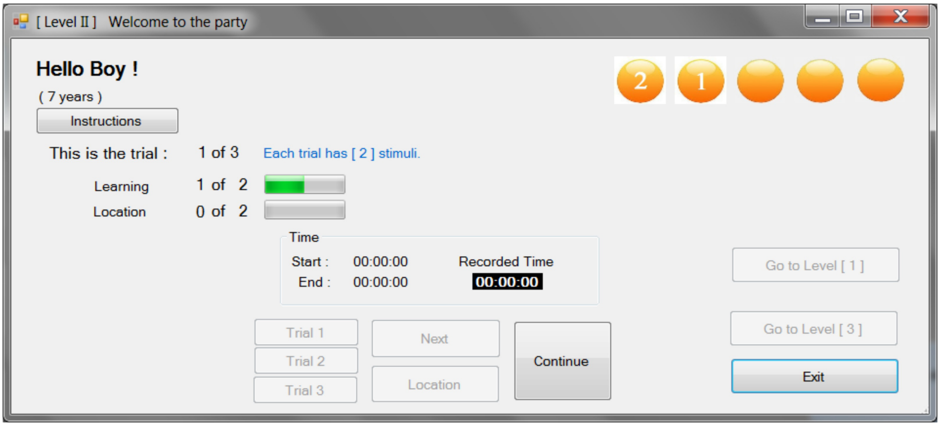

Figure 3.5: Screen that displays the player's performance.

3.4 Study

3.4.1 Participants

A total of 70 participants were involved in our study. A total of 32 healthy children (16 girls, 16 boys) took part in this study, with ages ranging from 9 to 10 years old. The children were attending the fifth grade at a public school. Before carrying out the study, the parents of the participating children received written information about the aims and procedures of the study, and they signed a consent form to allow their children to participate. The children who participated received a diploma and a snack immediately after the test session. They were not informed about this reward until the end of the study.

A total of 38 healthy adults (19 women, 19 men) took part in the study, ranging in age between 18 and 28 years old (M=21.32, SD=2.86). The participants were recruited throughout the campus of a large public university. The students had the following education levels: vocational education (28.95%), undergraduate (44.74%), or graduate (26.31%). Before the study, all of the participants were informed in writing about the aims and procedures, and they signed an informed consent form. The participants received a diploma and a snack right after the test session, but they were not informed about the snack until they had completed the procedures of the study.

The study was conducted in accordance with the European Directive 2001/20/EC and the Helsinki Declaration for biomedical research involving humans. The Ethics Committee of the Universitat Politècnica de València (UPV) approved the research protocol.

3.4.2 Measurements

We assessed the participants' ability to recall auditory stimuli and their locations by registering their performance during the task. The database of the system recorded successes or failures in the detection and location of stimuli. Four variables based on performance during the task were stored. These variables were the following: Number of Correct Stimuli (NCS), Number of Correct Levels (NCL), Task Time (TT), Number of Errors (NE). NCS was the number of auditory icons that a participant could successfully locate. NCL was the sum of the number of levels correctly performed. TT was the total time in seconds that a participant spent to complete the task. Finally, NE was the sum of the number of errors that a participant could commit. In addition, we calculated the task score (TS) which is the sum of all auditory icons (of any block and Level) for which the participant correctly indicated the emitting rabbit. The TS allows us to determine the performance of the participants. The maximum possible task score was 45.

Visuospatial learning and auditory learning were also assessed in the participants by using traditional methods. We selected specific subtests that are included in the Test of Memory and Learning battery (TOMAL) (Reynolds and Bigler 2001). The TOMAL battery assesses various domains of learning.

We also selected subtests that are included in the EDAF test. The EDAF measures auditory and phonological discrimination (Brancal et al. 2009). We used the direct scores obtained in all of the subtests used.

We selected the TOMAL subtest for the assessment of visuospatial learning: Memory for Location (ML). This subtest consists of a spatial recall task of one or more large dots that appear within a square or rectangle. The participant is asked to identify the location of the dots within a grid. The range of the grid is 3x3 and 4x4 (with 9 locations and 16 locations, respectively). In order to assess immediate retrieval of auditory items, we used two verbal span subtests of the TOMAL battery: Digits Forward (DF) and Digits Backward (DB). The DF is a number recall task that measures low-level rote recall of a sequence of numbers. The DB task (a variation of the DF task) consists of a sequential recall of a sequence of numbers but in reverse order. For the assessment of auditory and phonological discrimination, we selected the EDAF subtest: Environmental Sound Discrimination (ESD). The ESD is a discrimination task about sounds of the environment that are played on a CD (i.e., baby's crying, traffic noise, etc.). We also measured the participants' everyday memory. We selected eight questions from the ECM-Questionnaire (ECM) for this purpose (Kamphaus, Pérez-Hernández, and Sánchez-Sánchez 2014). The skills are rated on a 4-point Likert scale (1 = never to 4 = almost always). The questions are: I have good spatial orientation, I get lost where I have often been before, I forget where I have put things, I recognize the places I have been before, I know how to go home, I remember where I store my things, I get lost in familiar places, I forget how to go to a place that I have already been explained how to get to. In the case of the child participants, their parents completed the Parent Report version of this questionnaire.

To assess the participants' perceptions and satisfaction with the game, we designed a Questionnaire (QS) based on the questionnaires of Lewis (1995) and Lund (2001) (Table 3.1). Items were selected from these two existing instruments based on their appropriateness for assessing learning, satisfaction, and interaction with the game, and the items were adapted to our studies. The participants responded to the items using a 5-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree").

Table 3.1: Questionnaire (QS).

Question ID	Question
Q1	It was easy to use this task
Q2	It was easy to learn to use this task
Q3	I would recommend it to a friend
Q4	Overall, I am satisfied with this task
Q5	The interactive interface is pleasant (body movements)
Q6	I like using the auditory interface (sounds)
Q7	Overall, this interaction was fun

3.4.3 Study Design

For the children, the test sessions took place from Monday to Friday between 9:00 and 14:00 over three weeks during the normal school year. For the adults, the study was carried out over two weeks, from Monday to Friday between 9:00 and 15:00. A supervisor guided the participants through the steps to follow during testing and helped them become familiar with the area of interaction. The supervisor did not interfere with the game performance unless the participants requested assistance or experienced a technical problem (system failure). At the end of the session, the supervisor administered the QS questionnaire to each participant.

3.4.4 Performance Outcomes Using the Game

Data from the children and adults were analyzed using the statistical open source Toolkit R[1] with the RStudio IDE Desktop[2]. The normality of the data was analyzed based on Shapiro-Wilk and Anderson-Darling tests. The TS, NCS, NCL, and NE variables did not fit the normal distribution, so we applied the Mann-Whitney U test for unpaired data. The TT variable did fit the normal distribution, so an ANOVA test was used. The Mann-Whitney U test for unpaired data was used to determine the statistically significant differences for the QS questionnaire between children and adults.

The results showed that the group of children performed worse than the group of adults (See Table 3.2). The Task Score (TS) indicates statistically significant

[1] Toolkit R: https://www.r-project.org
[2] RStudio IDE: https://www.rstudio.com

differences in favor of the adults (See Figure 3.6). The results of the comparisons indicate statistically significant differences for the variables related to successes (NCS and NCL) in favor of the adults. Also, the group of children committed a significantly higher number of errors (NE) and they spent more time on the game (TT) than the adults.

Table 3.2: Mann-Whitney U test analysis for TS, NCS, NCL, and NE variables. ANOVA for the TT variable.

Var.	Child $\mu \pm \sigma$	Adult $\mu \pm \sigma$	U	Z	p
TS	34.28 $\pm$ 11.35	43.68 $\pm$ 1.97	153.0	-5.465	$<$ 0.001*
NCS	34.28 $\pm$ 11.35	43.68 $\pm$ 1.97	153.0	-5.465	$<$ 0.001*
NCL	2.75 $\pm$ 1.27	4.29 $\pm$ 1.01	199.5	-4.988	$<$ 0.001*
NE	4.53 $\pm$ 0.98	4.08 $\pm$ 0.78	849.0	3.117	$<$ 0.001*
Var.	Child $\mu \pm \sigma$	Adult $\mu \pm \sigma$	*d.f.*	F	p
TT	610.2 $\pm$ 165.5	518.2 $\pm$ 52.7	1, 68	10.49	0.002*

3.4.5 Outcomes Using Traditional Methods

The outcomes obtained with the traditional methods were analyzed to determine whether or not there were differences between the two groups. Table 3.3 shows the results and statistics. The results showed that adults demonstrated significantly greater visuospatial learning (DB, DF, ML and ECM). For the discrimination of sounds, there were no statistically significant differences for the ESD variable.

3.4.6 Correlations Between Our Game and Traditional Methods

In order to compare the participants' performance when using the game (TS) and traditional methods (DB, DF, ML, ESD, and ECM), correlations were calculated with the complete sample (32 children and 38 adults). The Spearman correlation was applied and the effect size of the correlation was obtained, rho (ρ). The correlations between the TS variable and the traditional method variables are: ML ($\rho = 0.43$, p <0.001*) and DB ($\rho = 0.45$, p <0.001). All correlations are linear and positive. These correlations demonstrate the similarity between our game and those traditional methods (ML and DB).

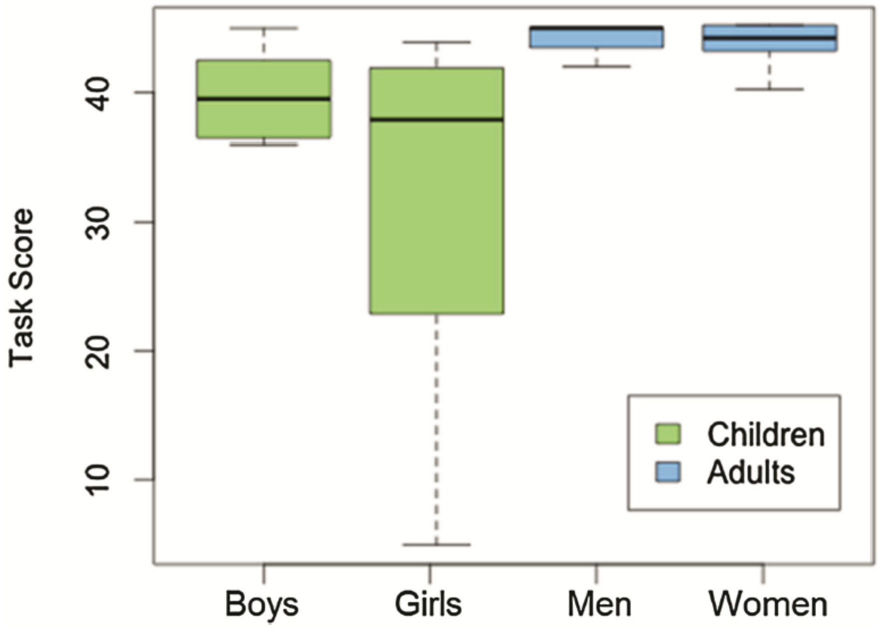

Figure 3.6: Graph showing the outcomes for the TS variable.

