SERIOUS GAMES FOR VISUALLY IMPAIRED PLAYERS AND TO PROMOTE FIRST-AID PROTOCOLS

Antonio Rodríguez Benítez

Universitat de Girona

DOCTORAL THESIS

Serious games for visually impaired players and to promote first-aid protocols

Antonio Rodríguez Benítez

2020

Universitat de Girona

DOCTORAL THESIS

Serious games for visually impaired players and to promote first-aid protocols

Author:
Antonio Rodríguez Benítez

2020

Doctoral Programme in Technology

Advisors:
Dra. Imma Boada Oliveras
Dr. Mateu Sbert Casasayas

A thesis submitted to the Universitat de Girona in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Universitat de Girona

El Dr. Mateu Sbert i la Dra. Imma Boada, de la Universitat de Girona,

DECLAREM:

Que el treball titulat *Serious games for visually impaired players and to promote first-aid protocols*, que presenta el Sr. Antonio Rodríguez Benítez per a l'obtenció del títol de doctor, ha estat realitzat sota la nostra direcció.

I, perquè així consti i tingui els efectes oportuns, signo aquest document.

Signatura

Girona, 30/10/2019

Agraïments

Aquesta tesi no hauria sigut possible sense moltes persones que m'han anat ajudant durant aquest projecte i al llarg de la meva vida, i que m'han permès arribar fins a aquest punt.

Un profund agraïment als meus directors de tesi, en Mateu Sbert i l'Imma Boada; sense la seva implicació i dedicació aquesta tesi no hauria vist la llum. Un especial agraïment a en Mateu Sbert, ell em va obrir les portes del món laboral i investigador. Va confiar en mi per formar part del grup de recerca GiLab, cosa que m'ha permès dedicar-me al que sempre he volgut, els videojocs, i continuar formant-me i fent la tesi pel camí. Sense la seva oportunitat m'hagués estat impossible fer aquesta tesi. No em puc oblidar d'agrair de manera molt sincera a l'Imma Boada tota l'ajuda i el suport oferts durant aquest llarg camí. És un plaer treballar i investigar al seu costat. M'ha ajudat enormement a entendre el món dels articles científics i com funcionen les publicacions; a més, sempre m'ha recolzat independentment del moment.

Moltes gràcies a tots els companys que han anat passant pel laboratori; l'ajuda i el suport de cada un d'ells ha sigut molt important per mi. Especial menció a en Juan Manuel García, company i amic. La nostra manera de treballar en equip, encara que moltes vegades acabés amb discussions sobre com fer les coses, m'ha ajudat a millorar com a treballador i com a persona. Un especial agraïment també a en Pau Xiberta, que sempre ha estat disposat a resoldre qualsevol dubte que pogués tenir; és un plaer treballar amb gent com ell. Em deixo molts companys que han anat passant pel laboratori; és impossible anomenar-los ara a tots, segur que me'n deixaria molts, però tots i cada un d'ells m'han anat ajudant en un moment o un altre i, sobretot, han creat un ambient de treball realment formidable.

Als meus pares, perquè sense el seu suport i confiança mai hauria arribat fins on he arribat. Sempre han confiat en mi i m'han donat suport en totes les decisions que he anat prenent i que m'han portat a ser qui sóc. Tampoc em puc oblidar dels meus avis, que sempre m'han donat suport en tot, i de tota la meva família, que sempre ha estat al meu costat.

A tots els meus companys de carrera i de màster; el fet d'intentar estar a l'altura de cada un d'ells m'ha fet millor estudiant, professional, investigador i persona. Moltes gràcies a tots, però sobretot als que encara formeu part de la meva vida com a amics. Especial menció a en David Quintana i novament a en Juan Manuel García; sense ells no sé com hagués anat superant tots els petits obstacles fins a arribar al final. En David Quintana ha sigut un suport molt important durant tots aquests anys d'estudi i investigació. Un dels millors programadors que he conegut, i que sempre ha estat disposat a ajudar-me en qualsevol dubte o problema que he tingut. No em puc oblidar tampoc d'en Marc Puigdemont i en David Muñoz, que amb la seva amistat demostren el valor que té fer amics dins del món acadèmic.

Voldria recordar també les amistats de tota la vida, en especial en Marc Garcia, que sempre hi han sigut quan les he necessitat, encara que moltes vegades jo estava massa enfeinat per ocupar-me d'elles.

Per últim, però no menys important, un fort agraïment a la meva esposa Elisabet Conill. Sense el seu suport res d'això hauria sigut possible. Ella m'ha fet costat en tot moment aguantant els meus problemes i moltes vegades el mal humor per coses que no acabaven de sortir; un pilar essencial que m'ha permès tirar endavant.

Moltes gràcies a tots de tot cor.

Acknowledgements

This work was supported by the Catalan Government grants 2014-SGR-1232 and 2017-SGR-1101, and by the Spanish Government grants TIN2013-47276-C6-1-R and TIN2016-75866-C3-3-R.

List of publications

This thesis is presented as a compendium of the following research articles:

- An Arduino-based device for visually impaired people to play videogames, Antonio Rodríguez, Imma Boada, and Mateu Sbert, Multimedia Tools and Applications, 77(15) , pp:19591 – 19613 (2018), ISSN: 1380-7501 DOI 10.1007/s11042-017-5415-1 JCR- Computer Science and software engineering; position: 40/107; IF:2.101; Quartile Q2.

- How the gender of a victim character in a virtual scenario created to learn CPR protocol affects student nurses performance, Imma Boada, Antonio Rodriguez, Santiago Thió-Henestrosa, Josep Olivet, and Josep Soler, Computer Methods and Programs in Biomedicine, August (162), Pp:233-241 (2018), doi: 10.1016/j.cmpb.2018.05.019. JCR-Computer Science interdisciplinary applications, position:25/106; IF:3,424; Quartile Q1

- 30:2 a Game Designed to Promote the Cardiopulmonary Resuscitation Protocol, Imma Boada,Antonio Rodriguez-Benitez, Juan Manuel Garcia-Gonzalez, Santiago Thió-Henestrosa, and Mateu Sbert, International Journal of Computer Games Technology, 2016 ISSN: 1687-7047. Scopus-Computer Graphics and Computer-Aided Design , position: 24/64-IF:1,54.

- CPRforBlind, A videogame to introduce CardioPulmonary Resuscitation protocol to blind people, Antonio Rodríguez, Imma Boada, Santiago Thió-Henestrosa, Mateu Sbert, British Journal of Educational Technology, 2018, ISSN: 1467-8535, JCR- Education and Educational research, 31/243; IF:2,588; Quartile Q1 (JCR)

- Design and evaluation of a serious game to educate on choking, Antonio Rodríguez-Benítez, Imma Boada, Santiago Thio-Henestrosa, and Josep Soler.
  This contribution has been submitted to *JMIR Serious Games*

List of figures

List of tables

Contents

Abstract

Serious games are games designed to entertain and also to teach or transmit some knowledge. They are present in many areas such as military, health, manufacturing, education or medicine, just to name a few. One of their main advantages is their capability to recreate scenarios to experiment with situations that otherwise would be impossible in the real world due to required safety, cost, and time. In addition, serious games enhance the development of analytical and spatial, strategic, or psychomotor skills.

Unfortunately, despite the advantages of serious games there are still some aspects that need further research and development. On the one hand, there are communities such as visually impaired players which have many difficulties to access them since most of serious games rely on impressive graphics and immersive visual experiences. On the other hand, there are topics of relevant importance such as first-aid protocols that have been considered but only taking into account players with experience on the topic. With the aim to overcome these limitations and exploit serious games advantages as much as possible, in this thesis we have centered our interest on two main focus of research.

The first focus of research, has been centered on how to make serious games (and video games in general) more accessible to players with visual impairments. To reach this objective we have done two main contributions. The first one is a device for visually impaired people to interact with virtual scenes of video games. The device has been designed considering as main features usability, economic cost, and adaptability. Regarding usability, we have considered the white cane paradigm since this is the most used device by the blind community. The proposed device supports left to right movements, collision detection and actions to manipulate scene objects such as drag and drop. To enhance realism, the device integrates a sound library. To reduce the economic cost, we have used Arduino as the basis of our development. The device can be adapted to different game engines. The second contribution is a serious game based on sound and tactile interaction designed to teach the cardiopulmonary resuscitation (CPR) protocol to players with visual impairment. The game denoted CPRforBlind is composed of different mini-games inspired by the CPR steps proposed by European Resuscitation Council. Both proposals have been tested in real scenarios obtaining very promising results.

The second focus of research, has been centered on how to extend serious games to first-aid survival procedures considering players with and without experience on the topic. To reach this objective we have centered our interest on CPR protocol and the protocol to be applied in case of choking victims. We have done three main contribution. The first one is a study on how the gender of victims in virtual scenarios can impact on player performance when practicing CPR protocol. Different emergency scenarios with victims of different genders have been modeled and integrated in a serious games designed to learn CPR. Student from the Nursery Faculty

have solved the emergencies while different performance parameters were evaluated. From the study, it has been seen that performance is not influenced by victim gender. The second and third contributions have been two serious games designed to promote the CPR and the choking protocol to non-experts on the topic. Both games have been designed as a set of mini-games that reproduce the main steps of these first-aid protocols. Games have been implemented and tested in real scenarios with very satisfactory results.

From the research carried out in the context of thesis, we can conclude that serious games have been extended to new player profiles and also to new topics.

Resum

Els jocs seriosos són jocs que, a més a més d'entretenir, ensenyen o transmeten algun coneixement. S'apliquen en diferents àrees com poden ser la militar, la salut, la indústria, l'educació o la medicina, entre d'altres. Un dels seus principals avantatges és la seva capacitat per recrear escenaris que permeten experimentar amb situacions que d'una altra manera serien impossibles a la vida real a causa de la seguretat, el cost o el temps que requeririen. A més a més, els jocs seriosos milloren el desenvolupament d'habilitats analítiques, espacials, estratègiques o psicomotrius.

Malauradament, tot i els avantatges dels jocs seriosos, encara hi ha certs aspectes en els que cal més recerca i desenvolupament. D'una banda, hi ha comunitats, com les persones amb discapacitats visuals, que hi tenen moltes dificultats d'accés, ja que la majoria de jocs seriosos es basen en gràfics i experiències visualment immersives. D'una altra banda, encara hi ha temes importants com els protocols de primers auxilis que, tot i haver estat considerats en l'entorn dels jocs seriosos, només han tingut en compte als usuaris experts en la matèria deixant-ne fòra altres perfils de judadors. L'objectiu d'aquesta tesi es ajudar a superar aquestes limitacions i aprofitar al màxim els avantatges dels jocs seriosos. Per assolir aquest objectiu ens hem centrat en dos focus de recerca.

El primer focus de recerca s'ha centrat en com fer els jocs seriosos (i els videojocs en general) més accessibles a persones amb discapacitat visual. Per aconseguir aquest objectiu s'han fet dues contribucions principals. La primera d'elles és un dispositiu per persones amb discapacitat visual que els permet interactuar amb els escenaris virtuals dels videojocs. El dispositiu s'ha dissenyat considerant la usabilitat, l'adaptabilitat i el cost com les seves característiques principals. Respecte a la usabilitat, s'ha agafat com a referència el bastó blanc en ser el dispositiu més utilitzat per desplaçar-se dins del col·lectiu. Per potenciar el realisme s'han integrat unes llibreries de so. Per reduir el cost econòmic s'ha utilitzat Arduino com a base del desenvolupament. El dispositiu es pot adaptar a diferents motors de videojocs. La segona contribució és un joc seriós basat en sons i interacció tàctil amb l'objectiu d'ensenyar el protocol de ressuscitació cardiopulmonar (RCP) a jugadors amb discapacitat visual. El joc, anomenat CPRforBlind, compta amb diferents minijocs inspirats en els diferents passos del RCP proposats pel *European Resucitation Council.* Les dues propostes s'han provat en situacions reals i s'han obtingut resultats molt prometedors.

El segon focus de recerca s'ha centrat en els jocs seriosos que promouen els primers auxilis i com extendre'ls als jugadors que no són experts en el tema. Per aconseguir aquest objectiu s'ha focalitzat l'interès en els protocols de RCP i el protocol que s'ha d'aplicar a una víctima d'ennuegament. En el context d'aquest segon focus s'han fet tres contribucions. La primera és un estudi de l'impacte que té el gènere de la víctima d'un escenari virtual per practicar RCP en el rendiment del jugador. L'estudi s'ha realitzat considerant estudiants de la Facultat d'Infermeria.

Aquests havien de resoldre diferents situacions d'emergències de RCP mentre se'ls hi avaluaven diferents paràmetres de rendiment. Durant l'estudi s'ha vist que el rendiment no es veia afectat pel gènere de la víctima. La segona i la tercera contribució han estat dos jocs seriosos destinats a promoure el protocol de RCP i el d'ennuegaments a usuaris no experts en el tema. Els dos jocs s'han dissenyat com un conjunt de minijocs que reprodueixen els principals passos d'aquests protocols de primers auxilis. Els jocs s'han implementat i avaluat en situacions reals obtenint resultats molt satisfactoris.

De la investigació realitzada en el context de la tesi es pot concloure que s'ha ampliat el camp d'aplicació del jocs seriosos a un nou perfil de jugador i a noves temàtiques.