3.4.7 User Experience

Table 3.4 shows the results of the statistical analysis applied to the answers to the QS questionnaire about the users' experience and the comparison of the scores between children and adults. Both groups found the game easy to use and easy to learn (Q1 and Q2). The children were significantly more likely than the adults to recommend the game to their friends (Q3), and they were significantly more satisfied with the game (Q4). Both groups found the interface pleasant to use with regard to body movements (Q5) and the auditory interface (Q6). The children found the interface significantly more fun than the adults (Q7) (Table 3.4).

Figure 3.7 shows graphically the mean scores for the QS questionnaire. The children gave a mean score of 4.55 ± 0.55 on the QS questionnaire, and the adults gave a mean score of 4.26 ± 0.47. These results and the observations of the supervisor indicate that both children and adults understood how to interact with the game and were able to learn and recall a sequence of auditory icons with their respective locations while moving.

Table 3.3: Mann-Whitney U test analysis for DB, ESD, and ECM. ANOVA for the DF and ML variables.

Var.	Child $\mu \pm \sigma$	Adult $\mu \pm \sigma$	U	Z	p
DB	20.66 ± 8.43	36.74 ± 13.80	144.5	-5.47	< 0.001*
ESD	14.34 ± 0.90	14.66 ± 0.53	510.0	-1.35	0.189
ECM	3.62 ± 2.77	11.11 ± 4.24	71.5	-6.34	< 0.001*
Var.	Child $\mu \pm \sigma$	Adult $\mu \pm \sigma$	*d.f.*	F	p
DF	8.12 ± 1.84	57.13 ± 14.86	1, 68	-18.52	< 0.001*
ML	11.03 ± 6.15	19.05 ± 5.11	1, 68	-5.96	< 0.001*

Table 3.4: Mann-Whitney U test analysis and r effect size for differences between children and adults on the QS questionnaire. '**' indicates significant difference at level $\alpha = 0.05$.

Q#	Children	$\mu_{CH} \pm \sigma_{CH}$	Adults	$\mu_A \pm \sigma_A$	U	Z	p	r
1	[5];[1]	4.44 ± 0.88	[4];[1]	4.21 ± 0.70	748.5	1.832	0.069	0.219
2	[5];[0]	4.81 ± 0.40	[5];[0]	4.82 ± 0.39	606.0	-0.035	> 0.99	0.004
3	[5];[0]	4.53 ± 0.98	[4];[1]	4.08 ± 0.78	849.0	3.117	<0.001**	0.373
4	[5];[1]	4.62 ± 0.55	[4];[1]	4.32 ± 0.62	772.0	2.182	0.035**	0.261
5	[4];[2]	4.09 ± 1.06	[4];[2]	3.89 ± 0.92	696.5	1.105	0.278	0.132
6	[4];[1]	4.25 ± 0.80	[4];[1]	4.29 ± 0.69	605.5	-0.032	0.997	0.004
7	[5];[0]	4.78 ± 0.49	[4];[1]	4.24 ± 0.54	918.5	4.162	<0.001**	0.497

3.5 Discussion

Our game combines Natural User Interfaces (using gestures) with smart devices. The game was designed for the assessment of spatial memory by using auditory stimuli. Previous proposals for the assessment of spatial memory are centered on visual cues (Juan et al. 2014; Cárdenas-Delgado et al. 2017b; Rodríguez-Andrés et al. 2016; Méndez-López, Pérez-Hernández, and Juan 2016). Traditional methods consider each skill separately (Reynolds and Bigler 2001; Brancal et al. 2009; Kamphaus, Pérez-Hernández, and Sánchez-Sánchez 2014). However, our game combines auditory stimuli with real visual cues for the assessment of spatial memory.

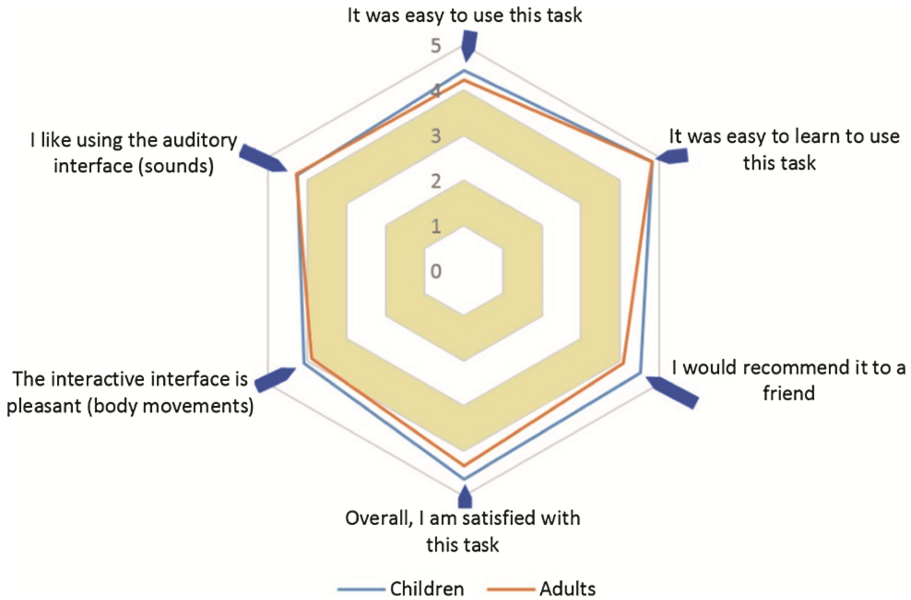

Figure 3.7: Graph showing the mean scores for the questionnaire

A study involving 70 participants (32 children and 38 adults) was carried out. The participants played with our game, and traditional tests (Reynolds and Bigler 2001; Brancal et al. 2009; Kamphaus, Pérez-Hernández, and Sánchez-Sánchez 2014) were also administered. The results of the game were compared with the results obtained using traditional methods. Correlations were found between our game and traditional methods, indicating that our game has proven to be a valid tool for assessing spatial memory by using auditory stimuli for both children and adults. This result affirmatively answers our first research question (RQ1). These correlations are in line with previous works for assessing spatial memory (only based in visual cues) that also obtained correlations between their tasks and traditional methods (Juan et al. 2014; Cárdenas-Delgado et al. 2017b; Rodríguez-Andrés et al. 2016; Méndez-López, Pérez-Hernández, and Juan 2016). This result is also in line with other previous works that have demonstrated that serious games have the potential to be used as assessment tools (e.g., Vallejo et al. 2017) or for diagnosis (e.g., Tarnanas et al. 2014).

With regard to ecological validity, in neuropsychological assessment, ecological validity can be defined as the "functional and predictive relation between the participant's performance on a set of neuropsychological tests and the participant's performance in a variety of real-world settings" (Spooner and Pachana 2006). Therefore, the development of new games for neuropsychological assessment represents an important tool for early identification of atypical development or for assessment of memory as a cognitive function that is linked to various intellectual and social activities of children and adults. Games of this type could contribute to a better understanding of the influence of different variables on the cognitive development of children and adults. Our game can be used for assessing cognitive processes in an ecological way. Our game is in line with previous serious games that have shown ecological validity (Tarnanas et al. 2013). However, we have not checked the influence that the ecological component has on the participants. A future study could determine the advantages and disadvantages of our proposal with respect to another modality that does not have the ecological component.

The performance outcomes with the game were significantly lower for the children. This result answers our second research question (RQ2) indicating that the age range of the participating children (9-10 years old) did not achieve full competence in the game. The game requires constant attention and concentration since it involves the simultaneous evaluation of spatial and auditory abilities. The fact that the results were better for adults is consistent with the idea that adults can store more elements in short-term memory than children because the ability of the humans increases continuously during maturation (Lezak 1995).

With regard to perceptions and satisfaction with the game, the mean scores for all questions for both the children and the adults were greater than 4 (on a scale of 1 to 5). Only Q5 for the adults had a mean score of 3.89 ("Q5: The interactive interface is pleasant (body movements)"). Therefore, we can conclude that all of the participants found the game easy to learn and easy to use, they had a good time, and they have shown their satisfaction with the game. The analysis showed that the children scored significantly higher on questions Q3 (recommend the game to a friend), Q4 (satisfied with the game), and Q7 (fun). This result answers our third research question (RQ3) indicating that the children were significantly more satisfied with the game than the adults. Since the game seemed easy to use for both children and adults, they were able to concentrate on the tasks to be done rather than on the control mechanisms. The Karotz make sounds and move their ears and illuminate their central part, so the participants can consider them as pets or toys. This aspect could influence the greater fun experienced by the children. The use of multiple sensory modalities may influence participants' satisfaction.

The communication of the participants with the Karotz raising their arms can be interpreted as a code of communication between equals, which can influence the attractiveness of the game. Many participants were accustomed to this type of interaction given the proliferation of games that use color-depth sensors, so this type of interaction seemed natural. From our point of view, all of this contributes to the immersion that our game induces and the motivation that the participants showed. The supervisor's observations corroborate our perception of immersion. The supervisor added that many participants did not realize that the Karotz rabbits were there and they even talked to the Karotz rabbits. However, we have not yet determined the influence that the physical appearance of the Karotz had on the children and their motivation for the activity. The study of this influence could be part of another work.

With regard to the interaction and selection of the Karotz, in this work the interaction has been achieved through gestures. However, the button that the Karotz have on top could be used, a natural language user interface could be used, the correct Karotz could be selected on a tablet, etc. As future work, we are studying the incorporation of other types of interaction and their comparison. However, the intention of our proposal is for the game to be used by blind people and the alternative interaction would also have to consider this population. Thus, pressing the button on the top of the Karotz or using a tablet would not be viable alternatives. Also, other types of robots that are currently on the market or that could appear in the future could be used to reproduce or improve our proposal.

3.6 Conclusion

Our game presents an alternative tool to assess both multimodal integration and learning of auditory and spatial information in children and adults. The game could be used for assessment and training of spatial memory. The game could help in the identification of alterations in spatial memory in both children and adults. In children, the game could help in the early identification of atypical development, children with Attention Deficit Hyperactivity Disorder, etc. In adults, the game could help in the identification of alterations in memory, such as Alzheimer's disease, other types of dementia with alterations of orientation, patients with sequelae after suffering a stroke or head trauma, etc. As a computer-based game, our game facilitates the control of the presentation of stimuli and the recording of responses. We assume that a supervisor of this experience might make some mistakes due to distraction and/or tiredness, among other causes. The game could be enhanced by adding visual keys (lights in the bellies of the Karotz rabbits or movement of their ears). In this paper, we have compared children and adults, but other comparisons are also possible. For example, it would be interesting to compare the performance of children with normal vision and blind children or to use this new game with children with developmental disorders. Another study could focus on the suitability of the game for people with autism. In that study, it would be very interesting to determine if the appearance of the Karotz is especially suitable for this population.

Acknowledgments

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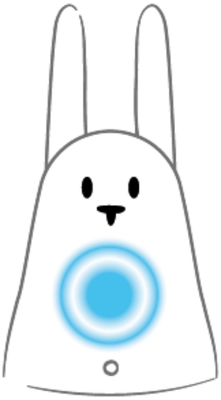

Chapter 4

Developing and Evaluating a Game for the Assessment of Spatial Memory Using Auditory Stimuli

"No hay que confundir nunca el conocimiento con la sabiduría. El primero nos sirve para ganarnos la vida; la sabiduría nos ayuda a vivir"

Sorcha Carey

Contents

Mauricio Loachamín-Valencia, M.-Carmen Juan, Magdalena Méndez-López, Elena Pérez-Hernández, M. José Vicent. "Developing and Evaluating a Game for the Assessment of Spatial Memory Using Auditory Stimuli", IEEE Latin America Transactions, Unpublished (submitted and under review)

Abstract

The combination of natural user interfaces and smart devices has become a new technological option to be exploited for the assessment of spatial memory. In this paper, we present an interactive game for assessing spatial memory using auditory stimuli. The distinct feature of our game is that it assesses the two types of information (i.e., acoustic and spatial) at the same time. We compared the performance of 100 children and 48 adults on the game with traditional neuropsychological tests. The performance on the game correlated with the performance on traditional neuropsychological tests for the assessment of spatial short-term memory. Children and adults considered our game as easy to use, and all of them were satisfied with it. The results suggest that our game could be a valid tool for the identification of alterations in the spatial memory in both children and adults.

4.1 Introducción

La creciente evolución de la tecnología ha permitido el desarrollo de nuevos sistemas y el uso de diferentes tipos de dispositivos con distintos propósitos. Dicha evolución incrementa las oportunidades para el desarrollo de herramientas y tecnologías, así como la fabricación de nuevos dispositivos inteligentes y nuevas interfaces naturales de usuario (NUI). Los dispositivos inteligentes son recursos tecnológicos capaces de comunicarse. Esta comunicación puede ser entre dispositivos similares a través de un protocolo de comunicación o con humanos a través de una interfaz de usuario. Las NUI permiten la interacción natural, en las que el propio cuerpo es el responsable de transmitir instrucciones a las aplicaciones, sin utilizar mandos o dispositivos de entrada. Las NUI utilizan dispositivos con sensores para capturar el movimiento del cuerpo, permitiendo al usuario interactuar sin necesidad de tener contacto físico con otros dispositivos de control.

Una de las habilidades cognitivas más críticas en seres humanos es almacenar el recuerdo de estímulos que se han experimentado en el pasado. Desde una perspectiva psicológica, existe interés en investigar la capacidad de aprender información espacial y auditiva. La razón es que son procesos significativos en la vida diaria. La memoria se puede dividir en memoria a corto plazo y a largo plazo, dependiendo de si la información a memorizar es útil por un período de tiempo limitado o es relevante para ser almacenada de forma estable ante cualquier necesidad futura (Burgess and Hitch 2005). Las memorias espacial y auditiva tienen la capacidad de almacenar representaciones de estímulos espaciales y auditivos, respectivamente. La de tipo espacial nos permite encontrar un lugar visitado con anterioridad, seguir una ruta después de consultar un mapa o recordar el lugar dónde dejamos nuestras pertenencias, entre otros ejemplos (Burgess et al. 2001). El aprendizaje espacial se asocia con resultados académicos (Rourke 1993). El aprendizaje auditivo facilita tomar notas mientras se escucha, la expresión escrita y oral (Dehn 2008). Algunos problemas de aprendizaje y de comportamiento están relacionados con las deficiencias en este proceso (Rauscher, Krauss, and Chen 1996). Además, muchas experiencias de aprendizaje requieren considerar la información auditiva y espacial simultáneamente. Algunos ejemplos son la orientación espacial y la identificación de personas u objetos. Dado que no existen procedimientos para evaluar la orientación espacial con estímulos auditivos, sus implicaciones para los diferentes tipos de discapacidades siguen siendo inciertas.

Las aplicaciones o herramientas relacionadas con la memoria espacial pueden ser para evaluación o para entrenamiento. Las aplicaciones para evaluación permiten determinar el estado de la memoria de una persona en un momento determinado. Los resultados de dicha evaluación permiten la identificación temprana del desarrollo atípico en niños, o bien si un adulto presenta alteraciones en su memoria, como es el caso de enfermos de Alzheimer, otros tipos de demencia con alteraciones de la orientación, pacientes con secuelas tras sufrir un accidente cerebrovascular o traumatismo craneal, etc.

Por lo que sabemos, no se ha explotado la combinación de NUI y dispositivos inteligentes para evaluar procesos cognitivos, y en especial, para evaluar la memoria espacial utilizando estímulos auditivos de forma inalámbrica y atractiva. El desarrollo de nuevos sistemas para la evaluación neuropsicológica representa una herramienta importante para la evaluación de la memoria como una función cognitiva que está vinculada a diversas actividades intelectuales y sociales, y también, como se ha comentado, para la identificación de alteraciones en la misma. Herramientas de este tipo podrían contribuir a una mejor comprensión de la influencia de diferentes variables en la función cognitiva.

En este artículo presentamos el desarrollo del primer juego para evaluar la memoria espacial a corto plazo utilizando estímulos auditivos, que incorpora NUI y dispositivos inteligentes. Para identificar las ventajas de nuestro juego respecto a tests tradicionales se ha llevado a cabo un estudio. El objetivo de dicho estudio es demostrar el potencial del juego para evaluar la memoria espacial a corto plazo. Para ello, se comparan los resultados obtenidos usando nuestro juego con la aplicación de test tradicionales aplicados a niños y adultos. La hipótesis principal es que los resultados del juego reflejarán la capacidad del mismo para evaluar la memoria espacial a corto plazo tanto para niños como para adultos, ofreciendo correlaciones significativas respecto a procedimientos tradicionales.

4.2 Estado del Arte

4.2.1 Interfaces naturales de usuario

La aparición de sensores de profundidad (p. ej., Kinect o Leap Motion) ha permitido que se puedan usar como dispositivos de entrada para interfaces naturales de usuario. Dichos sensores se han utilizado con distintos objetivos y para una gran variedad de aplicaciones, como por ejemplo aprendizaje (Martín-SanJosé et al. 2014); rehabilitación (Neto et al. 2015) reconocimiento del lenguaje de signos (Cheng, Yang, and Liu 2016); o diagnóstico de parálisis facial (Carro et al. 2016). La Tabla 4.1 muestra las características de los sensores de profundidad comerciales más utilizados, según Cheng et al. (2016).

Tabla 4.1: Sensores de profundidad comerciales.

Sensor	Resolución	Rango	Presición	Puntos de unión
Kinect 1.0	320x240	0.8 - 4.0 m	4.00 mm	20 cuerpo
Leap Motion	640x240	25 - 600 mm	0.01 mm	27 mano
Kinect 2.0	512x484	0.8 - 4.5 m	1.00 mm	25 cuerpo

Como se observa en la Tabla 4.1, Kinect, en sus dos versiones, se puede utilizar para identificar partes del cuerpo y Leap Motion se centra en los gestos de la mano. Leap Motion se ha utilizado, por ejemplo, para facilitar la comunicación de personas con trastornos de comunicación verbal (Kryvonos et al. 2016). En nuestro caso, y dado que se pretendía identificar que los usuarios levantasen los brazos se utilizó Kinect. Para ampliar la información sobre sensores de profundidad, se recomienda consultar el artículo publicado por Cheng et al. (2016).

4.2.2 Dispositivos Inteligentes

Los dispositivos inteligentes, especialmente aquellos con apariencia humana (robots), han contribuido al desarrollo de varias aplicaciones. Uno de los robots más utilizados hasta la fecha, ha sido el robot NAO, que se ha utilizado, por ejemplo, con niños autistas para promover la comunicación y habilidades sociales como parte de un programa de rehabilitación (Malik et al. 2013); o en KindSAR para ayudar a niños preescolares en su desarrollo cognitivo a través de la interacción social (Keren and Fridin 2014).

También se han utilizado otros robots, por ejemplo, Robovie, que es un robot humanoide autónomo (1.2 m de alto, 50 cm de diámetro, y 40 kg de peso) con ojos y manos de aspecto humano. Moriguchi et al. (2011) utilizaron Robovie para que niños de entre 4 y 6 años pudieran aprender palabras. Por lo que sabemos, el único estudio que ha utilizado hasta la fecha el robot Karotz es el presentado por de Graaf et al. (2015). Karotz es el robot incluido en nuestro sistema. De Graaf et al. (2015) instalaron Karotz en la casa de personas mayores. El objetivo era mejorar su salud. La función del robot era la de un "asistente personal" que se interesaba por sus progresos y les hacía recomendaciones, como por ejemplo controlar su peso.