Resumen

Los juegos serios son juegos destinados no solo a entretener sino también a enseñar o transmitir algún conocimiento. Están presentes en diversas áreas como son la militar, la salud, la industria, la educación o la medicina, entre muchas otras. Una de sus principales ventajas es su capacidad para representar escenarios donde poder experimentar con situaciones que no se podrían reproducir en la vida real a causa de problemas de seguridad, de costes o tiempo. Además, los juegos serios mejoran el desarrollo de habilidades analíticas, espaciales, estratégicas o psicomotrices.

Por desgracia, a pesar de sus muchas ventajas, todavía hay aspectos de los juegos serios que necesitan de más investigación y desarrollo. Por un lado, tenemos comunidades, como la de las personas con discapacidad visual, que tienen muchas dificultades de acceso a los juegos serios, ya que la mayoría de ellos se basan en gráficos impresionantes y experiencias visuales inmersivas. Por otro lado, todavía hay temas relevantes como los protocolos de primeros auxilios que, a pesar de haber estado consideradas como temática de juegos serios, solamente han tenido en cuenta a usuarios expertos en la materia. Con el objetivo de superar estas limitaciones y explotar al máximo los juegos serios, esta tesis ha centrado el interés en dos focos de investigación.

El primer foco de investigación se ha centrado en como hacer juegos serios (y videojuegos en general) más accesibles a personas con discapacidad visual. Para conseguir este objetivo se han hecho dos contribuciones principales. La primera de ellas es un dispositivo para personas con discapacidad visual que les permite interactuar con los escenarios virtuales de los videojuegos. El dispositivo se ha diseñado considerando la usabilidad, la adaptabilidad y el coste como sus características principales. Respecto a la usabilidad, se ha cogido como referencia el bastón blanco por ser el dispositivo más utilizado para desplazarse dentro del colectivo. Para potenciar el realismo se han integrado unas librerías de sonido. Para reducir el coste económico se ha utilizado Arduino como base de su desarrollo. El dispositivo se puede adaptar a diferentes motores de videojuegos. La segunda contribución es un juego serio basado en sonidos e interacción táctil con el objetivo de enseñar el protocolo de resucitación cardiopulmonar (RCP) a jugadores con discapacidad visual. El juego, llamado CPRforBlind, tiene un conjunto de diferentes minijuegos inspirados en los diferentes pasos del RCP propuestos por el *European Resucitation Council*. Las dos propuestas se han probado en situaciones reales con resultados muy prometedores.

El segundo foco de investigación se ha centrado en como ampliar los juegos serios de primeros auxilios de supervivencia considerando a los jugadores sin experiencia previa en el tema. Para conseguir este objetivo se ha puesto el foco en los protocolos de RCP y el protocolo que se tiene que aplicar a una víctima de atragantamiento. En el contexto de este segundo foco se han hecho tres contribuciones. La primera es un estudio sobre como el género de la víctima en un escenario virtual para aprender RCP puede afectar al rendimiento del jugador. El estudio se ha realizado con estu-

diantes de la Facultad de Enfermería. Estos debían resolver diferentes emergencies de RCP mientras se les evaluaban diferentes parámetros de rendimiento. Durante este estudio se ha visto que el rendimiento no se ve afectado por el género de la víctima. La segunda y la tercera contribución han sido dos juegos serios destinados a promover el protocolo de RCP y de atragantamiento a usuarios que no sean expertos en el tema. Los dos juegos se han diseñado como un conjunto de minijuegos que reproducen los principales pasos de estos dos protocolos de primeros auxilios. Los juegos se han implementado y evaluado en situaciones reales obteniendo resultados muy satisfactorios.

De la investigación realizada en el contexto de la tesis se puede concluir que se ha ampliado el campo de aplicación de los juegos serios a nuevos perfiles de jugadores y a nuevas temáticas.

CHAPTER 1

Introduction

In the last decades, video games have become increasingly popular and have grown to be a significant market force. In a recent report from the Global Games Market, it is forecasted for 2019 that 2.5 billion gamers across the globe will spend 152.1 billion dollars which represents an increase of +9.3% from the year before. For next years, these forecasts are expected to increase as a result of advances on technology and application areas [Wijman 2019].

The fact is that advances on game technologies have been spectacular. We have evolved from simple physics-based games like Pong, with very poor graphics, to current video games, where players can navigate in virtual immersive environments reproduced with high fidelity and where augmented reality techniques can be applied as well as sophisticated interaction techniques with face, voice, or body movements recognition (see Figure 1.1). Obviously, all these advances have had an effect on gamer profiles. Currently, there are games for all the ages and preferences, from kids to elders passing through teens and adults. The applications of video games have also been extended, being serious games one of the last tendencies.

Serious games are games that not only aim to entertain but also teach or transmit some knowledge. This new type of games is becoming increasingly popular and is present in many areas of knowledge such as military, health, manufacturing, education or medicine, just to name a few [Michael 2006]. For instance, in the context of health, there are games designed to educate and train professionals to avoid medical errors [Wattanasoontorn 2013, Laamarti 2014, Ricciardi 2014] or in rehabilitation processes, to reproduce the repetitive tasks that have to be done by the patient [Qin 2010, Sabri 2010, Chan 2012, VirtualHeroes 2019, Richards 2017, Rego 2010].

Despite the advances in the area, there are still some communities that remain

(a) (b)

Figure 1.1: (a) Pong game [Winter 1996] (b)Evolution of video games [4AGames 2019]

outside of video games (and serious games) due to a disability. In this thesis, we will focus on blind players which have many difficulties to access video games since most of them rely on impressive graphics and immersive visual experiences. Our aim is to investigate and propose new strategies to make video games accessible to visually impaired people. In addition, we aim to investigate how serious games can be used to teach and promote first-aid procedures such as the cardiopulmonary resuscitation and the choking protocols [Redcross 2019a, AHAE 2012, ERC 2019].

1.1 Video games for the blind

Video games are predominantly a visual medium and its adaption to players with visual impairment requires some strategy to transform visual information to other that can be perceived. The different strategies that have been proposed to carry out this transformation can be grouped in three main categories: audio-based, text-based, and haptic-based techniques. These strategies can be applied independently or combined in a single game.

- Audio-based techniques use auditory icons and earcons to associate visual information to sound [Brewster 1998, Friberg 2004, Miller 2007]. There are also more sophisticated audio solutions such as 3D sound [Sánchez 2010]. These techniques are used for all type of players, sighted and non-sighted. Focusing on non-sighted players, this is the most popular approach and it was the first one to be proposed.

  There are a lot of titles of audio-based games which can be accessed via Audio Games community [DCH 2002]. Some games of this category are presented below.

  TouchMe, the first audio game, is an arcade game where the player touches a series of buttons that produce sound, in a similar way to the classic electronic game, Simon. In the racing category, Mach 1 [Kitchen 2008] is an audio racing game that uses sound effects to indicate toward which direction the player should turn. We can find a lot of first-person shooter audio games such as Shades of Doom [GMA 2001], which is played using either directional keys, or a computer mouse, while using wind noises and footstep echoes to navigate through the tunnels. Terra formers [Westin 2004] is a first-person shooter playable by people with or without visual impairments or blindness. This game has a 3D world and uses 3D sound for the blind. AudioQuake [Atkinson 2006] uses a similar strategy to make a first-person shooter playable by the blind. There are also audio versions of role playing games. One example of them is The Last Crusade [Dwyer 2004a], developed using an RPG game engine [Dwyer 2004b] which allows users to create their own RPG audio games. Finger Dance (2007) [Miller 2007] is a rhythm audio game that uses audio cues to indicate which keys the player must press. Speed Sonic Across the Span [Oren 2007] is a platforming audio game that uses audio cues to indicate objects and obstacles. In the context of simulation audio games, there is GMA Lander) [GMA 2013] where the player tries to land their ship on a moon, asteroid or planet. Finally, in the field of audio games for mobile phones, some examples are Papa Sangre [SomethingElse 2010] which is the most famous audio game for iPhone. This game has no visual interface and is played entirely through sound cues. By using headphones, the player hears sounds in the game in three dimensions, and has to navigate the world using the touchscreen.

- Text-based techniques use text as a substitute of visual information and also to interact with the system. To play these games a human helper or a screen reader is required. For these reasons, they were not really accessible to visually disabled players until screen readers arrived. The first commercial screen reader was IBM Screen Reader [Cooke 2019], released in 1986. The most popular screen reader software among visually impaired is JAWS (1989) [FreedomScientific 1989].

  Regarding games of this category, the first one was Colossal Cave [Adams 1976], an adventure game first playable in 1976, although it did not reach the public until 1980. This game inspired many subsequent text-based games, such as Adventureland [Adams 1978], in 1978. Other games are Zork [Infocom 1980], The Hitchhiker's Guide to the Galaxy [Infocom 1984], Avalon [Simmons 1989], and Spy Snatcher [Mobygames 1999]. There are also text-based games that combine audio techniques, such as Trek2000 [GMA 2000]. Currently, this genre is practically extinct and all of them have pictures that make gameplay more difficult for the blind.

- Haptic-based techniques are currently the most popular. They use haptic devices to transmit information to the player using the sense of touch. These haptic devices are used to improve immersion and realism for the player and to help visually disabled people to interact with the game. The most common haptic technology in videogames is vibration.

  In 1976, the game Fonz [SegaRetro 1976], developed by Sega, was the first arcade videogame to feature vibrotactile feedback. In home videogame consoles, the first haptic device came from Nintendo in 1997, with the Rumble Pak [Johnston 2000], an accessory for the controller of their latest console at the time, the Nintendo 64. From these humble haptic devices, this technology has greatly evolved [Nacke 2010], reaching enough definition to allow players to sense the feeling of different surface textures, or the movement of an object inside the device [Nintendo 2019b]. Using this technology, videogames with no need for visual interaction have already been released, like 1-2-Switch (2017) [Nintendo 2019a]. There are also videogames with their specific haptic device such as AuditoryPong [Heuten 2007] or Sonic Badminton [Kim 2016]. Other examples are VI-Tennis and VI-Bowling that integrate a haptic interface based on a motion sensing controller enhanced with vibrotactile and audio cues that allow blind players detect key events of Wii Sports game [Morelli

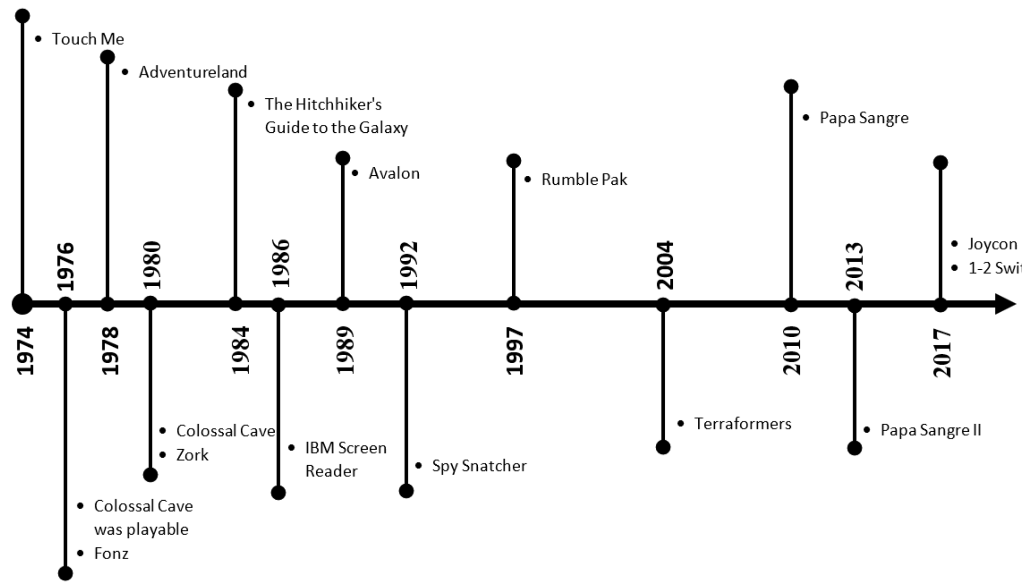


Figure 1.2: Some of the most representative games for visually impaired players.

2010a, Morelli 2010b].

In Figure 1.2 some of the most representative video games for visually impaired players are presented. Although the number of video games for visual impaired people is still far from general video games offer, the interest on the topic has increased considerable in the last years. Not only researchers but also actors of game industry are aware that something must be done to improve the accessibility of computer games. Moreover, current technology makes the adaption of video games easier.

1.2 Serious games for first-aid and emergency training

First-aid protocols define the procedures that have to be applied in case of emergency. Two examples are the cardiopulmonary resuscitation protocol (CPR), applied when someone suffers a heart attack (see Figure 1.3), and the choking maneuver, applied to treat upper airway obstructions instantly (see Figure 1.4). The knowledge of these protocols is invaluable since it allows people to assist victims of accidents and emergency situations until help arrives. The more people know the protocols the more safer the community is. But, the challenge is how to introduce them to community.

Focusing on CPR, different organizations such as the European Resuscitation Council (ERC) [ERC 2019], the Red Cross [Redcross 2019a], and the American Heart Association [AHAE 2012], have defined guidelines that describe how resuscitation should be undertaken both safely and effectively. In addition, many countries have initiated CPR programs to train lay rescuers in CPR and several strategies have been used to teach it including mass training, video self-instruction, or serious games, amongst others. In the serious games context, some examples are: JUST VR System [Ponder 2002] an immersive virtual reality situation training system for non-professional health emergency operators; MicroSim Prehospital [Medical 2012] designed for pre-hospital training on emergency medical services, and Staying Alive [Ilumens 2011], an online 3D simulator which provides a learning experience of saving a virtual patient from cardiac arrest in four minutes; Relive [Semeraro 2014] a first person 3D adventure where the player faces different rescue situations and can test the quality of CPR, directly; Viva!Game [Settimanaviva 2013], a Web-based serious game designed to create awareness on cardiac arrest and cardiopulmonary resuscitation; HeartRun [Schmitz 2015], a mobile simulation game to train resuscitation and targeted at giving school children an understanding of CPR and getting them to take action; and LISSA that presents an emergency situation to the user who has to save the victim applying the CPR actions selected from a menu.