4.2.3 Evaluación de la memoria espacial

La evaluación de la memoria espacial utilizando estímulos visuales se ha llevado a cabo utilizando distintos tipos de aplicaciones. Por ejemplo, ARSM Task (Juan et al. 2014) es un sistema de realidad aumentada para evaluar la memoria espacial en niños, utilizando para ello una Tablet protegida con una carcasa. La sala en la que se realizó el estudio era de 5 m^2. En ella se colocaban unas cajas reales y en su interior se encontraban los objetos virtuales a localizar. El sistema constaba de 7 niveles, en los que el número de cajas y objetos a recordar se incrementaba. En el Nivel I había 2 cajas y 1 objeto a recordar, en el Nivel II, cuatro cajas y 2 objetos a recordar, etc. Juan et al. (2014) encontraron similitudes en los resultados utilizando ARSM Task y métodos tradicionales. En MnemoCity Task (Rodríguez-Andrés et al. 2016), se utilizó un entorno de realidad virtual, con estereoscopía pasiva e interacción natural para evaluar la memoria espacial en niños. En el estudio se compararon dos tipos de interacción: un gamepad; y un volante (con un control Wii Remote™ en su interior) para determinar los giros del usuario y Wii Balance Board™ para determinar los pasos del participante (velocidad). Se diseñó un entorno que recreaba un parque en el que se colocaron unas mesas sobre las que aparecían los elementos que el usuario debía localizar. Rodríguez-Andrés et al. (2016) también obtuvieron correlaciones entre su sistema y métodos tradicionales. Cárdenas-Delgado et al. (2017b) desarrollaron un laberinto virtual para evaluar la memoria espacial en adultos. En dicho sistema, el participante tenía que recordar el recorrido en el laberinto para encontrar la salida. En su estudio se compararon dos tipos de interacción: un gamepad y una bicicleta (el pedaleo indicaba la velocidad y el giro del manillar condicionaba el giro del avatar presente en el mundo virtual). Los resultados de los participantes obtenidos con el laberinto correlacionaron con métodos tradicionales. Sin embargo, por lo que sabemos, no existen estudios que hayan evaluado la memoria espacial utilizando estímulos auditivos.

4.3 Desarrollo

4.3.1 Diseño del juego

El proceso de diseño del juego fue centrado en el usuario. El juego debía contemplar su uso por diferentes colectivos: niños, adultos e invidentes. Se llevaron a cabo varias sesiones de diseño participativo con usuarios potenciales (niños y adultos), expertas psicólogas y expertos en informática gráfica e interacción persona-ordenador. El objetivo principal de estas sesiones fue diseñar el juego. Para ello, en primer lugar, se estudió el tipo de ambiente más adecuado (con o sin pistas visuales), la distribución de las fuentes de sonido, el tipo de interacción y la dinámica del juego. Para la distribución de las fuentes de sonido, tras varias propuestas se consideró que dichas fuentes tenían que estar frente al usuario, no detrás de él, es decir, el sonido debía llegar al usuario de frente. Por lo tanto, máximo se podría considerar un ángulo de 120°. Con este ángulo se estimó el número de fuentes de sonido que se podrían llegar a utilizar y se determinó que el número ideal era 5. Para el tipo de interacción fue vital la contribución de los usuarios potenciales. Una vez identificada la interacción natural como el tipo de interacción a utilizar, se determinó qué tipo de gestos eran más fáciles para los usuarios. Para ello se realizó un estudio preliminar con quince niños. Se identificó que el gesto más apropiado era levantar ambos brazos al mismo tiempo delante de la fuente de sonido. A continuación, se estudiaron las alternativas en cuanto a los dispositivos a utilizar para la emisión de los sonidos y de la interacción. También se plantearon los temas a utilizar en el juego y cuáles serían los que se utilizarían en cada nivel. El número de sonidos-fuentes a memorizar para cada nivel se estableció en orden de dificultad creciente, de 1 a 5, basándonos en la capacidad humana para memorizar sonidos (un máximo de 9 elementos en el caso de adultos (Kalm, Davis, and Norris 2012)). El diseño del juego se definió como resultado de estas sesiones.

4.3.2 Descripción general del juego

El juego permite comprobar la capacidad del usuario para detectar y localizar estímulos auditivos que se emiten en diferentes posiciones de un área de juego (Figura 4.1). Para la emisión de sonidos se ha utilizado un dispositivo inteligente (robot) con la forma de conejo, Karotz. El juego utiliza una interfaz natural de usuario mediante gestos, utilizando el sensor Kinect de Microsoft. Concretamente, Kinect se utiliza para detectar que los usuarios levantan los brazos frente a un determinado Karotz con el fin de seleccionarlo. El usuario debe memorizar las posiciones de los Karotz. Los Karotz no tienen ninguna característica física que los distinga unos de otros, solo su colocación en la sala. Los Karotz pueden mover las orejas y encender la luz que se encuentra en el centro del dispositivo.

El área de juego fue de 5 m^2. Esta área se delimitó en una habitación con dimensiones mayores. Las paredes estaban cubiertas con papel de embalaje para eliminar cualquier pista visual. Se colocó césped artificial en el suelo para guiar las rutas, y se utilizó una alfombra para indicar la posición inicial del usuario. La altura de los Karotz se ajustó a la altura de los usuarios colocando cajas de cartón sobre las mesas y encima de dichas cajas se colocaban los Karotz. Concretamente, los cinco Karotz se disponen en la sala con la siguiente configuración: Karotz 1 ($-60°$); Karotz 2 ($-30°$); Karotz 3 ($0°$); Karotz 4 ($+30°$); Karotz 5 ($+60°$).

El juego incluye un total de 45 estímulos auditivos, que se emiten aleatoriamente en diferentes posiciones para evitar repeticiones o secuencias preestablecidas. El juego se compone de cinco niveles diferentes (Figura 4.2). Cada nivel consta de 3 ensayos o intentos y está relacionado con un tema de sonidos específico, que son los siguientes: naturaleza, fiesta, granja, casa y una gran ciudad. La diferencia entre niveles radica en el número de sonidos a utilizar por ensayo, que irá incrementándose en 1 en cada nivel posterior. Por ejemplo, Nivel I (1 estímulo acústico para cada ensayo); Nivel II (2 estímulos acústicos para cada ensayo); o Nivel V (5 estímulos acústicos para cada ensayo). Cada

Figura 4.1: Área de juego.

nivel cuenta con dos fases: la fase de búsqueda y la fase de localización. En la fase de búsqueda, el usuario aprende los sonidos y su ubicación. Primero, el usuario escucha las instrucciones a través de los altavoces. Luego, escucha el sonido que emite un Karotz constantemente y memoriza su ubicación. Mientras se reproduce el sonido, el participante se mueve para situarse frente al Karotz que emite el sonido y levanta los brazos para su selección. El Karotz emite un mensaje para indicar que ha entendido el gesto. A los usuarios se les indica que tienen que escuchar el mensaje de los dispositivos tras levantar los brazos. Si el dispositivo no emite dicho mensaje, el usuario debe repetir la acción.

En la fase de localización se evalúa la memoria espacial del participante. Primero, el usuario escucha las instrucciones a través de los altavoces y también el sonido que tiene que localizar. En esta fase de localización, el usuario tiene que recordar la ubicación del Karotz que emitió el estímulo (sonido). Los estímulos sólo se emiten una vez. El usuario tiene que moverse a la localización correcta y levantar los brazos delante del Karotz para seleccionarlo. Después, debe volver a la posición inicial. El juego almacena todas las respuestas (aciertos o fallos).

Un ensayo se supera con éxito si todos los sonidos del mismo se localizan correctamente. Si no se localiza correctamente un sonido, el ensayo no ha sido superado. Si hay, al menos, un ensayo con éxito de los 3 ensayos de un

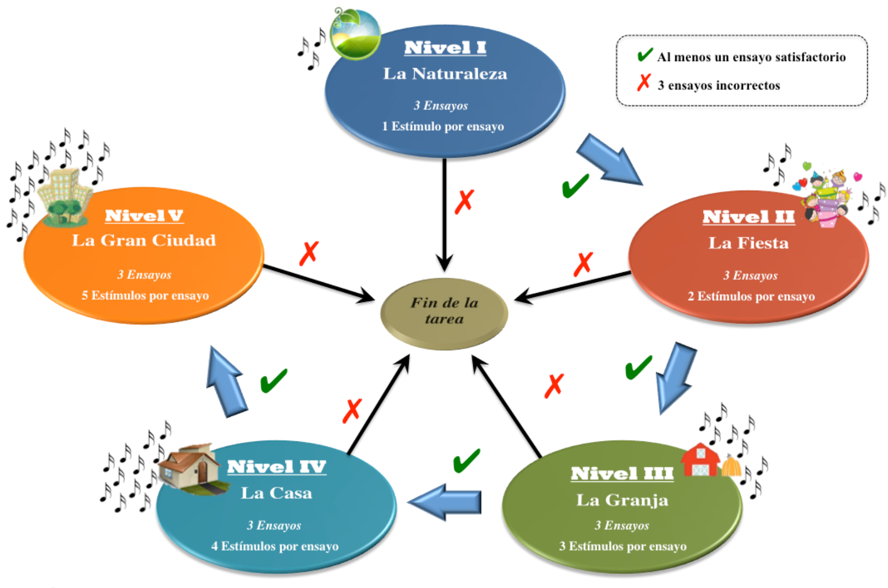

Figura 4.2: Niveles del juego.

nivel dado, el usuario ha superado dicho nivel y avanza al siguiente nivel. El participante debe realizar los 3 ensayos de un nivel, independientemente de que haya acertado todos los estímulos del primer ensayo. Si falla en los 3 ensayos en cualquiera de los niveles, el juego termina. El juego también termina cuando el participante completa el nivel V.

4.3.3 Hardware y Software

Se utilizan dos sensores Kinect de Microsoft 1.0 para abarcar todo el área de juego y cinco Karotz. Los sensores Kinect de Microsoft 1.0 incluyen una cámara RGB con una resolución de 640x480 píxeles, una cámara infrarroja y un proyector de infrarrojos. Los Karotz tienen forma de conejo y miden 30 cm de altura. Pueden conectarse a Internet. Tienen altavoces, una cámara web, un LED de luz (en su parte central), y pueden mover sus orejas. Las luces pueden ser de diferentes colores. En nuestro juego, los códigos de colores son los siguientes. El color verde indica que el juego está listo para comenzar. El color azul indica éxito. El color naranja indica fallo. El color blanco indica que el Karotz está esperando la respuesta del usuario. El color rojo indica que no se ha comunicado con el servidor.

Se utilizó un ordenador con controlador de puertos USB separados para poder utilizar dos sensores Kinect simultáneamente. Además, este ordenador se utilizó como servidor. Se usaron dos altavoces convencionales para dar instrucciones durante el juego.

Se utilizó Visual Basic 2008 Express Edition para el desarrollo del sistema que gestiona el juego y la interfaz gráfica para el supervisor. Para programar los sensores Kinect, se utilizó Visual C ++ 2010 Express Edition, Kinect SDK 1.8, OpenNI 2.0 SDK y Nite. El sistema tiene tres módulos: (a) un módulo para configurar y administrar los Karotz, sus IPs y el IP del servidor de sonidos; (b) un módulo para gestionar la comunicación entre los Karotz y los Kinect; (c) un módulo para registrar la información del participante y para el juego, propiamente dicho (proceso de evaluación).

El sistema tiene una interfaz gráfica que permite al supervisor introducir el código del participante, su fecha de nacimiento y género. La función del supervisor es supervisar el progreso del participante observando dicha interfaz, es decir, nivel, ensayos, éxitos y fallos. El supervisor no controla a los Karotz.

4.4 Estudio

4.4.1 Muestra del Estudio

El estudio consta de una muestra de 148 participantes. De los cuales, 100 fueron niños de edades comprendidas entre 5 y 10 años, y 48 adultos de edades comprendidas entre 18 y 28 años. La edad media de los niños fue de 7.49 $\pm$ 1.69 años, y de los adultos 20.98 $\pm$ 2.76. La distribución de la muestra de los niños fue de 50 niños (50%) y de 50 niñas (50%). La distribución de la muestra de los adultos fue de 24 hombres (50%) y de 24 mujeres (50%). El total de participantes se dividió en tres grupos: Grupo A (niños de 5 a 7 años), Grupo B (niños de 8 a 10 años), y Grupo C (adultos de 18 a 28 años). El estudio se llevó a cabo de conformidad con la Directiva Europea 2001/20/EC y la Declaración de Helsinki para la investigación biomédica con seres humanos. Los padres de los niños y los adultos recibieron información por escrito sobre los objetivos y procedimiento del estudio y firmaron consentimiento informado para participar en el mismo. Los participantes tuvieron plena libertad para abandonar el estudio en cualquier momento. El estudio fue aprobado por el Comité de Ética de la Universitat Politècnica de València.

4.4.2 Variables utilizadas en el análisis

Se utilizan tres variables relacionadas con el juego: Número de Niveles Correctos (NNC), Número de Estímulos Auditivos Acertados (NEA) y Tiempo Total (TT). La variable NNC es el número de niveles correctamente superados, y mide la capacidad para recordar los estímulos auditivos y sus ubicaciones. La variable NNC puede tener un valor de cero a cinco, en función de los niveles superados con éxito. NEA es el número de estímulos auditivos que el participante pudo localizar con éxito. TT es el tiempo total en minutos que el participante empleó para completar el juego.

También se evaluó la capacidad para recordar estímulos auditivos y sus respectivas ubicaciones utilizando métodos tradicionales. Para ello se seleccionaron pruebas específicas, que fueron las siguientes: TOMAL (Reynolds and Bigler 2001), EDAF (Brancal et al. 2009), y ECM (Kamphaus, Pérez-Hernández, and Sánchez-Sánchez 2014). Para la evaluación de la memoria visuoespacial se seleccionó el sub-test de la batería TOMAL: Memoria de Lugares (ML). En este sub-test, el participante tiene que identificar la ubicación de unos puntos en unas cuadrículas. El rango de las cuadrículas es de 3x3 y 4x4. Con el fin de evaluar el recuerdo inmediato de elementos auditivos, se utilizaron dos subpruebas de amplitud de memoria verbal de la batería TOMAL: Dígitos Directos (DD) y Dígitos Inversos (DI). DD es una tarea que mide el recuerdo de una secuencia de números en el mismo orden que el indicado por el evaluador. La tarea DI (una variación de la tarea DD) consiste en recordar una secuencia de números, pero en orden inverso. Para la evaluación de la discriminación auditiva y fonológica, se seleccionaron las subpruebas de EDAF: Memoria Secuencial Auditiva (MSA), y Discriminación de Sonidos del Medio (DSM). MSA es una tarea de repetición de palabras. DSM es una tarea de discriminación de sonidos (p. ej., el llanto del bebé, el ruido del tráfico, etc.). Por último, se utilizaron algunas preguntas de la Escala Clínica de Memoria (ECM) para evaluar la memoria espacial del participante en el día a día.

Se diseñó un cuestionario de usabilidad y satisfacción para evaluar la experiencia de los participantes y sus percepciones al utilizar el juego, ver Tabla 4.2. Para su diseño, se utilizaron como base los cuestionarios de Lewis (1995) y de Lund (2001). Los participantes respondieron a las preguntas utilizando una escala Likert de 5 puntos (de 1 = “totalmente en desacuerdo” a 5 = “totalmente de acuerdo”).

Tabla 4.2: Cuestionario de Usabilidad y Satisfacción.

No.	Preguntas
PU1	El juego fue fácil de usar
PU2	Fue fácil aprender a usar este juego
PS1	Lo he pasado bien
PS2	Se lo recomendaría a un amigo
PS3	En general, estoy satisfecho con este juego
PS4	Me ha gustado moverme para localizar la fuente del sonido
PS5	Me ha gustado jugar con los Karotz

4.5 Resultados

Los datos del estudio se analizaron utilizando R[1], versión 3.2.1, y RStudio, versión 0.99. En primer lugar, se realizó un análisis descriptivo inicial. A continuación, se comprobó la normalidad de los datos utilizando las pruebas Shapiro-Wilk y Anderson-Darling. Los datos no se ajustan a una distribución normal. Por lo que se han utilizado pruebas no paramétricas (U de Mann-Whitney y Kruskal-Wallis). En las tablas, el símbolo "*" indica diferencias estadísticamente significativas. En las tablas de esta sección, cuando aparecen dos valores separados por "±" indican medias y desviaciones estándar

4.5.1 Resultados del juego

La Tabla 4.3 muestra los resultados del juego para los Grupos A y B. Se observa que el rendimiento del Grupo A fue estadísticamente menor que el del Grupo B (NEA y NNC). No hubo diferencias estadísticamente significativas en el tiempo empleado entre ambos grupos (TT).

La Tabla 4.4 muestra los resultados del juego para los Grupos B y C. Se observa que el rendimiento de los niños fue estadísticamente menor que el de los adultos (NEA y NNC). También, hubo diferencia estadísticamente significativa en el tiempo empleado entre ambos grupos (TT), los niños necesitaron un tiempo mayor.

Considerando los dos grupos de niños (Grupos A y B), se realizaron pruebas de Kruskal-Wallis para determinar la influencia de tres factores (Género, Edad,

[1] Toolkit R: https://www.r-project.org

Tabla 4.3: Prueba de U Mann-Whitney para las viariables obtenidas durante el juego (Grupos A y B).

Var.	Grupo A	Grupo B	U	Z	r	p
NEA	20.0 ± 10.5	39.0 ± 6.9	181.5	−7.38	0.74	$< 0.001*$
NNC	1.4 ± 0.7	3.0 ± 1.3	389.5	−6.16	0.62	$< 0.001*$
TT	10.0 ± 3.7	11.1 ± 2.2	991.0	−1.79	0.18	0.074

Tabla 4.4: Prueba de U Mann-Whitney para las viariables obtenidas durante el juego (Grupos B y C).

Var.	Grupo B	Grupo C	U	Z	r	p
NEA	39.0 ± 6.9	43.8 ± 1.8	497.0	−5.10	0.52	$< 0.001*$
NNC	3.0 ± 1.3	4.3 ± 1.0	507.5	−5.12	0.52	$< 0.001*$
TT	11.1 ± 2.2	8.7 ± 1.0	2037	5.95	0.60	$< 0.001*$

y Grupo) en la variable NNC, Tabla 4.5. Los resultados muestran que hubo diferencias estadísticamente significativas para la Edad y el Grupo, pero no para el Género. Como se observa en la Tabla 4.3, los niños de 8 a 10 años presentan un rendimiento significativamente mejor que los niños de 5 a 7 años.

Tabla 4.5: Prueba Kruskal-Wallis para la viariable NNC, considerando los Grupos A y B.

Factores	χ^2	*d.f.*	p
Género	0.001	1	0.983
Edad	49.299	5	$< 0.001*$
Grupo (A/B)	37.944	1	$< 0.001*$

4.5.2 Resultados utilizando métodos tradicionales

La Tabla 4.6 muestra los resultados del análisis estadístico aplicado a los datos obtenidos por los Grupos A y B en los métodos tradicionales. Las puntuaciones en las subpruebas ML, DD, y ECM no ofrecen diferencias estadísticamente significativas entre los dos grupos respecto a su capacidad para recordar ubicaciones espaciales, secuencias de sonidos verbales, y su memoria espacial en el día a día. Hubo diferencias estadísticamente significativas entre los dos grupos en las valoraciones de las subpruebas DI y DSM.

Tabla 4.6: Prueba de U Mann-Whitney aplicada a las puntuaciones obtenidas utilizando metodos tradicionales y considerando los Grupos A y B.