Generally, all described methods have been designed considering experts on healthcare as players candidates and few attention has been paid to non-experts, and even less, to visually impaired players. Therefore, our interest is on the design of serious game based strategies to introduce CPR protocol to non-experts and also to blind community. Unfortunately, as far as we know, no proposals to teach CPR to blind people have been presented. There is only one study from Bertini et al. [Bertini 2015] that evaluated the capability of blind people to perform CPR. They concluded that blindness appeared not to be a limitation for adequately performing CPR maneuvers particularly in adult training. Blind trainees achieved successful CPR performance, and successfully used the automatic external defibrillator although they recognized a striking difficulty to identify the proper button in the absence of Braille characters on the button.

As in the case of CPR, different approaches have been proposed with the aim to educate about choking risks, prevention and treatment. On the one hand, organizations, such as the Resuscitation Council [ERC 2019], the Red Cross [Redcross 2019a], or the American Heart Association [AHAE 2012], have defined guidelines that describe how choking interventions should be undertaken both safely and effectively. These organizations also offer courses, videos, and other materials to teach the choking rescue procedure. In addition, many countries have initiated campaigns to educate citizens about prevention, risks, and treatment of choking. Special attention has been given to children since they are the most susceptible to choking [Thamboo 2009]. The effectiveness of these initiatives have also been studied and, in most of the cases, the general conclusion is that prevention strategies are effective and contribute to decrease choking incidence [Bentivegna 2018, Karatzanis 2007, Sadan 1995]. On the other hand, there are initiatives focused on the development of first-aid training devices. Zoll Medical corporation proposed a handheld device that uses several accelerometers to monitor abdominal thrusts [Totman 2014]. More recently, Watson and Zhou [Watson 2018] presented BreathEZ, a smartwatch application that provides both choking first-aid instruction and real-time tactile and visual feedback on the quality of the abdominal thrust compressions. Carvalho et al. [Carvalho 2007]

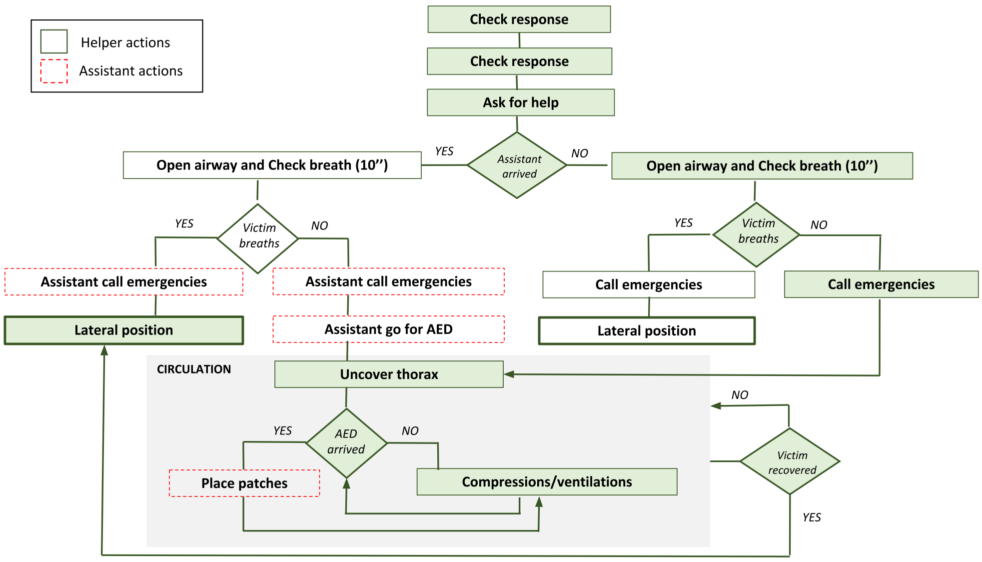


Figure 1.3: Main steps of the cardiopulmonary resuscitation protocol according to ERC [ERC 2019].

proposed an Android application video game where different first-aid actions are presented to familiarize users with these scenarios being choking one of them. In most of the cases, games focused on first-aid procedures have been designed for players with a health background being the game a media to practice on a given topic [de Urturi 2011]. Again, little attention has been paid to non-experts although first-aid protocols would be a basic knowledge for everyone. Therefore, we will extend our interest to the development of serious game-based strategies to introduce choking protocol to non-experts.

1.3 Objectives

Our main interest is in the development of strategies that make serious games accessible to blind players and also in techniques that exploit the advantages of serious games to educate on first-aid protocols. In particular, we aim to:

- Make video games more accessible to blind players

  To adapt video games to blind players, two main issues have to be considered. The first one, focused on how to transform visual stimuli to other ones that can be interpreted without requiring the sight sense. The second one, focused on interaction techniques and how to make them possible. Both problems have been studied and different solutions based on sound, touch screens, haptic equipment, and specially designed software and hardware, have been proposed. Generally, these solutions have been designed to solve specific situations and

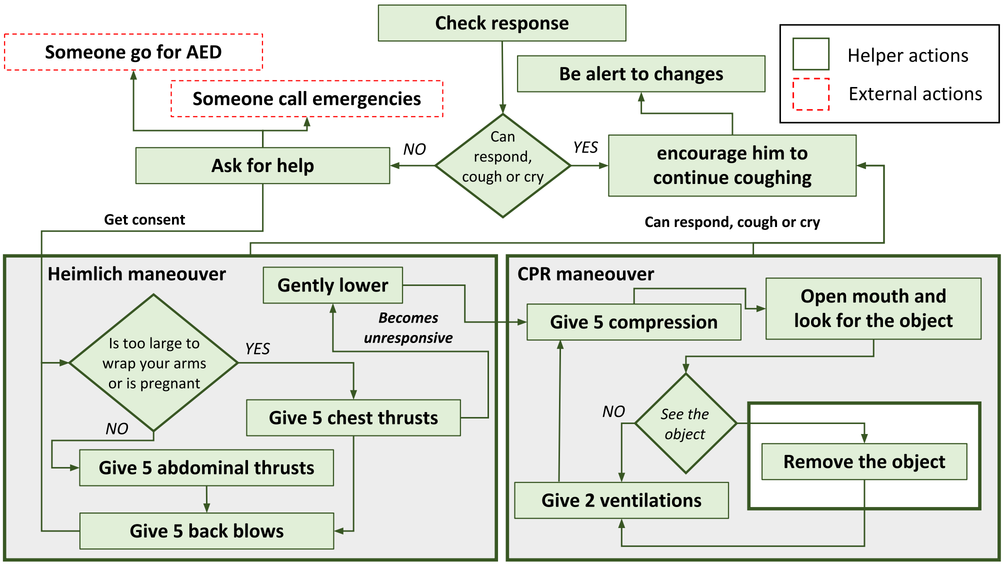


Figure 1.4: Main steps of the choking protocol according to AHA [AHAE 2012].

its use out of experimental contexts becomes difficult. In other cases, the high cost or the low usability of the solutions also limit their application in a real context.

> *The first objective of our research is to design new strategies to adapt video games to blind players taking into account usability, economical cost, and adaptability as main requirements.*

- Propose and evaluate serious games as a method to teach first-aid protocols

  Serious games have great potential not only for entertainment but also as a tool to address specific problems or to improve different skills. Cardiopulmonary resuscitation is a first-aid key survival technique used to stimulate breathing and keep blood flowing to the heart. Its effective administration can significantly increase the survival chances of cardiac arrest victims. In the same way, first-aid choking protocol which consists of abdominal thrusts combined with back blows [Redcross 2019a], can save victims from choking. Unfortunately, not everyone knows these procedures and strategies, another to educate on them are necessary [Nichols 2012].

> *The second objective of our research is to evaluate how serious games can improve CPR knowledge in an educational context and also propose new games to promote CPR and choking protocol among people.*

- Exploit serious games capabilities for blind players

  Serious games contributions focused on blind players have been designed to improve navigation and orientation skills. Few attention has been paid to other topics such as first aid procedures.

  > *The third objective of our research is the design and evaluation of a new serious games to introduce the CPR protocol to blind players.*

1.4 Thesis outline

The contents of the thesis are structured in eigth chapters. After the introduction and the definition of the objectives included in Chapter 1, the next five chapters describe the contributions made to achieve the main goals. Chapter 2 presents a device for visually impaired people to interact with virtual scenes of video games. The device has been designed following the white-cane paradigm and using Arduino to reduce costs. Chapter 3 evaluates the application of LISSA, a video game designed to teach and refresh cardiopulmonary resuscitation protocol, in a Nurse Faculty focusing on the gender of emergency victims. Chapter 4 presents 30:2, a computer game designed to promote the cardiopulmonary resuscitation protocol among citizens and especially among children. Chapter 5 presents CPRforblind, a videogame to introduce CardioPulmonary Resuscitation protocol to blind people. Chapter 6 describes a videogame to introduce the choking protocol to non-experts players. Finally, the results and the discussion of all these contributions are summed up in Chapter 7, and the conclusions are given in Chapter 8, where a summary of the presented contributions is listed and some potential future directions of research are proposed.

Chapter 2

An Arduino-based device for visually impaired people to play video-games

---

The first main goal of this thesis is the design of new strategies to adapt video games to blind players taking into account usability, economical cost, and adaptability as main requirements. In this chapter, an arduino-based device designed for visually impaired people to interact with the virtual scenes of video games is proposed. The device is inspired by smart-canes supporting left-right movements as well as drag and drop operations. Its combination with a sound library provides a real experience for any player. The device is easy to use and can be adapted to any game thanks to the provided application programming interface.

An Arduino-based device for visually impaired people to play videogames, Antonio Rodríguez, Imma Boada, and Mateu Sbert, Multimedia Tools and Applications, 77(15) , pp:19591 – 19613 (2018), ISSN: 1380-7501 DOI 10.1007/s11042-017-5415-1 JCR- Computer Science and software engineering; position: 40/107; IF:2.101; Quartile Q2.

Multimed Tools Appl
https://doi.org/10.1007/s11042-017-5415-1

An Arduino-based device for visually impaired people to play videogames

Antonio Rodríguez[1] · **Imma Boada**[1] · **Mateu Sbert**[2,1]

Received: 21 December 2016 / Revised: 6 November 2017 / Accepted: 9 November 2017

Abstract Blind players have many difficulties to access video games since most of them rely on impressive graphics and immersive visual experiences. To overcome this limitation, we propose a device designed for visually impaired people to interact with virtual scenes of video games. The device has been designed considering usability, economic cost, and adaptability as main features. To ensure usability, we considered the white cane paradigm since this is the most used device by the blind community. Our device supports left to right movements and collision detection as well as actions to manipulate scene objects such as drag and drop. To enhance realism, it also integrates a library with sounds of different materials to reproduce object collision. To reduce the economic cost, we used Arduino as the basis of our development. Finally, to ensure adaptability, we created an application programming interface that supports the connection with different games engines and different scenarios. To test the acceptance of the device 12 blind participants were considered (6 males and 6 females). In addition, we created three mini-games in Unity3D that require navigation and walking as principal actions. After playing, participants filled a questionnaire related to usability and suitability to interact with games, among others. They scored well in all features without distinction among player gender and being blind from birth. The relationship between device responsiveness and user interaction has been considered satisfactory. Despite our small test sample, our main goal has been accomplished, the proposed device prototype seems to be useful to visually impaired people.

✉ Imma Boada
imma.boada@udg.edu

Antonio Rodríguez
antonio.rodriguez@udg.edu

Mateu Sbert
mateu.sbert@udg.edu

1 Graphics and Imaging Laboratory, University of Girona, Girona, Spain

2 Department of Computer Science and Technology, Tianjin, China

Published online: 18 November 2017

Keywords Interacion devices · Video games · Visually impaired

1 Introduction

In last years, there has been a growing demand for video games across a whole range of age, gender groups, and application fields. According to the Entertainment Software Association, 63% of U.S. households have at least one person who plays video games regularly (3 hours or more per week) with an average age of players of 35 years old [70]. This interest in video games has lead to different studies that evaluate their effects on players. Although, first studies focused on negative aspects such as potential harm related to violence, addiction, and depression, last decade studies have highlighted positive aspects of playing video games from cognitive, motivational, emotional, or social perspectives [68]. The fact is that video games have great potential not only for entertainment but also as a tool to address specific problems or to improve different skills. Currently, games are used in education, health, or business, among others [72].

Despite the increased level of interest in games and their provided benefits, a large group of people is left out from playing video games due to a disability. To overcome this limitation, the creation of inclusive computer games such that nobody is left out and everyone has access, has become an emerging focus of research. In this paper, we will focus on visually impaired people. Video games could offer new socialization, education, employments and health opportunities for these individuals [39]. According to the World Health Organisation 285 million people are estimated to be visually impaired worldwide (39 million are blind and 246 have low vision) (http://www.who.int/blindness/GLOBALDATAFINALforweb.pdf).