Var.	**Grupo A**	**Grupo B**	U	Z	r	p
ML	10.6 ± 6.2	12.3 ± 7.5	1074.5	-1.212	0.121	0.227
DD	8.1 ± 1.8	8.1 ± 1.9	1282.5	0.230	0.023	0.821
DI	13.2 ± 6.5	20.0 ± 7.7	426.5	-5.688	0.569	$< 0.001*$
DSM	13.6 ± 1.1	14.1 ± 0.9	934.5	-2.279	0.228	$0.023*$
ECM	3.9 ± 3.3	3.4 ± 2.8	1341.0	0.633	0.063	0.530

Se realizaron pruebas de Kruskal-Wallis para determinar la influencia de tres factores (Género, Edad, y Grupo) en la subprueba DSM, considerando los niños, Tabla 4.7. Los resultados muestran que hubo diferencias estadísticamente significativas para la Edad y el Grupo, pero no para el Género. Como se observa en la Tabla 4.6, los niños mayores obtienen un rendimiento significativamente mejor que los niños más pequeños en la discriminación de sonidos.

La Tabla 4.8 muestra los resultados del análisis estadístico aplicado a los datos obtenidos utilizando métodos tradicionales y para los Grupos B y C. Las puntuaciones en las subpruebas muestran diferencias estadísticamente significativas entre los dos grupos a favor de los adultos en todas las pruebas, a excepción de la prueba DD. Pero, en todas las pruebas los adultos obtuvieron una puntuación mayor que los niños.

Tabla 4.7: Prueba de Kruskal-Wallis para una de las pruebas tradicionales (DSM) en los niños.

Factores	χ^2	*d.f.*	p
Género	1.120	1	0.290
Edad	17.223	5	$0.004*$
Grupo (A/B)	5.193	1	$0.022*$

Tabla 4.8: Prueba U de Mann-Whitney aplicada a las puntuaciones obtenidas utilizando métodos tradicionales y considerando los Grupos B y C.

Var.	Grupo B	Grupo C	U	Z	r	p
ML	12.3 ± 7.5	18.8 ± 5.0	546.5	-4.65	0.47	$< 0.001*$
DD	8.1 ± 1.9	8.7 ± 2.6	339.0	-0.58	0.07	0.574
DI	20.4 ± 7.6	36.5 ± 13.7	303.5	-6.38	0.64	$< 0.001*$
DSM	14.1 ± 0.9	14.7 ± 0.5	762.5	-3.46	0.35	$< 0.001*$
ECM	3.4 ± 2.8	11.6 ± 4.4	114.0	-7.74	0.78	$< 0.001*$

4.5.3 Correlaciones entre el juego y métodos tradicionales

Para comparar el rendimiento de los participantes al utilizar el juego (NNC) y los métodos tradicionales (ML, DI, DSM y ECM), se han calculado las correlaciones con la muestra completa (100 niños y 48 adultos). Se aplicó la correlación de Spearman y se obtuvo el tamaño del efecto de dicha correlación, rho (ρ). Las correlaciones entre la variable NNC y las variables de métodos tradicionales son las siguientes: ML ($\rho = 0.49$, p < 0.001*), DI ($\rho = 0.62$, p < 0.001*), DSM ($\rho = 0.34$, p < 0.001*) y ECM ($\rho = 0.43$, p < 0.001*). Todas las correlaciones son lineales y positivas. Estas correlaciones demuestran la similitud entre nuestro juego y los métodos tradicionales.

4.5.4 Resultados de usabilidad y satisfacción

Se aplicó la prueba U de Mann-Whitney a los datos obtenidos del cuestionario de usabilidad y satisfacción. Los resultados para el Grupo A y B se muestran en la Tabla 4.9. Los resultados del Grupo B y C se muestran en la Tabla 4.10. Existen diferencias estadísticamente significativas entre los grupos A y B, para las preguntas PS1 y PS5. Los niños mayores se han divertido más y les ha gustado más jugar con los Karotz. Sin embargo, ambos grupos otorgaron una puntuaron muy alta a las preguntas de usabilidad y satisfacción (la media más baja fue de 4.28 en una escala de 1 a 5). Al comparar el grupo de los niños mayores (Grupo B) con el grupo de los adultos (Grupo C), se observa que existen diferencias estadísticamente significativas en todas las preguntas, a favor de los niños, excepto en la PU2 (Fue fácil aprender a usar este juego).

Tabla 4.9: Prueba U de Mann-Whitney para las preguntas de usabilidad y satisfacción, considerando los grupos A y B.

Var.	Grupo A	Grupo B	U	Z	r	p
PU1	4.76 ± 0.56	4.80 ± 0.40	1245	-0.050	0.005	< 0.990
PU2	4.70 ± 0.54	4.78 ± 0.42	1189	-0.567	0.057	0.577
PS1	4.76 ± 0.56	4.96 ± 0.20	1072	-2.261	0.226	0.030*
PS2	4.64 ± 0.83	4.74 ± 0.53	1237	-0.124	0.012	0.875
PS3	4.64 ± 0.63	4.76 ± 0.48	1160	-0.822	0.082	0.426
PS4	4.38 ± 0.99	4.44 ± 0.76	1263	0.103	0.010	0.931
PS5	4.28 ± 0.78	4.64 ± 0.53	953	-2.317	0.232	0.024*

Tabla 4.10: Prueba U de Mann-Whitney para las preguntas de usabilidad y satisfacción, considerando los grupos B y C.

Var.	Grupo B	Grupo C	U	Z	r	p
PU1	4.80 ± 0.40	4.23 ± 0.66	178.0	4.743	0.479	< 0.001*
PU2	4.78 ± 0.42	4.83 ± 0.38	1136.0	-0.66	0.067	0.612
PS1	4.96 ± 0.20	4.25 ± 0.56	1980.0	6.628	0.669	< 0.001*
PS2	4.74 ± 0.53	4.04 ± 0.82	1804.5	4.804	0.485	< 0.001*
PS3	4.76 ± 0.48	4.38 ± 0.61	1614.0	3.446	0.348	< 0.001*
PS4	4.44 ± 0.76	3.85 ± 0.90	1627.0	3.262	0.330	0.001*
PS5	4.64 ± 0.53	4.27 ± 0.64	1569.5	2.962	0.299	0.024*

4.6 Discusión

Nuestro juego implica la evaluación simultánea de habilidades espaciales y auditivas. Por contra, los métodos tradicionales consideran cada habilidad por separado. Se han encontrado correlaciones entre nuestro juego y métodos tradicionales, indicando que nuestro juego ha demostrado ser una herramienta válida para evaluar la memoria espacial tanto para niños como para adultos. Hecho que corrobora nuestra hipótesis. Por lo que sabemos, ningún estudio ha probado este tipo de evaluación utilizando la tecnología propuesta.

El rendimiento con el juego ha sido significativamente incremental y directamente relacionado con el grupo de edad (Grupo A $<$ Grupo B $<$ Grupo C). El juego requiere atención y concentración constantes, dado que implica la evaluación simultánea de habilidades espaciales y auditivas. Que los resultados hayan sido mejores para los adultos y los niños mayores, por este orden, es consistente con la idea de que los adultos pueden almacenar más elementos en la memoria a corto plazo que los niños, debido a que la capacidad de memoria aumenta a lo largo del desarrollo evolutivo hasta su maduración en la etapa adulta (Rohde and Plaut 2003).

Respecto a la usabilidad y satisfacción con el juego, entre los niños no ha habido diferencias estadísticamente significativas para las 8 preguntas, excepto para la PS1 (Lo he pasado bien) y PS5 (Me ha gustado jugar con los Karotz), a favor de los niños mayores. Sin embargo, ambos grupos otorgaron una puntuación muy alta a las preguntas de usabilidad y satisfacción (la media más baja fue de 4.28 en una escala de 1 a 5). Por lo que se puede concluir, que a todos los niños les ha parecido fácil de aprender a usar y fácil de utilizar, que se lo han pasado bien, y que han mostrado su satisfacción con el juego. Dado que el juego les ha parecido fácil de utilizar, los niños han podido concentrarse en las tareas a realizar, en lugar de la interacción en sí. Los Karotz emiten sonidos y mueven sus orejas e iluminan su parte central, por lo que los niños los pueden consideran como mascotas o juguetes. El uso de múltiples modalidades sensoriales puede influir en la satisfacción de los niños. La comunicación de los participantes con los Karotz levantando los brazos se puede interpretar como un código de comunicación entre iguales, que puede influir en lo atractivo del juego. Muchos niños estaban acostumbrados a este tipo de interacción dada la proliferación de juegos que utilizan Kinect, y por ello este tipo de interacción les parecía natural. Desde nuestro punto de vista, todo ello contribuye a la inmersión que induce nuestro juego y a la motivación demostrada por parte de los participantes. Las observaciones de la supervisora corroboran nuestra percepción de inmersión. La supervisora añade que muchos niños no se daban cuenta de que ella estaba allí y que incluso, hablaban con los Karotz.

Considerando la comparación entre los niños mayores y los adultos, se encontraron diferencias estadísticamente significativas en todas las preguntas, a favor de los niños, excepto en la PU2 (Fue fácil aprender a usar este juego), que ambos grupos consideraron que fue fácil de aprender (medias de 4.78 (niños) y 4.83 (adultos)). Los niños mayores otorgaron una puntuación muy alta a las preguntas de usabilidad y satisfacción (la media más baja fue de 4.44 en una escala de 1 a 5). Los adultos otorgaron valores inferiores, estando la media alrededor de 4 en todas las preguntas, excepto en PU2 que fue de 4.83. Por lo que, se puede concluir que, el juego, a los adultos también les pareció fácil de aprender a usar y fácil de utilizar, que se lo pasaron bien, y mostraron su satisfacción con el mismo. Sin embargo, las diferencias estadísticamente significativas obtenidas en 6 de las 7 preguntas, a favor de los niños, indican que el juego sería especialmente atractivo para niños. Estas diferencias se podrían explicar considerando la brecha generacional entre niños y adultos, que implica disparidad en la capacidad y el conocimiento de la tecnología (Warschauer 2007). A este respecto, Prensky (2005) argumenta que los niños son "nativos digitales" y que los adultos son "inmigrantes digitales".

Con respecto a la interacción y a la selección de los Karotz, en este trabajo se ha utilizado la interacción mediante gestos. Sin embargo, se podría haber utilizado el botón que los Karotz tienen en la parte superior, utilizar una interfaz de usuario de lenguaje natural, seleccionar en una Tablet el Karotz correcto, etc. Como trabajo futuro se está estudiando la incorporación de otro tipo de interacción y su comparación. No obstante, nuestra propuesta pretendía que el juego pudiese ser utilizado por población invidente y la interacción alternativa también tendría que considerar este colectivo, por lo que, por ejemplo, pulsar el botón de la parte superior de los Karotz o utilizar una Tablet no serían alternativas viables. Respecto a los Karotz, para reproducir o mejorar nuestra propuesta se podría utilizar otro tipo de robots que actualmente estén en el mercado o que pudieran aparecer en el futuro.

Nuestro juego se podría comparar con otros métodos con el mismo principio, por ejemplo, utilizando como base la idea del juego "*El director de orquesta*". En este juego, un grupo de niños se coloca en círculo mirando todos hacia el interior del mismo, mientras un niño del grupo queda fuera (niño A). Se nombra a un director de orquesta, sin que el niño A sepa quién es. El director de orquesta indica un sonido que los demás niños tienen que imitar. El objetivo del niño A es adivinar quién es el director. A su vez, el director tiene que cambiar el sonido sin que el que busca al director se dé cuenta, y los demás le siguen. El juego termina cuando se adivina quién es el director de orquesta. Para la comparativa con nuestro juego, se podría utilizar una variante del juego "*El director de orquesta*", en el que el director de orquesta haría las tareas del ordenador de nuestro juego, el resto de niños harían las tareas de los Karotz, y el niño A sería el participante en nuestro juego.

4.7 Conclusiones

Nuestro juego permite evaluar la integración multimodal de la información auditiva y espacial tanto en niños como en adultos. El juego podría ser una buena herramienta para identificar alteraciones en la memoria espacial tanto en niños como en adultos. En los niños se podría realizar una identificación temprana del desarrollo atípico, niños con trastorno por déficit de atención e hiperactividad (TDAH), etc. En los adultos se podría utilizar para identificar alteraciones en su memoria, como por ejemplo, la enfermedad de Alzheimer, otros tipos de demencia con alteraciones de la orientación, pacientes con secuelas tras sufrir un accidente cerebrovascular o traumatismo craneal, etc. En otro trabajo futuro, el juego se podría mejorar combinando claves visuales y auditivas (p. ej., se podrían incluir como claves visuales los movimientos de los robots). En este trabajo, hemos comparado niños y adultos, pero también son posibles otras comparaciones. Por ejemplo, sería interesante comparar el rendimiento de los niños con visión normal y los niños ciegos o usar este nuevo juego con niños con TDAH. El conocimiento sobre cómo aprenden en diferentes entornos inteligentes proporcionaría una base para entender sus fortalezas y debilidades cognitivas, además de contribuir al desarrollo de nuevas formas de aprendizaje.

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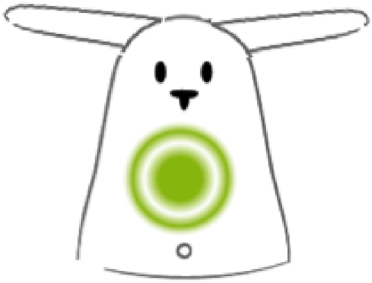
Part III

Discussion & Conclusions



Chapter 5

Discussion

"You do not have to be great to start, but you have to start to be great"

Zig Ziglar

Contents

In this chapter, the main results achieved in this thesis are discussed. Each of the three papers included in this thesis has its own discussion section, which complete the discussion presented in this section.

5.1 Discussion

This thesis is part of the CHILDMNEMOS project. As mentioned in the introduction section, in CHILDMNEMOS, different systems to assess spatial memory were designed and developed. The main feature of CHILDMNEMOS is the use of devices and technology that have not been used to date for the assessment of spatial memory. Moreover, all the tasks developed in CHILDMNEMOS include a fundamental difference with respect to the tasks that had been used to date and it is the physical movement of the user in the real space. In our other works (Juan et al. 2014; Méndez-López, Pérez-Hernández, and Juan 2016; Rodríguez-Andrés et al. 2015; Rodríguez-Andrés et al. 2018; Cárdenas-Delgado et al. 2017a; Cárdenas-Delgado et al. 2017b), the stimuli received by the user was only visual. Traditional methods consider each skill (visual or auditory) separately (Reynolds and Bigler 2001; Brancal et al. 2009). However, this thesis combines auditory stimuli with real visual cues for the assessment of spatial memory.

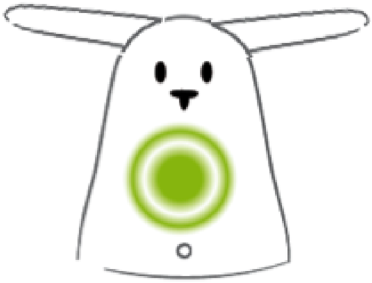
For the validation, three studies were carried involving healthy children, children with symptoms of inattention and healthy adults. The first study involved children with and without symptoms of inattention. A total of 34 children participated. There were 17 children with inattention and 17 children without inattention. The second study compared the performance in the task between older children and adults. A total of 70 participants were involved in this study. There were 32 healthy children from 9 to 10 years old, and 38 healthy adults from 18 to 28 years old. In the third study, a total of 148 participants were involved. They were distributed in three groups (younger children, older children and adults). A total of 100 children from 5 to 10 years old and 48 adults from 18 to 28 years participated in this study. The participants played with our task, and traditional tests were also administered (Reynolds and Bigler 2001; Brancal et al. 2009). The general conclusions for these three studies are discussed below.

Correlations were found between our task and traditional methods, indicating that our task has proven to be a valid tool for assessing spatial memory by using auditory stimuli for both children and adults. These correlations are in line with our previous works for assessing spatial memory (only based in visual cues) that also obtained correlations between our previous tasks and traditional methods (Juan et al. 2014; Méndez-López, Pérez-Hernández, and Juan 2016; Rodríguez-Andrés et al. 2016; Cárdenas-Delgado et al. 2017b). This result is also in line with other previous works that have demonstrated that serious games have the potential to be used as assessment tools (e.g., Vallejo et al. 2017) or for diagnosis (e.g., Tarnanas et al. 2014).

The performance outcomes in the task were significantly incrementally and directly related to the age group (younger children < older children < adults). This implies that the children did not achieve full competence in the task. Our explanation for this result is that the task requires constant attention and concentration since it involves the simultaneous evaluation of spatial and auditory abilities. The fact that the results were better for adults is consistent with the idea that adults can store more elements in short-term memory than children because the ability of the humans increases continuously during development (Lezak 1995). One of the results derived from the CHILDMNEMOS project was that a visual version of a spatial memory task, developed with Augmented Reality, confirmed that the visuospatial span improved significantly between ages 8 and 9. However, the development of this ability was not yet completed, and only the group of adult participants reached the maximum performance (Méndez-López, Pérez-Hernández, and Juan 2016). Based on the results of this thesis, the number of spatial items recalled by a human across development when auditory processing was involved suffers the same maturation. Therefore, we suggest that these results contributed to confirm a developmental trajectory of short-term memory skills (Logie and Pearson 1997). Other developmental factors could facilitate the maximum performance. For example, the verbal skills (Cowan, Saults, and Morey 2006) and the maturation of the brain substrates for memory and spatial cognition (Klingberg, Forssberg, and Westerberg 2002; Kwon, Reiss, and Menon 2002; Nagy, Westerberg, and Klingberg 2004; Muftuler et al. 2012; Sowell et al. 2004; Zald and Iacono 1998).

With regard to perceptions and satisfaction with the task, the mean scores for nearly all of the questions for both the children and the adults were greater than 4 (on a scale of 1 to 5). Therefore, we can conclude that all of the participants found the task easy to learn and easy to use, they had a good time, and they have shown their satisfaction with the task. The analysis showed that the children scored significantly higher than adults in different questions. Therefore, we can conclude that the children were significantly more satisfied with the task than the adults. Since the task seemed easy to use for both children and adults, they were able to concentrate on the tasks to be done rather than on the control mechanisms. The smart devices emit sounds and move their ears and illuminate their central part, so the participants can consider them as pets or living toys. This aspect could influence the greater fun experienced by the children. The use of multiple sensory modalities may influence participants' satisfaction. The communication of the participants with the smart device raising their arms can be interpreted as a code of communication between equals, which can influence the attractiveness of the task or add a plus of a communication game. Many participants were accustomed to this type of interaction, so they found it natural. From our point of view, all of this contributes to the participants' satisfaction with the task. The supervisor's observations corroborate that the children were satisfied with the task. The supervisor added that many participants did not realize that the smart devices were artificial and they even talked to them. However, in this work, we have not yet determined the influence that the physical appearance of the smart devices had on the children and their motivation for the task. With regard to the first study involving children with inattention, the outcomes of children with symptoms of inattention were not as good as the outcomes obtained by children without these symptoms for the task or for the traditional method of testing the memory of verbal sounds. However, they had no difficulties for auditory discrimination of verbal and environmental sounds. We believe that our task promoted greater cognitive effort. Therefore, we suggest that the cognitive effort needed to solve this task plays a crucial role in the detection of the difficulties presented by children with symptoms of inattention. The task requires constant attention and concentration. Children with inattention have difficulty sustaining attention over time (Williams, Wright, and Partridge 1999). Besides these problems, there is also impaired performance on tasks of spatial memory (Arai et al. 2016).

With regard to ecological validity, in neuropsychological assessment, ecological validity can be defined as the "functional and predictive relation between the participant's performance on a set of neuropsychological tests and the participant's performance in a variety of real-world settings" (Spooner and Pachana 2006). Therefore, the development of new tasks for neuropsychological assessment represents an important tool for early identification of atypical development or for assessment of memory as a cognitive function that is linked to various intellectual and social activities of children and adults. Tasks of this type could contribute to a better understanding of the influence of different variables on the cognitive development of children and adults. Our task can be used for assessing cognitive processes in an ecological way. Our task is in line with previous serious games that have shown ecological validity (Tarnanas et al. 2013). However, we have not checked the influence that the ecological component has on the participants. We conclude that our task offers a great opportunity to assess spatial memory using auditory stimuli in healthy children, children with inattention and healthy adults. However, our task and other similar tasks could be used not only for assessment, but also for training. As indicated in the introduction section, as assessment tools could allow the early identification of atypical development in children, or if an adult has alterations in his/her memory. These difficulties in orientation usually occur in disorders or diseases. As a training tools can help in improving the performance in situations of spatial orientation by practicing help strategies (Caffò et al. 2014).