Blind players have many difficulties to access video games since most of them rely on impressive graphics and immersive visual experiences. They may also find barriers in providing input. Different strategies to replace visual stimuli have been proposed in order to adapt videogames to this community. On the one hand, there are audio-based techniques that use auditory icons and earcons to associate information to sound [7, 15, 43]. There are also more sophisticated audio solutions such as spatial or 3D sound [57] which assigns a 3D effect to the sound allowing it to come from any part of the scene. Modern engines such as Unity 3D (https://unity3d.com/) and Unreal Game Development Kit (https://www.unrealengine.com/) provide functionalities to create these effects. The Audio Games community provides lots of titles of audio-based games designed for users with a visual disability [50]. On the other hand, there are haptic-based strategies which can be used to enhance immersion, for instance, by vibrating when collisions are detected. Westin et al. presented a literature study of the advances in game accessibility research describing different proposals for blind users. Game accessibly was also surveyed by Yuan et al. [72] and recent advances on video game accessibility for users with visual impairment can be found in [39]. In general, video games use a combination of these strategies together with screen readers that turn what is displayed on the monitor into a different non-standard output such as speech or text on a Braille output device [18, 25, 45, 60]. For a summary of all these strategies see (http://game-accessibility.com/documentation/visually-impaired-gamers-where-to-go-what-to-play/) [3].

In this paper, we propose a device designed for visually impaired people to interact with virtual scenes of video games. Our device provides three main advantages. First, it is easy to use since it reproduces the movements of a white cane in a virtual scenario. The white cane is the most used device thanks to be inexpensive, lightweight and foldable [28]. However, it has some limitations such as the difficulties to detect overhanging obstacles at head-level or ranges further than approximately one meter from the user [38], and the solutions proposed to tackle these problems have high prices and poor user interface that limit their use [1, 27, 41, 55]. Second, it has a low cost since the basis of its design is Arduino [4]. Third, it is easy to integrate in any game since we provide an application programming interface that supports the connection with different games engines and different scenarios. Our device is recommended for games with a strong component in navigation and walking.

The paper has been structured as follows. In Section 2, we present some of the techniques and games that have been proposed for blind players and related work on white cane since this is the basis of our proposal. In Section 3, we give a detailed description of our proposed device, the application programming interface, and an example created using Unity3D. In Section 4, we present the experiment set-up that has been designed to test the acceptance of the device. Obtained results as well as main limitations are described in Section 5. Finally, in Section 6, we present our conclusions and future work.

2 Related work

In this section, we will present first, some of the techniques and games that have been proposed for blind players, and second, we will describe advances related with the white cane since this is the basis of proposed device.

2.1 Video games for blind players

Video game playing can be characterized as a three step process, where first, player receives an stimuli (visual, auditory, haptic or a combination of these), second, player determines a response according to possible game actions, and third, game responses according to previous selected action [72]. After successfully performing these three steps, internal state of the game may change and new stimuli may be provided. The process is repeated until the player wins, loses or quits the game. In all this process, visual stimuli are the most common and this makes playability difficult for blind players. To transform visual stimuli to other, different computer interaction techniques that use sound, touch screens, haptic equipment, and specially designed software and hardware have been proposed.

Audio-based techniques are the most popular. These use speech strategies provided either by screen readers, audio cues, and sonification [52]. Audio techniques alone or combined with haptics have been used not only to create video games but also virtual environments to help visually impaired people develop spatial orientation and mobility skills [59]. Some of the proposed games are: Finger Dance, an audio-based rhythm-action game [43]; AuditoryPong [21], an interactive game that transfers the game pong into a physical and acoustic space where users move the game paddle with body interaction or haptic devices, and receives immediate acoustic feedback; or Sonic Badmington, an audio-augmented badminton game that uses a virtual shuttlecock with audio feedback [26].

Focusing on enhancement of navigation and orientation skills, Sanchez et al. proposed Audiopolis [59], an educational game that simulates a city and its environmental sounds to teach blind children how to navigate in urban scenes by using haptic devices as virtual canes. Maidenbaum et al. [36] designed an orientation experiment where a cane controlled by the space bar is simulated by audio feedback only. Balan et al. [6] reviewed the most notable audio-based games in what concerns their usability as an education tool for visually impaired people. Torres et al. [65] proposed a virtual reality simulator that makes an auditory representation of the virtual environment, rendering the virtual world entirely through the hearing. It uses a 3D tracking system to locate user's head orientation and position to provide a natural user interaction since the user only has to walk through the environment perceiving it through acoustic information. There are also navigation aids which use ultrasound information to sense the surroundings and acquire spatial information (NavBelt [61], Sonic Eye [62], SonicGuide [24], iGlasses [51]). For a review of recent advances in virtual reality technology for blind and visual impaired people see [16].

Tactile-based techniques replace visual stimulus into tactile stimulation. The first system, proposed fifty years ago [5], converted signals from a video camera into tactile stimulation applied to the back of the subject. Currently, thanks to technological advances, much smaller portable devices that allow hands-free interactions have been proposed. Some of them are head-mounted devices, wrist-bands, vests, belts, shoes etc. [47, 67]. There are also small electro-tactile and vibro-tactile stimulators that can be placed on body surfaces such as fingers, wrists, head, abdomen, or feet [23]. Yuan and Folmer [71] developed a glove that transforms visual information into haptic feedback using small pager motors attached to the tip of each finger. This allows a blind player to play Guitar Hero. VI-Tennis and VI-Bowling integrate a haptic interface based on a motion sensing controller enhanced with vibrotactile and audio cues that allows blind players detect key events of Wii Sports game [45, 46]. To navigate in 2D environments, the simulation of different tactile surfaces with various materials was proposed by TiM games [2] and Digital Clock Carpet [58]. Milne et al. [44] proposed Braille Play which teaches how to write and read Braille letters using vibration feedback and touch interface of smartphones. Nikolakis et al. [49] proposed a haptic virtual reality tool that allows visually impaired, to study and interact with various virtual objects in specially designed virtual environments. The system is based on the use of CyberGrasp [69] and PHANToM [40] haptic devices. PHANToM is the most commonly used force feedback device. It provides the sense of touch along with the feeling of force feedback at the fingertip.

Focusing on mobile technology, this is gaining sophistication and widespread use. Current research is centered on making mobile phones and other handheld computer devices more efficient, cost-effective, functional, and accessible which will also benefit visually impaired[9, 19]. Rodriguez et al. [54] proposed a smartphone-based method that uses phone camera to capture pathway scenes as images and transform them into messages and warnings to avoid collisions. Lu et al. [35] used smartphone accelerometers to recognize daily living activities and sporting activities. For a review of all these technologies see [17, 22]. Moreover, human-computer interaction based research is increasingly exploring the possibility of supporting eyes-free interaction methods for smartphones and other handheld devices. Consider for instance, the scheme to recognize human activities from sensor data proposed by Liu et al. [31] or the same author's proposed algorithm which is capable of efficiently mining temporal patterns from low-level actions to represent high-level human activities [34].

2.2 The white cane

Many different techniques and devices have been proposed to enhance the interaction between humans and computers [20]. However, it is important to choose the right form of interaction to reach a high usability of the resulting system. In our case, motivated by the extensive use of the white cane we have considered this option as the basis of our interaction device.

Improvement of the white cane performance is a continuos focus of research. The aim is detecting obstacles at wider ranges and at a distance above-knee level. Generally, the proposed methods are based on sensors and multi sensory displays mounted on the classic white cane, but which can sometimes be removed from the cane and used independently. These smart canes come in two forms [64]. In the first type, a detection device is mounted on the cane to form a stick, making this a detachable unit. Some canes in this group are Teletact [13], Tom-Pouce [14], Vistac Laser Long Cane (https://www.vistac.com) and UltraCane (https://www.ultracane.com/soundforesigntechnologyltd). In the second type, devices have detection sensors built into the canes such as LaserCane [38]. For a review of technological canes see [11].

We conclude this section with a final comment about the use of the described systems. A main limitation is that most of them have been tested only in experimental conditions and are not used in daily life by visually impaired people. Only few of them have been commercialized. Gori et al. [17] described possible reasons of these facts. A first reason could be that most of them are invasive devices. A second one could be that processing acoustical or tactile signals might overwhelm cognitive abilities of the user. A third one could be that many of these devices require a long period of training in order to be used. A fourth one could be that the level of performance of these systems is insufficient to justify the invasiveness and effort needed to use them. Another aspect to consider is that many of the described devices do not take into account the important link established by action and perception in learning process. In addition, the cost of the device can also be a limiting factor. Taking into account all these limitations, our aim is to develop an easy to use device that does not require any special training and has a low cost. Although our device is focused on video games, we consider that these limitations have to be also taken into account.

3 The proposed device

Our main objective is the creation of a device to interact with video games in order to adapt them to blind players. To create it, we consider as main features usability, economic cost, and adaptability. In this section, we will present all the details of the proposed device. First, we will present the design of the device, then the application programming interface required to connect the device with a game, third an application example using Unity3D, and fourth some final considerations.

3.1 Device description

To create the device, we first focused on usability and economic cost. Our device should be easy to use and without requiring any significant training process for its use. To satisfy this first requirement, we consider the white cane as our inspiration since this is the most popular device among blind community. Such a decision fixed the design and movements that have to be supported by the device. To start, we considered movements in one dimension, from left to right and vice versa. In addition, the device should be able to detect collisions in the virtual scenarios of the game returning different sounds according to collided materials. Finally, the device should be used both when sitting and standing to satisfy different players preferences.

Our device should have a low cost. To satisfy this requirement, we decided to use Arduino as the basis of our development. Arduino has been specifically designed for people with little or no background in electronics or programming, is free to download online, and supported by an expanding open-source online community [4]. Its hardware is inexpensive and can be combined with any number of sensors and instruments that are available from a variety of retailers. In addition, it requires minimal development effort or experience, allowing developments without large financial investment. There are previous works based on this technology. For instance, Sakhardande et al. [56] proposed a detachable unit to extend the functionality of the existing white cane, to concede above-knee obstacle detection as well as below-knee detection. The proposed stick uses ultrasound sensors for detecting obstructions before direct contact providing haptic feedback to the user in accordance with the position of the obstacle. More recently, Sudhanthiradevi et al. [63] proposed a theoretical model of a walking stick for visually impaired people that consists of three modules to detect heat, obstacles, and water, respectively.

Taking into account all these requirements, we created the device illustrated in Figs. 1 and 2. As we can see in Fig. 1, the device is composed of a rectangular wooden basis (25cm×25cm) and at each vertex of the basis there is a vertical piece of wood (front face 22cm × 25cm, back face 12cm×25cm). These pieces create an inclined plane where the cane can move. Two pieces of wood and lateral limits of the device restrict left to right movements of the cane. In Fig. 2, the main components of the device have been labelled. There are two *engines* on the back face, one at each extreme of the guide. These engines control the movement of a vertical piece of wood, labelled as *lateral limit*, that determines the space where the cane can move. There are also two *way-end push buttons* that restrict movements of these lateral limits. When we initialize the device, engines place the limits at the extremes. There is a *loudspeaker* to simulate collision effects. We have integrated different sounds of materials to increase realism to the collision. These are activated each time the *cane*, which is covered with aluminum paper, collides with the metallic pieces attached to the lateral limits placed at both sides of the device. The device has two engine *controllers* Easy Driver which control movements that have to be performed to reach a desired position. An *Arduino ONE* is used to control the device and to connect it with the PC via USB port.

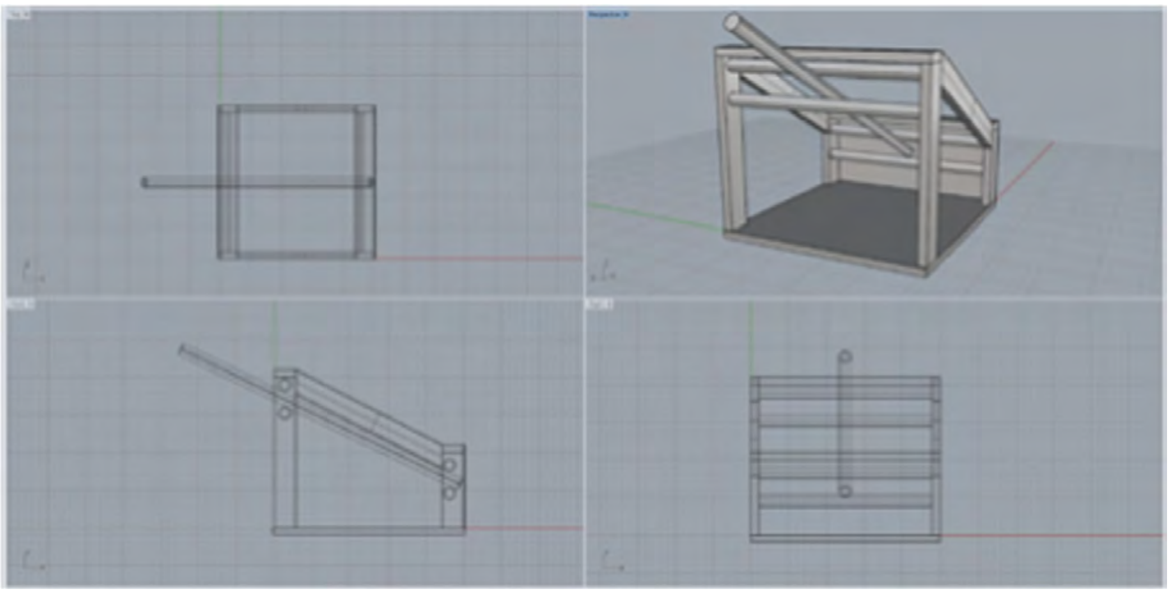


Fig. 1 Different views of the proposed device

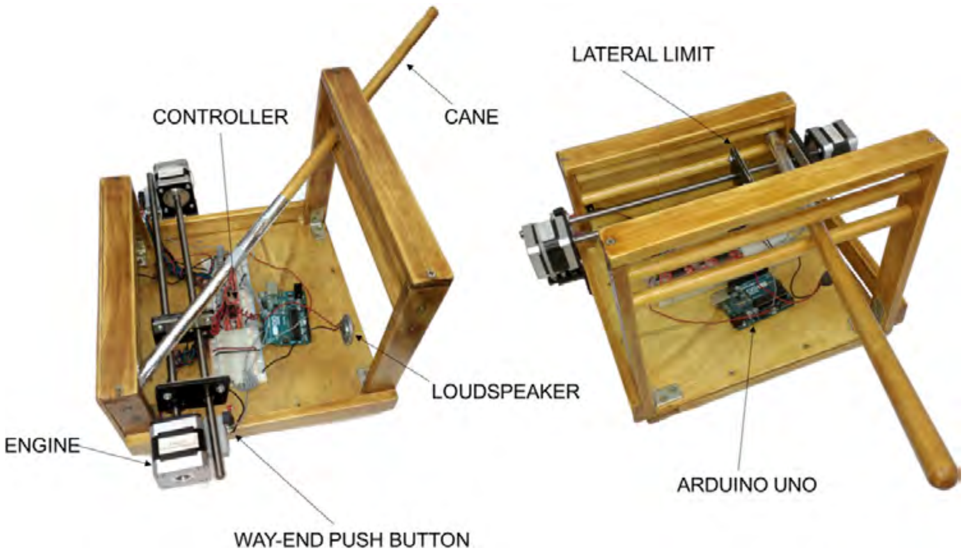


Fig. 2 The main components of the proposed device

3.2 The device API

Our device should be adaptable to different video games. To satisfy this requirement, we created an application programming interface (API) to support the connection with different game engines, and also to support different scenarios. This last feature requires calibration parameters to control the movements of the device according to player movements and objects of the video game scenario.

The API is composed of two different parts, the `external API` that communicates the device with the game engine, and the `internal API` integrated in the game engine used to develop the video game. The main modules of the API are illustrated in Fig. 3 and described below.

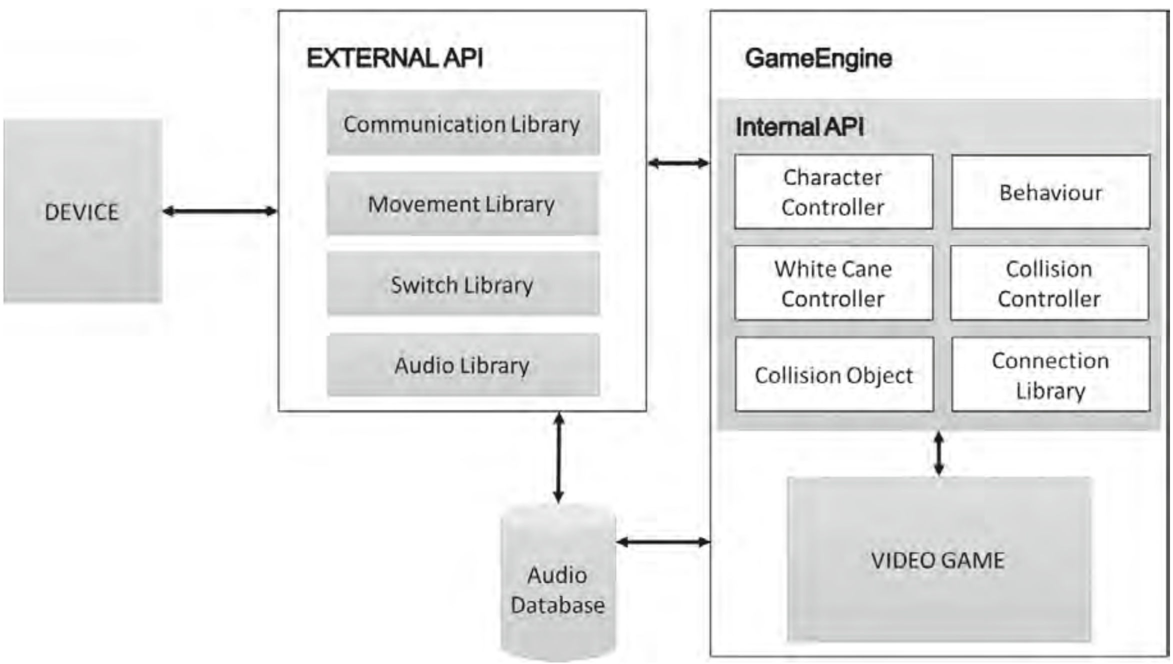


Fig. 3 The main modules of the proposed API to connect the device with a video game. In this example, Unity 3D is the game engine

3.2.1 External API

External API has been programmed in C. Main modules of the external API are illustrated in Fig. 4 and described below.

`Communication Library` connects the device with computer. It configures the connection to receive and emit data from the Serial Port COM3 and waits for game engine API information related to position of the lateral limits of device, and information of collisions between white cane and an object of the game scenario. To carry out this process it has the following methods: `OnStart()` which configures communication Serial Port COM3 to send and receive messages; `OnPositionReceive()` which waits for the game engine API message with the position of lateral limits; `SendCollision()` which controls if the cane collides with lateral limits; `OnSoundReceive()` which reproduces the sound assigned to the collided object; and `OnStop()` which closes the device.

`Movement Library` controls lateral limits of the device used to simulate virtual objects. It starts placing the limits to an initial position and then, waits for information related to the position of the object in the scene to move the limits according to it. It has two private methods, `Move()` and `Calibrate()`. The first has two input parameters, representing the positions of lateral limits, and moves the limits to these positions. The second, moves the limits to the initial position. `Movement Library` also has three public methods, `OnStart()` and `OnEnd()`, used to turn on and turn off the device,

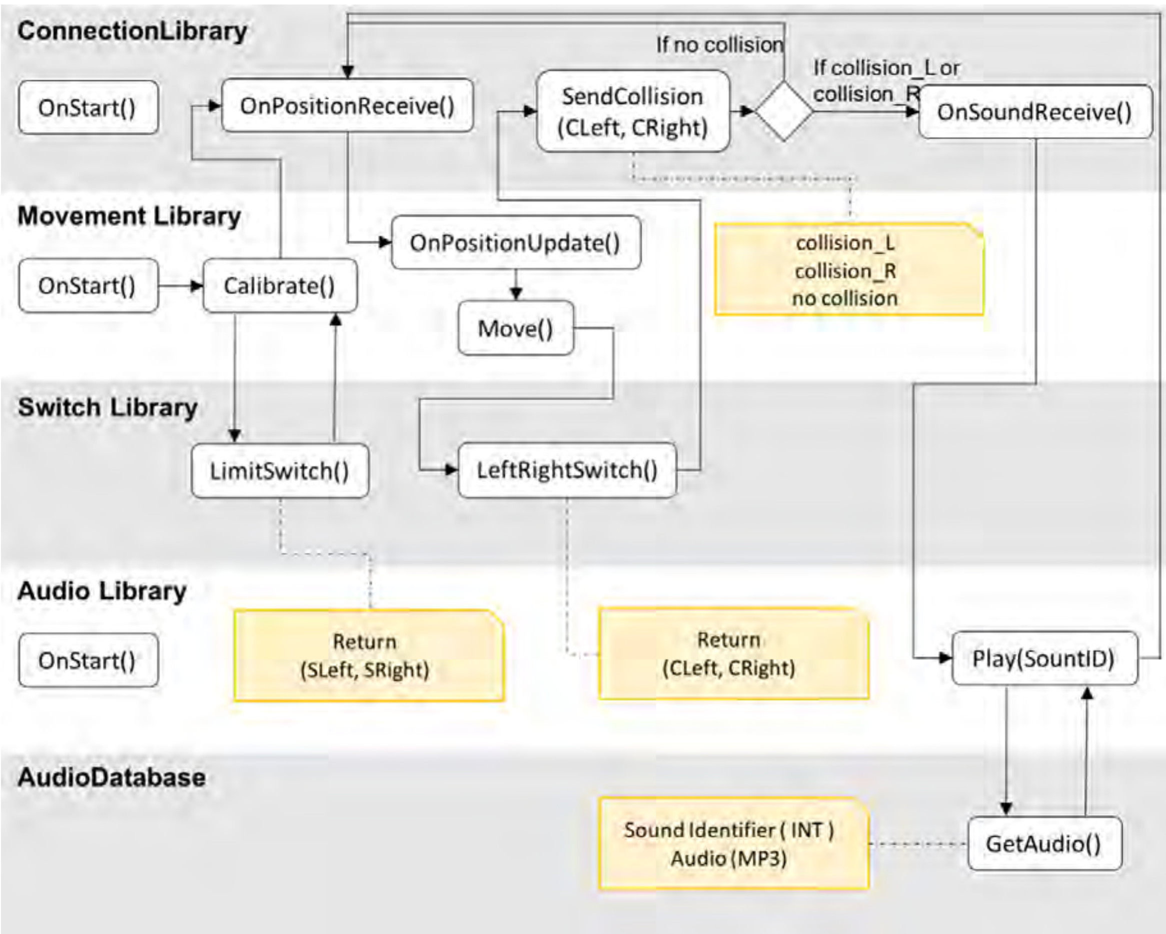


Fig. 4 Main methods of the external API

respectively, and `OnPositionUpdate()`, called by `OnPositionReceive` from `Communication library`, that calls `Move()` method to move the limits.

`Switch Library` controls device switches. It has two main methods, `Limit Switch()` that controls if left and right limits are in initial position or not, and `LeftRightSwitch()` that controls if the white cane collides with limits.

`Audio Library` reproduces the sound assigned to the collided object. It is composed of a class and an `Audio database` that stores sounds in MP3 format and their relationships with objects. The class has `OnStart()` method to init loudspeaker, and `Play(SoundID)` method, called by `OnSoundReceive()`, that has as input the identifier of the sound from the Audio data base that has to be reproduced.

3.2.2 Game engine API

Main modules of the internal API are illustrated in Fig. 5 and described below.

`Connection Library` connects the computer and the device. It configures the connection to send and receive information from Serial Port COM3. It sends to external API

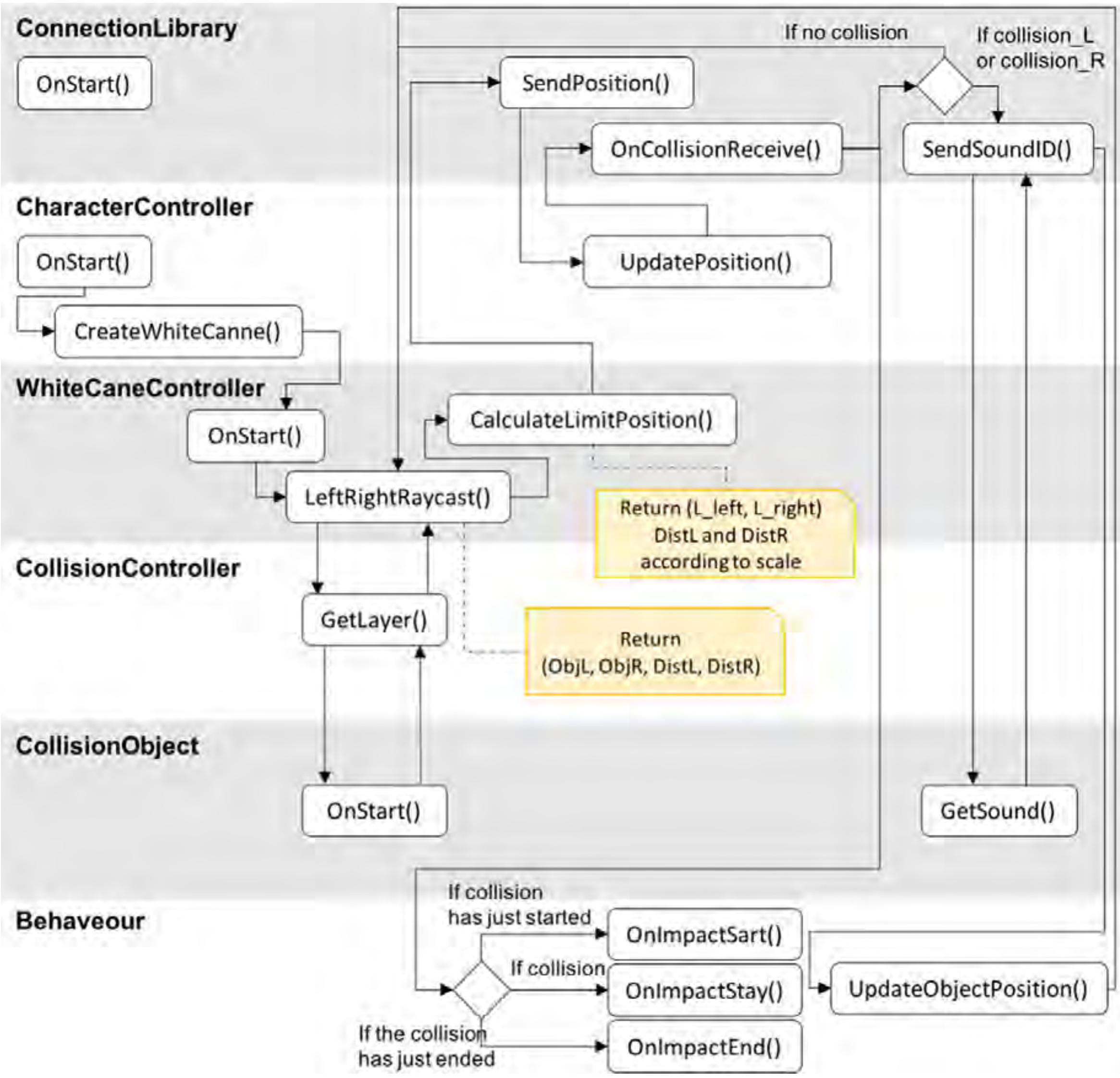


Fig. 5 Modules and methods of the internal API

the position of the lateral limits and it waits for collisions. In case of collision, it sends the sound identifier. The methods of this module are: `OnStart()` which configures the communication with the Serial Port COM3; `SendPosition()` that sends the positions of the lateral limits; `OnCollisionReceive()` that receives the data when it has been a collision with one of the lateral limits; `SendSoundID()` that sends the identifier of the sound that have to be reproduced; and `OnStop()` that closes connection when we exit.