Chapter 6

General Conclusions

"By perseverance, everything reaches its target"

Catalan Proverb

Contents

In this chapter are summarized the main contributions of this thesis. Also, some lines for future works are described.

6.1 Conclusions

A new task for the assessment of spatial memory was designed and developed based on auditory stimuli, smart devices and gesture interaction. The task tests the ability of children and adults to detect and localize auditory stimuli that are emitted in different positions of the task area. The task integrated Natural User Interfaces and smart devices. The task recognizes the movements of the arms of the user. Kinect^{TM} was used for this purpose. Smart devices (Karotz rabbits) were used for emitting auditory stimuli and also as visual cues (e.g., movement of the ears). Therefore, the task combined auditory stimuli with real visual cues for the assessment of spatial memory. The area of the task for our studies was defined to be around 5 m^2. Artificial turf was placed on the floor for guide paths, and a rug was used to indicate the initial position of the player. The walls were covered with wrapping paper to eliminate any spatial cues. The height of the Karotz rabbit was adjusted. Five Karotz rabbits were placed on tables with a difference of angles of 30°. Each Karotz rabbit emits its assigned sound. The task included a total of 45 acoustic stimuli, which should be randomly emitted in different locations. The task was defined to be composed of five different levels based on the number of stimuli presented in each trial. Each level was defined to relate to a specific theme. The chosen themes were: nature, a party, a farm, a house, and a big city. Each level consists of 3 trials. The difference between levels lies in the number of sounds to be used in each trial, which will increase by 1 at each subsequent level.

In this thesis, three studies were carried out that focused on studying and comparing different factors and performance measures between data collected with the task and classical methods for testing memory skills. We also assessed other aspects such as usability, fun, perception and overall satisfaction with the task. Moreover, to our knowledge, this is the first work in which is combined Natural User Interfaces and smart devices for the assessment of spatial memory using auditory stimuli. The benefits that offer the new task has been shown in the results of this thesis. The development of new tasks for neuropsychological assessment represents an alternative for the assessment of spatial memory. Our task and other similar tools can be used for assessment of the spatial memory as well as for training.

The conclusions of the three studies are described as follow:

Study 1. Inattentive children vs. control group.

- The children with inattention showed statistically worse performance in the task. Result that corroborates the first part of the first hypothesis.
- Traditional methods did not offer significant differences between the two groups. Result that does not corroborate the second part of the first hypothesis.
- There were no statistically significant differences between the two groups for the satisfaction and interaction outcomes. Results that corroborate the second hypothesis.
- The task is a good tool for distinguishing spatial memory difficulties in children with symptoms of inattention.

Study 2. Older children vs. adults

- The performance outcomes with the task were significantly lower for the older children. Result that corroborates our third hypothesis.
- Correlations were found between our task and traditional methods, indicating that our task has proven to be a valid tool for assessing spatial memory by using auditory stimuli for both older children and adults.
- With regard to perceptions and satisfaction with the task, the mean scores for all questions for both the older children and the adults were greater than 4 (on a scale of 1 to 5).
- All of the participants found the task easy to learn and easy to use, they had a good time, and they have shown their satisfaction with the task. From the analysis, we can conclude that the older children were significantly more satisfied with the task than the adults. Conclusion that corroborates our fourth hypothesis.

Study 3. Small children vs. older children vs. adults.

- The performance outcomes in the task were significantly incrementally and directly related to the age group (younger children $<$ older children $<$ adults).
- Correlations were found between our task and traditional methods, indicating that our task has proven to be a valid tool for assessing spatial memory for both children and adults. Result that corroborates our fifth hypothesis.
- For the satisfaction with the task, there were no statistically significant differences between younger and older children. However, there were statistically significant differences between children and adults in favor of the children.

From the development and the studies carried out we can present the following general conclusions:

- Natural user interfaces and smart devices are appropriated for developing tasks for the assessment of spatial memory.
- As a computer-based game, our task facilitates the control of the presentation of stimuli and the recording of responses.
- Our task and similar tasks could be used for assessment and training of spatial memory in children and adults.
- The task could be an alternative tool to assess spatial memory in children with symptoms of inattention.
- The task promoted engagement and allowed the assessment in an ecological way.
- The task could help in the identification of alterations in spatial memory in both children and adults. In children, the task could help in the early identification of atypical development, children with Attention Deficit Hyperactivity Disorder, etc. In adults, the task could help in the identification of alterations in memory, such as Alzheimer's disease, other types of dementia with alterations of orientation, patients with sequelae after suffering a stroke or head trauma, etc.

6.2 Future Works

Our task could serve as a basis for the development of new tools for the assessment of spatial memory. For example, using the last affordable smart devices. Another work could study the influence of the physical appearance of the smart devices.

With regard to the interaction and selection of the smart device, in this work the interaction was achieved through gestures. However, the button built-in the smart device or a natural language user interface could be used, inclusive the correct smart device could be selected on a tablet or with other devices. Furthermore, as future work, we could incorporate other types of interaction and their comparison. For example, it would be interesting to compare the performance of children with normal vision and blind children or to use this new task with children with developmental disorders. Another study could focus on determining the potential of the smart devices in the development of learning tasks for people with autism. A system of these characteristics could attenuate the social factor that sometimes seems to be painful for children with autism. Finally, the usefulness of our task with adults with and without brain injury could also be analyzed for both assessment and training.

6.3 Scientific contributions

The publications derived from this thesis are following:

6.3.1 Papers in indexed conferences

- Mauricio Loachamín-Valencia, M.-Carmen Juan, Magdalena Méndez-López, Elena Pérez-Hernández (2017). "Auditory and Spatial Assessment in Inattentive Children Using Smart Devices and Gesture Interaction", In: *IEEE* 17^{th} *International Conference on Advanced Learning Technologies (ICALT 2017)*. pp. 106-110, DOI: https://doi.org/10.1109/ICALT.2017.28 (CORE B).

- Mauricio Loachamín-Valencia, M.-Carmen Juan, Magdalena Méndez-López, Elena Pérez-Hernández (2018). "Using a Serious Game to Assess Spatial Memory in Children and Adults", In: *International Conference on Advances in Computer Entertainment Technology (ACE 2017).* LNCS 10714, pp. 809-829, DOI: https://doi.org/10.1007/978-3-319-76270-8_55 (CORE B).

6.3.2 Papers submitted to indexed journals

- Mauricio Loachamín-Valencia, M.-Carmen Juan, Magdalena Méndez-López, Elena Pérez-Hernández, M. José Vicent (2017). "Developing and Evaluating a Game for the Assessment of Spatial Memory Using Auditory Stimuli". In: *IEEE Latin America Transactions.* Unpublished (submitted and under review).

6.3.3 Other conferences

- Jimena Bonilla-Carvajal, Mauricio Loachamín-Valencia, Elena Pérez-Hernández, M.-Carmen Juan, Magdalena Méndez-López (2014). "Los beneficios del entrenamiento musical sobre el desarrollo infantil". In: *IV Congreso Internacional de Psicología y Educación.* pp. 2-27.

- Elena Pérez-Hernández, Magdalena Méndez-López, Jimena Bonilla-Carvajal, Mauricio Loachamín-Valencia, M.-Carmen Juan (2015). "A preliminary study of the performance of primary school children on an auditory spatial memory task". In: 3^{rd} *International Congress of Educational Sciences.* pp. 688.

- Jimena Bonilla-Carvajal, Mauricio Loachamín-Valencia, Elena Pérez-Hernández, M. Carmen Juan, Magdalena Méndez-López (2015). " ¿Existen diferencias sexuales en la memoria espacial auditiva en el desarrollo? Un estudio". In: *VII Congreso Nacional de Neuropsicología* (Neuropsicología 3.0). Comunicación 6.

- Jimena Bonilla-Carvajal, Elena Pérez-Hernández, Mauricio Loachamín-Valencia, M.- Carmen Juan, Magdalena Méndez-López (2017). "Efecto de las Actividades Extraescolares en el Desempeño Académico y Cognitivo". In: *Congreso Colombiano de Psicología*, pp. 836-837.

6.4 Other diffusions

- Mauricio Loachamín-Valencia and M.-Carmen Juan, "A New System with Auditory Stimuli to Evaluate Spatial Memory", *I Encuentro de Estudiantes de Doctorado - Universitat Politècnica de València*, Poster 118, 2014.

- M.-Carmen Juan, Sonia Cárdenas-Delgado, Mauricio Loachamín-Valencia. "Demostración de aplicaciones de realidad aumentada y autoestereoscopía para aprendizaje". Jornadas-Recursos educativos digitales: estrategias innovadoras. Valencia, 2014.

- M.-Carmen Juan, Sonia Cárdenas-Delgado, Mauricio Loachamín-Valencia, David Rodríguez-Andrés, and Juan-Fernando Martín-SanJosé, "Aplicaciones de la Realidad Aumentada, Autoestereoscopía e Interfaces Naturales en Educación y Psicología", *In I Jornada de Aplicaciones Industriales de Investigación,* Valencia, 2014.

- Mauricio Loachamín-Valencia, "Aplicaciones de realidad virtual y sistemas de visualización e inmersión". United Nations Day 2014, Valencia, 2014.

- Mauricio Loachamín-Valencia, M.-Carmen Juan, Elena Pérez-Hernández, "Development of a System with Natural Interaction and Environmental", *II Encuentro de Estudiantes de Doctorado - Universitat Politècnica de València*, Poster 114, 2015.

- Mauricio Loachamín-Valencia, and M.-Carmen Juan, "Interaction with Social Robots: Children vs. Adults", *III Encuentro de Estudiantes de Doctorado - Universitat Politècnica de València*, Poster 77, 2016.

6.5 Other works

- M.-Carmen Juan, Mauricio Loachamín-Valencia, Inmaculada Garcia-Garcia, José Manuel Melchor, Josep Benedito (2017). "ARCoins. An Augmented Reality App for Learning about Numismatics" *In: IEEE 17th International Conference on Advanced Learning Technologies (ICALT 2017)*, pp. 466-468, DOI: https://doi.org/10.1109/ICALT.2017.27 (CORE B).

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