`Character controller` configures player parameters such as distance and velocity of player movements. It also inits the white cane fixing the walking distance. It has the following methods: `OnStart()` that configures movement velocity and white cane parameters; `CreateWhiteCane()` that creates and inits the white cane object; and `UpdatePosition()` that moves the player from one position to the next.

`White Cane controller` controls the movements of white cane. It fixes the amplitude of white cane movements and, during execution, it controls if there are collisions between white cane and scene objects. It has the following methods: `OnStart()` that configures the width of white cane movements and other parameters; `LeftRightRayCast()` that casts a ray perpendicular to the player position in order to detect left and right collisions. The ray only can collide with the objects of the collision layer. The method returns the identifier and the distance of the first collided object with respect to player position. represented as (`objL, objR, DistL, DistR`). In case of no collisions, it returns -1 for all the values. `CalculateLimitPosition()` method receives distance values and width of the white cane, and it returns the position of the limits, represented as `L-left` and `L-right`. These values are defined according to the device-game scale.

`Collision controller module` defines the layer of objects of the scene that can be collided by the white cane. It will be used to improve the `WhiteCane Controller`. It has a `GetLayer()` method that assigns the layer to the objects.

`Object Collision` is a class assigned to each object of the scene that can be collided by white cane. Each instance of this class has a sound identifier and a `OnStart()` method that assigns the object to the layer, and a `GetSound()` that returns the sound of the object.

`Behaviour module` which determines the action that have to be performed when an object is collided. It has the following methods: `OnImpactStart()` called when the object is collided; `OnImpactStay()` called while object is collided; and `OnImpactEnd()` that is called when collision has stopped. The module allows the creation of new behaviours by class inheritance and new implementation of these methods. There is also another method, `UpdateObjectPosition()` that moves the object if it is necessary.

3.2.3 Unity3D API

As an example, we present the GameEngine API created for Unity3D game engine. This has been programmed in C# and uses some of the Unity 3D functionalities. In particular, for the Communication Library we have used C# methods for communicating via Serial Port COM3. For the Character Controller module, we have used the physics library of Unity3D to move the player character, and the hierarchy of objects of Unity 3D, to place the white cane in the correct position with respect to the character position to be controlled. For the WhiteCane controller, we have used the RayCast methods from Unity 3D physics library which cast rays and detect objects in a layer. For Collision Controller and Object Collision modules, we have used the system of layers of Unity3D. In this way, we can distinguish collided objects from non collided. For the Behaviour module, we have implemented two different behaviors, the first one, drags the object at the opposite direction of collision, and, the second one, detects the number of knocks on the object and depending on this number it moves the object or not.

In addition. for all possible game scenarios we have identified all objects that can be collided by the player. For each object, we have assigned a sound, that will be reproduced when object is collided, layer of the collider, and also supported behaviours. Moreover, we have defined the correspondence scale between the movement of virtual white cane and the scenario. Part of these information is illustrated in Fig. 6 where a screen of video game *Direction to Saint Narcis Church*, presented in next section, has been considered.

3.2.4 Considerations

We conclude this section with some final considerations. With respect to the design of game objects, and player movements, it has to be taken into account that lateral limits simulate the object position and the device engines place them in the correct location. The movement speed of these limits depends on the engine capabilities, the threat of the guides used to move them, and the distance between previous position and current one. In the worst situation, when lateral limit is at the device extreme and has to move to the other extreme it requires 2.0 seconds. To ensure that all objects can be detected, we have to adapt the velocity of player movements to lateral limits speed. Once this is determined, to control player movements, we can consider two strategies. In the first one, player moves automatically with the velocity adapted to lateral limits speed. In the second one, player moves using keyboard

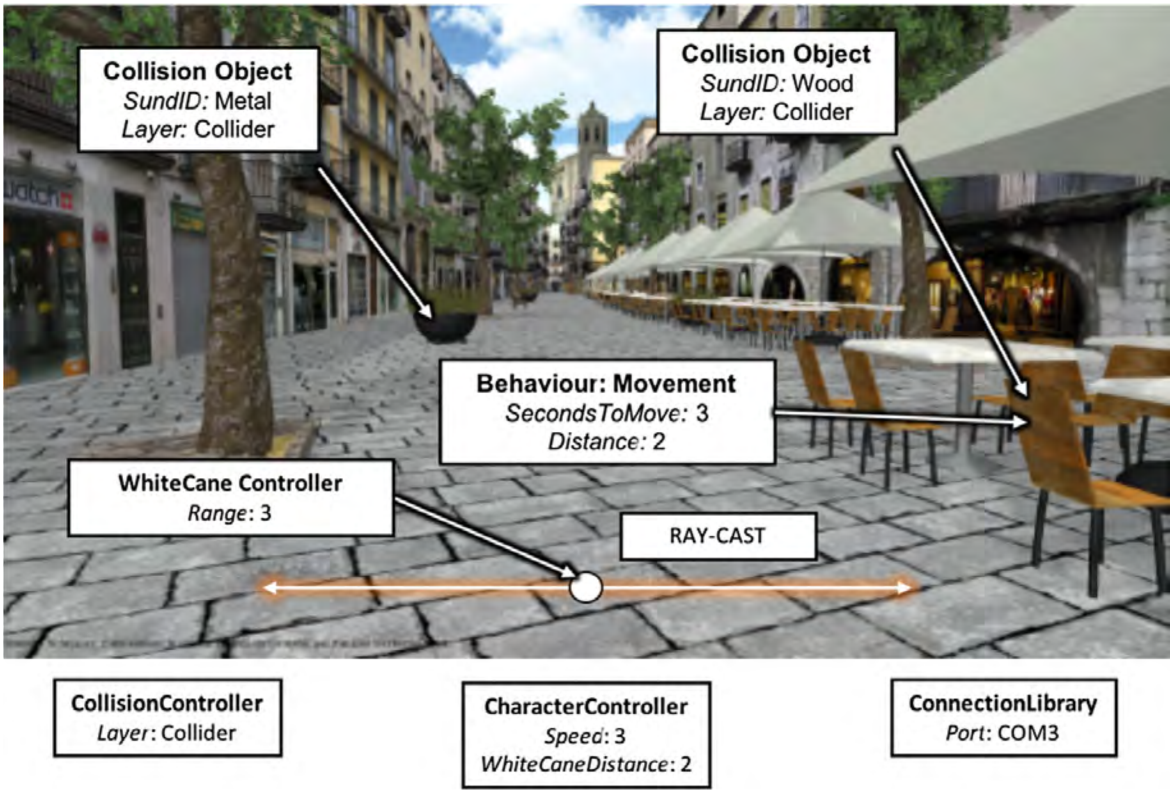


Fig. 6 An example of the required scene information to properly connect the proposed device with a video game programmed with Unity 3D

keys. With respect to the reality of the provided feedback, different to other devices, in case of collision, there is a real impact with lateral limit. This feature gives more realism to the collision than other devices that return a vibrotactile feedback [40, 66]. Moreover, economic and computation costs of our device with respect to these others are lower.

4 Experimental set-up

In this section, we describe the experiment that has been designed to test the acceptance of the proposed device.

4.1 Testing video games

Our device is particularly well suited for video games where navigation and walking is the principal action. For this reason, we created three mini-games that require these player actions as the main ones. These three mini-games have been integrated in Legends of Girona game [53]. A brief description of each one is given below.

First game, called *Entering the defensive wall of Girona*, reproduces the entrance into the defensive wall of Girona town (see Fig. 7a). It reproduces a corridor with obstacles at both sides, left and right. Player has to detect the obstacles on the left and also on the right and she/he has to remember the number of detected obstacles at each side. When player reaches the end of the corridor, he/she finds at each side two final obstacles that have to be moved. To move them he/she has to knock as many times as obstacles has found in the corresponding side and wait five seconds. If the number is correct, he/she will access to the other side of the defensive wall. The challenge is doing it as fast as possible.

Second game, called *Direction to Saint Narcis Church*, reproduces the way to the Saint Narcis Church (see Fig. 7b). The player has to avoid colliding with different objects, such as chairs, tables or benches. The game is over when player arrives to the church.

Third game, called *Saint Narcis and the Flies*, recreates part of the Saint Narcis and the flies legend (see Fig. 7c). This took place in the 18th century when French army entered the

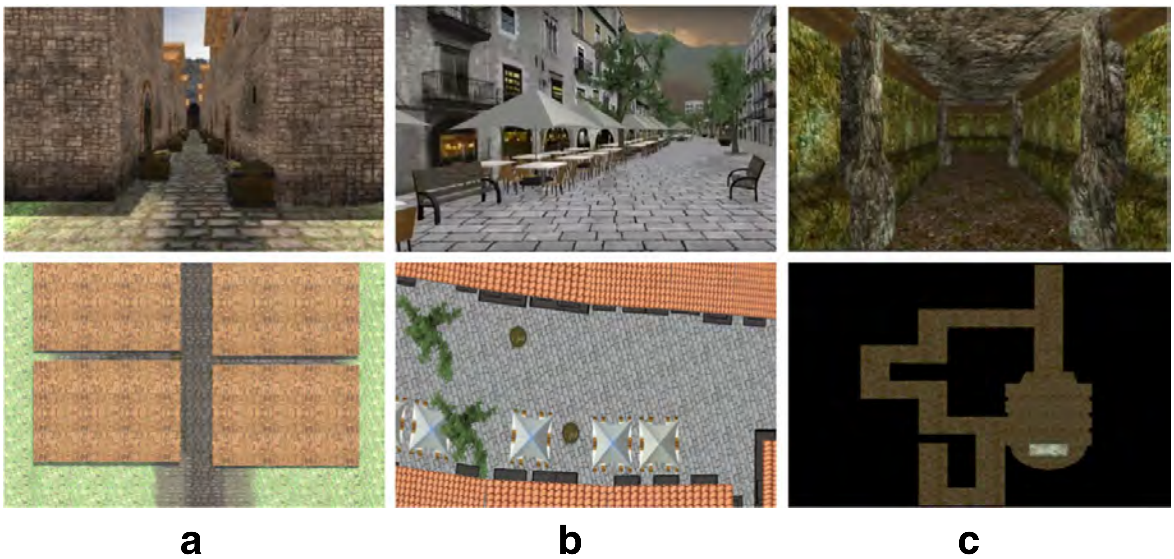


Fig. 7 From left to right, two views of testing scenarios correspoding to the three designed mini-games

town of Girona and occupied the outside city walls including the Church of Sant Feliu where tomb of Sant Narcis laid. To avoid French soldiers to attack, the player has to reach the tomb going through a maze and set free the flies that are inside the tomb. Player knows that there are the same number of turns on the right than on the left. At the last corner, the player can go to the right or to the left, the option that equals the number of corners is the correct one. If the player selects it, the game will be over. At each play, the maze configuration changes. To perform movements the player uses the keyboard arrows.

4.2 Participants

To evaluate the acceptance of the proposed device, we considered a group of 12 participants who were blind. There were 6 females and 6 males. Their average age was 35 years old and a standard deviation of 10.86 for the males, and an average age of 29.83 years old and a standard deviation of 8.05 for the females. Participants were recruited through personal contacts. The study was conducted in a laboratory at the University of Girona.

4.3 Designed study

We designed a study composed of three different parts. Each participant carried out the study individually. First, we described the experiment to the participant and we asked him/her to answer a first questionnaire (see Table 1 from question Q1 to Q4). Second, we introduced the device and the three mini-games to the participant. The participant played games alone under authors observation. At the end of playing session, participants answered questions related to the device (see Table 1 from question Q5 to Q7). For each mini-game, they also answered questions related to the played game (see Table 1 questions Q8 and Q9). To answer, players used a five-level Likert scale where 1 means *Strongly disagree* and 5 *Strongly agree*. We also asked him/her about the experience, about their feelings, how they feel at the beginning of the session and how at the end.

Table 1 Questions of the interviews. Second and third questionnaires were answered using the five-level Likert scale where 1 means *Strongly disagree* and 5 *Strongly agree*

FIRST QUESTIONNAIRE		
Q1	Are you blind from birth?	(Yes/No)
Q2	Do you use the white cane?	(Yes/No)
Q3	Do you play video games?	(Yes/No)
Q4	Would you like to play video games?	(Yes/No)
SECOND QUESTIONNAIRE		
Q5	The device simulates the white cane properly	(1-5)
Q6	Is the device robust?	(1-5)
Q7	You have a good object detection impression	(1-5)
THIRD QUESTIONNAIRE		
Q8	The device is suitable to play the game	(1-5)
Q9	Did you enjoy the game?	(1-5)

Table 2 Responses to first questionnaire

Question	Answered YES
Q1 Are you blind from the birth?	66.7%
Q2 Do you use the white cane?	100%
Q3 Do you play video games?	16.7%
Q4Would you like to play videogames?	83.3%

4.4 Statistical analysis

Fisher exact, and Mann-Whitney U were used to test primary outcome measures in the experimental design of participants gender (male vs. female) and if they are blind from the birth or not. Fisher's exact is used to test independence of two categorical variables. The null hypothesis is that the relative proportions of one variable are independent of the second variable. We use this test as it is well known that it is more accurate than chi-squared test or G-test of independence when expected numbers are small. Also, Mann-Whitney U is used to test if two independent groups are homogeneous and have the same distribution. Null hypothesis stipulates that the two groups come from the same population. We use this test instead of t-test because it is particularly suitable when the dependent variable is scalar or ordinal, as it is the case in questions Q5 to Q9 (see Table 1).

5 Results

In this section, we present the obtained results. We also present a time performance evaluation and the limitation of the experiment.

In Table 2 we present the responses to the first questionnaire (see Table 1 from question Q1 to Q4). From the 12 participants of our testing group we can see that 66.7% are blind from birth, all of them use white cane, 83.3% would like to play videogames but only 16.7% of them had played.

From the answer to the second questionnaire (see Table 1 from question Q5 to Q7), we evaluated device usability focusing on its similarity with white cane, its robustness, and player's impression when colliding with virtual objects. The answers were scored from 1 to 5. The obtained results are shown in Table 3. Note that the median of the scores is 4 in all questions.

We also asked, on same scale, about the suitability of the device in the game, and player enjoyment for each one of the games. The obtained results are presented in Tables 4 and 5, respectively. Regarding the device suitability in the game, it seems to be suitable since all quartiles are 4 or higher except for game 2 where first quartile is 3 (see Table 4). With respect to enjoyment, results are completely different, medians are 4, 3 and 5, respectively.

Table 3 Responses to second questionnaire

	Mean	Min	1st Q	Median	3st Q	Max
Q5 Proper white cane simulation	3,917	3	3	4	4,25	5
Q6 Is the device robust?	3,833	2	3,75	4	4	4
Q7 Good object detection impression	4	3	3	4	5	5

Table 4 Responses to device suitability in the game

	Mean	Min	1st Q	Median	3st Q	Max
Q8.1 Device suitability in game 1	4.25	3	4	4	5	5
Q8.2 Device suitability in game 2	3.833	2	3	4	4.25	5
Q8.3 Device suitability in game 3	4.333	3	4	4.5	5	5

The worst results were obtained in mini-game 2. We think that this is due to the fact that there is no challenge in the game, as the player only has to walk avoiding obstacles.

We also look for significant differences among gender and if they are blind from birth. Our sample is well balanced according to gender, with 6 people on each group (see Table 6). We did not find significant differences on age (p-value 0.4848) and on questions Q1, Q3, and Q4 (p-values=0.55, 1,1, respectively). Table 7 shows the differences on the scores according to gender. The least value of median is 3 but most of them are 4 or higher. Also, after a U mann-Whitney test, we did not find significant differences on these scores of males and females.

If we separate our sample according to participants blindness from birth, groups are not as well balanced, 8 born blind and 4 not (see Table 8). We did not find significant differences on age (p-value 0.2141), and on questions Q1, Q3, and Q4 (p-values=0.55, 0.09,1, respectively). Table 9 shows the differences on the scores according to the born blind condition. Again, the least value of median is 3 but most of them are 4 or higher. Also, after a U mann-Whitney test, we did not find significant differences on these scores of being blind from birth or not.

To use the device, the user can both sit or stand. In the last case, it is necessary to place the device at the correct height. In our experiment, all players preferred to sit.

Although the number of participants is small, from this evaluation, we have seen that the device is well accepted and that it fits into games. We have also observed that the game requires a final challenge to be more attractive to player. Moreover, we did not find significant differences according to gender of being blind from birth. With respect to players feelings, we asked them how they feel at the beginning of the test and at the end. Their feelings range from anxiety, fear, and scepticism, at the beginning, to happiness, and euphoria. at the end. We consider that this issue needs a deeper study to reproduce experiments such as the ones presented in [73].

5.1 Time performance

The relationship between application responsiveness and user attention is one well-studied area of human-computer interaction, as Jakob Neilson describes in Usability Engineering [48], and basic advice regarding response times has been about the same for thirty

Table 5 Responses related to game enjoyment

	Mean	Min	1st Q	Median	3st Q	Max
Q9.1 Did you enjoy video game 1?	4.083	3	4	4.	4.25	5
Q9.2 Did you enjoy video game 2?	3.333	2	3	3	4	4
Q9.3 Did you enjoy video game 3?	4.583	3	4	5	5	5

Table 6 Description of the sample according to gender of the player

	Age			Play videogames		Like to play videogames		Blind from birth	
	Mean	Sd	p-value	%Yes	p-value	%Yes	p-value	%Yes	p-value
Women (n=6)	29.83	8.085	0.4848	16.67%	1	83.33%	1	16.67%	0.55
Men (n=6)	35	10.863		16.67%		83.33%		50.00%	

years [8, 42]. Time limit for users feeling that they are directly manipulating objects in a user interface is 0.1 second. Time limit for users feeling that they are freely navigating the command space without having to unduly wait for the computer is 1 second. Finally, the limit for users keeping their attention on the task is 10 seconds. Unfortunately, the relationship between game responsiveness and player attention can not be measured in the same way since depending on game genre the player requirements can be very different. For instance, role games do not require faster interaction while shooter games do. In our context, we focused on the experience of true immersion and we consider that players must be able to manipulate the game world almost as intuitively as they manipulate the real-world. Therefore, response time of our device is a key factor to keep the player attention.

To evaluate time response, we considered the first mini game, *Entering the defensive wall of Girona*, since response time is decisive as player has to detect all obstacles in minimal time. First time to be considered is time to detect collisions. This is 100 microseconds which is the delay time set in communication protocol between the computer and the device. Note that this is a maximum time. Second time to be considered is time to detect other actions such as number of knocks on an object. This depends on the bounce control which in our

Table 7 Differences on the scores according to the gender (W represents women and M men)

	Gender	Mean	Min	1st Q	Median	3rd Q	Max	p
Q5 Proper white cane simulation	W(n=6)	4.333	4	4	4	4.75	5	0.0733
	M(n=6)	3.5	3	3	3	3.75	5	
Q6 Device robustness	W(n=6)	3.833	3	4	4	4	4	0.8577
	M(n=6)	3.833	2	3.25	4	4.75	5	
Q7 Detection impression	W(n=6)	4.333	3	4	4.5	5	5	0.2043
	M(n=6)	3.667	3	3	3.5	4	5	
Q8.1Suitable device for game 1	W(n=6)	4.5	4	4	4.5	5	5	0.2012
	M(n=6)	4	3	4	4	4	5	
Q8.2 Suitable device for game 2	W(n=6)	3.667	2	3.25	4	4	5	0.6734
	M(n=6)	4	3	3.25	4	4.75	5	
Q8.3 Suitable device use game 3	W(n=6)	4	3	4	4	4	5	0.0968
	M(n=6)	4.667	3	5	5	5	5	
Q9.1 Did you enjoy game 1	W(n=6)	4.333	4	4	4	4.75	5	0.2406
	M(n=6)	3.833	3	3.25	4	4	5	
Q9.2 Did you enjoy game 2	W(n=6)	3.333	2	3	3.5	4	4	0.9324
	M(n=6)	3.333	2	3	3	3.75	5	
Q9.3 Did you enjoy game 3	W(n=6)	4.667	4	4.25	5	5	5	0.9233
	M(n=6)	4.5	3	4.25	5	5	5	

Table 8 Description of the sample according to being blind from birth

	Age			Play videogames		Like to play videogames		Blind from birth	
	Mean	Sd	p-value	%Yes	p-value	%Yes	p-value	%Yes	p-value
Blind from birth (n=8)	29.25	6.62	0.2141	0.00%	0.0909	87.50%	1	37.50%	0.55
Not blind from brith (n=4)	38.75	12.23		50.00%		75.00%		75.00%	

Table 9 Differences on the scores according to the born blind condition

	Born blind	Mean	Min	1st Q	Median	3rd Q	Max	p
Q5 Proper white cane simulation	Y (n=8)	4	3	3,75	4	4.25	5	0.0651
	N (n=4)	3.75	3	3	3,5	4,25	5	
Q6 Device robustness	Y(n=8)	4,125	4	4	4	4	5	0.1281
	N (n=4)	3.25	2	2.75	3	3,5	5	
Q7 Object detection impression	Y (n=8)	3.875	3	3	4	4,25	5	0.5298
	N(n=4)	4,25	3	3,75	4.5	5	5	
Q8.1 Suitable device for game 1	Y(n=8)	4,25	3	4	4	5	5	1
	N(n=4)	4,25	4	4	4	4,25	5	
Q8.2 Suitable device for game 2	Y (n=8)	3,75	2	3	4	4,25	5	0.7885
	N (n=4)	4	3	3.75	4	4,25	5	
Q8.3 Suitable device for game 3	Y (n=8)	4,25	3	4	4	5	5	0.5164
	N (n=4)	4.5	3	4,5	5	5	5	
Q9.1 Did you enjoy game 1	Y (n=8)	4.125	3	4	4	4.25	5	0.8481
	N(n=4)	4	3	4	4	4.25	5	
Q9.2 Did you enjoy game 2	Y (n=8)	3.375	2	2,75	3.5	4	5	0.8573
	N (n=4)	3.25	3	3	3	3.25	4	
Q9.3 Did you enjoy game 3	Y (n=8)	4.5	3	4	5	5	5	0.6831
	N (n=4)	4.75	4	4.75	5	5	5	

case has been set to 0,02 seconds. We also have to take into account time required to place lateral limits of the device in the correct position to simulate the collided obstacle. As we mentioned, this time depends on engine speed and distance between previous position and the current one. We have considered the worst situation when lateral limit is at the extreme. In this case 2,7 seconds are required. To compute this time we used the `TimeCatch` module which is part of the External API and also the Internal one. In External API case, this module has two methods: `StartMovement` that saves the time when the movement has to start, and `OnFinishMovement` that is triggered when movement finishes. In Internal API case, this module has a `SendFinishMovement` method that calls OnFinishMovement when movement finishes. Players have a feeling of immediate feedback. The obtained results satisfy Jakob's restrictions and we consider that are good enough response times. Moreover, if we compare with Shneiderman and Seow classifications [12] the obtained response times can be considered good enough.

From these experiments, we have seen that response time can be also improved by modifying the shape of the elements in the game scenario. In particular if rectangular shapes are transformed into circular shapes the object detection will be faster without loosing playability.

5.2 Limitations

Although, we are satisfied with the results of our experiments, we are conscious that low number of participants is a main limitation of our work and a more exhaustive experiment has to be carried out. For this reason, as immediate work we will carry on a new experiment with more participants, we are recruiting more blind players. In addition, we want to prepare our laboratory to perform a video controlled experiment registering all the details of the participants during playing sessions. We want to evaluate other factors that may influence comfort when using the device, such as human motion [10, 29, 30, 32]. Moreover, to predict the interest of users on the device, we want to apply machine learning techniques such as in [33]. We consider that these steps are necessary before device commercialization.

6 Conclusions and future work

Visual channel is the main component of the majority of video games. This fact makes designing games for visually impaired people challenging. In this paper, we have focused not on a game design but on an interaction device specifically designed for visually impaired people. Inspired by smart-canes, we have presented an Arduino-based device that supports left-right movements as well as drag and drop operations. Moreover, combined with a sound library the proposed device provides a real experience for any player. The device is suitable for exploration games that require identification of objects placed on the floor. It is easy to use and can be adapted to any game thanks to the provided application programming interface. Our future work will be centered on the development of a new version of the device that supports more movements and that can be used not only with PC's. In addition, we want to define games capable to combine visual and non-visual players together. Finally, we are working on the design of a new experiment with more participants and considering more advanced techniques to evaluate player performance and preferences.

Acknowledgments This work was supported by the Catalan Government (Grant No. 2014-SGR-1232) and by the Spanish Government (Grant No. TIN2016-75866-C3-3-R).

References

1. Abdel-Wahab AG, El-Masry AAA (2011) Mobile information communication technologies adoption in developing countries: effects and implications. Hershey, IGI Global
2. Archambault D (2004) The TIM project: overview of results. In: Proc. Computers helping people with special needs, pp 248–256
3. Archambault D, Ossmann R, Gaudy T, Miesenberger K Computer games and visually impaired people (https://cedric.cnam.fr/fichiers/RC1204.pdf)
4. Arduino What is Arduino. Available online: https://www.arduino.cc/en/Guide/Introduction. Accessed 22 May 2017
5. Bach-y-Rita P, Collins CC, Saunders FA, White B, Scadden L (1969) Vision substitution by tactile image projection. Nature 221:963–964
6. Balan O, Moldoveanu A, Moldoveanu F (2015) Navigational audio games: an effective approach toward improving spatial contextual learning for blind people. Int J Disabil Hum Dev 14(2):109–118
7. Brewster SA (1998) Using non-speech sounds to provide navigation cues. ACM Trans Comput-Human Interact 5:224–259
8. Card SK, Robertson GG, Mackinlay JD (1991) The information visualizer: an information workspace. In: Proc. ACM CHI'91 Conf, 181–188
9. Csapó G, Nagy H, Stockman T (2015) A survey of assistive technologies and applications for blind users on mobile platforms: a review and foundation for research. J Multimodal User Interf 9(4):275–286
10. Cui J, Liu Y, Xu Y, Zhao H, Zha H (2013) Tracking generic human motion via fusion of low- and high-dimensional approaches. IEEE Trans Syst Man Cybern Syst 43(4):996–1002
11. Cuturi LF, Aggius-Vella E, Campus C, Parmiggiani A, Goria M (2016) From science to technology: orientation and mobility in blind children and adults. Neurosci Biobehav Rev 71:240–251
12. Dabrowski J, Munson EV (2011) 40 Years of searching for the best computer system response time. Interact Comput 23:555–564

13. Damaschini R, Legras R, Leroux R, Farcy R (2005) Electronic travel aid for blind people. Assistive Technol Virtual Realit 16(1):251–255
14. Farcy R, Leroux R, Damaschini R, Legras R, Bellik Y, Jacquet C, Pardo P (2003) Laser telemetry to improve the mobility of blind people: report of the 6 month training course. In: Proc. 1st International conference on smart homes and health telematics12, pp 113–115
15. Friberg J, Gärdenfors D (2004) Audio games: new perspectives on game audio. In: Proc. Int. ACM conference on advances in computer entertainment technology, pp 148–154
16. Ghali NI, Soluiman O, El-Bendary N, Nassef TM, Ahmed SA, Elbarawy YM, Hassanien AE (2012) Virtual reality technology for blind and visual impaired people: reviews and recent advances. In: Gulrez T, Hassanien A E (eds) Advances in robotics and virtual reality, ISRL 26, pp 363–385
17. Gori M, Cappagli G, Tonelli A, Baud-Bovy G, Finocchietti S (2016) Devices for visually impaired people: High technological devices with low user acceptance and no adaptability for children. Neurosci Biobehav Rev 69:79–88
18. Gutschmidt R, Schiewe M, Zinke F, Jürgensen H (2010) Haptic emulation of games: haptic Sudoku for the blind. In: Proc. Int. Conf. on pervasive technologies related to assistive environments. Article 2. ACM
19. Hakobyan L, Lumsden J, OSullivan D, Bartlett H (2013) Mobile assistive technologies for the visually impaired. Surv Opthalmol 58(6):513–528
20. Haptics rendering and applications Edited by Dr. Abdulmotaleb El Saddik, 978-953- 307-897-7 (2012)
21. Heuten W, Henze N, Boll S, Klante P (2007) Auditorypong, playing pong in the dark. In: Audio mostly-proc. conference on interaction with sound
22. Hossain E, Khan R, Muhida R, Ali A (2011) State of the art review on walking support system for visually impaired people. Int J Biomechatron Biomed Robot 1(4):232–251
23. Kajimoto H, Inami M, Kawakami N, Tachi S (2003) Smart Touch-augmentation of skin sensation with electro cutaneous display, haptic interfaces for virtual environment and teleoperator systems. HAPTICS 2003. In: Proc. Symposium on IEEE, pp 40–46
24. Kay L (2000) Auditory perception of objects by blind persons, using a bioacoustic high resolution air sonar. J Acoust Soc Am 107:3266–3275
25. Kim J, Ricaurte J (2011) TapBeats: accessible and mobile casual gaming. In: Proc. ACM Conference on computers and accessibility. ACM, pp 285–286
26. Kim S, Lee K, Nam T (2016) Sonic-badminton: audio-augmented badminton game for blind people. In: Proc. Conference on human factors in computing systems. ACM, pp 1922–1929
27. Lacey G, Dawson-Howe KM, Vernon D (1995) Personal autonomous mobility aid for the frail and elderly blind (Technical Report, No. TCD-CS-95-18). Trinity College, Dublin
28. Leonard R (2002) Statistics on vision impairment: a resource manual, 5th edn. Arlene Gordon Research Institute of Lighthouse International, New York
29. Liu Y, Zhang X, Cui J (2010) Visual analysis of child-adult interactive behaviors in video sequences. Int Conf Virt Syst Multimed
30. Liu Y, Cui J, Zhao H, Zha H (2012) Fusion of low-and high-dimensional approaches by trackers sampling for generic human motion tracking. Int Conf Pattern Recogn 898–901
31. Liu Y, Nie L, Han L, Zhang L, Rosenblum DS (2015) Action2Activity: recognizing complex activities from sensor data. In: Yang Q, Wooldridge M (eds) Proc. int. conference on artificial intelligence. AAAI Press, pp 1617–1623
32. Liu L, Cheng L, Liu Y, Jia Y, Rosenblum DS (2016) Recognizing complex activities by a probabilistic interval-based model. Int Conf Artific Intell, 1266–1272
33. Liu Y, Zhang L, Nie L, Yan Y, Rosenblum DS (2016) tFortune teller: predicting your career path. Int Conf Artif Intell, 201–207
34. Liu Y, Nie L, Liu L, Rosenblum DS (2016) From action to activity: sensor-based activity recognition. Neurocomputing 181(2016):108–115
35. Lu Y, Wei Y, Liu L, Zhong J, Sun L, Liu Y (2017) Towards unsupervised physical activity recognition using smartphone accelerometers. Multimed Tools 76(8):10701–10719
36. Maidenbaum S, Levy-Tzedek S, Chebat D, NamerFurstenberg R, Amedi A (2014) The effect of expanded sensory range via the eyecane sensory substitution device on the characteristics of visionless virtual navigation,MSR. ISSN 2213–4794
37. Manduchi R, Coughlan JM (2012) Computer vision without sight. Commun ACM 55(1):96–104
38. Manduchi R, Kurniawan S (2011) Mobility-related accidents experienced by people with visual impairment. Res Pract Vis Impairment Blindness 4(2):44–54
39. Manduchi R, Kurniawan S (2012) Assistive technology for blindness and low vision. CRC Press, ISBN 9781439871539

40. Magnusson C, Rassmus-Grhn K, Sjstrm C, Danielsson H (2002) Navigation and recognition in complex haptic virtual environments? Reports from an extensive study with blind users? In: Proc. Eurohaptics 2002. Edinburgh
41. Mau S, Melchior NA, Makatchev M, Steinfeld A (2008) BlindAid: an electronic travel aid for the blind (Technical Report, No. CMU-RI-TR-07-39). The Robotics Institute at Carnegie Mellon University, Pittsburgh
42. Miller RB (1968) Response time in man-computer conversational transactions. Proc AFIPS Fall Joint Comput Conf 33:267–277
43. Miller D, Parecki A, Douglas S (2007) Finger dance: a sound game for blind people. In: Proc. Int. ACM conference on computers and accessibility, pp 253–254
44. Milne L, Bennett C, Ladner R, Azenkot S (2014) Brailleplay: educational smartphone games for blind children. In: Proc. Int. conference on computers and accessibility, pp 137–144
45. Morelli T, Foley J, Columna L, Lieberman L, Folmer E (2010) VI-Tennis a vibrotactile / audio exergame for players who are visually impaired categories and subject descriptors. In: Proc. Int. ACM conference on the foundations of digital games, pp 147–154
46. Morelli T, Foley J, Folmer E (2010) Vi-bowling: a tactile spatial exergame for individuals with visual impairments. In: Proc. International conference on computers and accessibility, pp 179–186
47. Nagarajan R, Yaacob S, Sainarayanan G (2003) Role of object identification in sonification system for visually impaired. In: IEEE Tencon (IEEE region 10 conference on convergent technologies for the AsiaPacific). Bangalore, pp 15–17
48. Neilson J (1993) Usability engineering
49. Nikolakis G, Tzovaras D, Moustakidis S, Strintzis M (2004) Cybergrasp and phantom integration: Enhanced haptic access for visually impaired users. Conf Speech Comput 20–22
50. Papa Sangre (2013) http://www.papasangre.com/
51. Rempel J (2012) Glasses that alert travelers to objects through vibration? An evaluation of iGlasses by RNIB and AmbuTech. AFB Access World Mag 13:9
52. Revuelta P, Ruiz B, Sánchez JM, Bruce N (2014) Scenes and images into sounds: a taxonomy of image sonification methods for mobility applications. J Audio Eng Soc 62(3):161–171
53. Rodriguez A, Garcia RJ, Garcia JM, Magdics M, Sbert M (2013) Implementation of a videogame: legends of girona actas del primer simposio espaol de entretenimiento digital. In: Gonzlez P A, Gmez, M A (eds) pp 96–107
54. Rodriguez-Sancheza MC, Moreno-Alvareza MA, Martin E, Borromeoa S, Hernandez-Tamamesa JA (2014) Accessible smartphones for blind users: a case study for a way finding system. Expert Syst Appl 41(16):7210–7222
55. Roentgen UR, Gelderblom GJ, Soede M, de Witte L (2008) Inventory of electronic mobility aids for persons with visual impairments: a literature review. J Vis Impairment Blindness 102(11):702–724
56. Sakhardande J, Pattanayak P, Bhowmick M (1163) Arduino based mobility caneinternational. J Sci Eng Res 4:4
57. Sánchez J, Sáenz M, Ripoll M (2009) Usability of a multimodal videogame to improve navigation skills for blind children. In: Proc. ACM Computers and accessibility, pp 35–42
58. Sánchez J, Sáenz J, Garrido JM (2010) Usability of a multimodal video game to improve navigation skills for blind children. TACCESS 3:2010
59. Sánchez J, Campos M, Espinoza M, Merabet LB (2014) Audio haptic video gaming for developing way finding skills in learners who are blind. In: Proc. International conference on intelligent user interfaces. ACM, pp 199–208
60. Savidis A, Stamou A, Stephanidis C (2007) An accessible multimodal pong game space. Universal Access Ambient Intell Environ 405–418
61. Shoval S, Borenstein J, Koren Y (1998) The Navbelt-A computerized travel aid for the blind based on mobile robotics technology. IEEE Trans Biomed Eng 45:1376–1386
62. Sohl-Dickstein J, Teng S, Gaub BM, Rodgers CC, Li C, DeWeese MR, Harper NS (2015) A device for human ultrasonic echolocation. IEEE Trans Biomed Eng 62:1526–1534
63. Sudhanthiradevi M, Suganya Devi M, Roshini R, Sathya T (2016) Arduino based walking stick for visually impaired. Int J Adv Res Trends Eng Technol 5:4
64. Sung-Yeon K, Kwangsu C (2013) Usability and design guidelines of smart canes for users with visual impairments. Int J Des 7:1
65. Torres-Gil MA, Casanova-Gonzalez O, Gonzalez-Mora JL (2010) Applications of virtual reality for visually impaired people. WSEAS Trans Comput 2(9):184–193

66. Tzovaras D, Moustakas K, Nikolakis G, Strinzis M (2009) Interactive mixed reality white cane simulation for the training of the blind and the visually impaired. Person Ubiq Comput 13(1):51–58
67. Velzquez R (2010) Wearable assistive devices for the blind. Wearable and autonomous biomedical devices and systems for smart environment. Lect Notes Electr Eng 75:331–349
68. Vorderer P, Bryant J (2006) Playing video games-motives, responses and consequences, Mahwab, NJ:LEA, ISBN: 978-0805853223
69. Wood J, Magennis M, Cano Arias EF, Gutierrez T, Graupp H, Bergamasco M (2003) The design and evaluation of a computer game for the blind in the GRAB haptic audio virtual environment eurohaptics 2003. Dublin
70. www.theesa.com/. Accessed on May 2017
71. Yuan B, Folmer E (2008) Blind hero: enabling guitar hero for the visually impaired. In: Proc. International ACM conference on computers and accessibility, pp 169–176
72. Yuan B, Folmer E, Harris FC (2011) Game accessibility: a survey. Univers Access Inf Soc 10(1):81–100
73. Zhao S, Yao H, Gao Y, Ji R, Xie W, Jiang X, Chua TS (2016) Predicting personalized emotion perceptions of social images. Proc ACM Multimed Conf 1385–1394

Antonio Rodríguez is a Ph.D. student in Computer Science at the University of Girona, Spain. He received a degree in Computer Science (University of Girona, 2004) and a Master's Degree in Computer Science (University of Girona, 2016). The main fields of his research are Serious Games, E-learning and adapted games for handicapped people.

Imma Boada is an associate professor in Computer Science at the University of Girona, Spain. She received a M.Sc. in Computer Science (1992) from the Universitat Autònoma de Barcelona and a Ph.D. in Computer Science from the Universitat Politècnica de Catalunya, 2001. The main fields of her research are Visualization, Image Processing, Serious Games, E-learning, and Medical Applicacions.

Mateu Sbert is professor in Computer Science at the University of Girona, Spain, and 1000 Plan professor at Tianjin University, China. He received a M.Sc. in Theoretical Physics (1977) at the University of Valencia, a M.Sc. in Mathematics (Statistics and Operations Research, 1983) at UNED university (Madrid) and a Ph.D. in Computer Science at the UPC (Technical University of Catalunya, 1997, Best PhD Award). Mateu Sbert's research interests include Serious Games, Computer Graphics, Visualization, and Image Processing. He has authored or co-authored more than 200 papers in his areas of research.

Chapter 3

How the gender of a victim character in a virtual scenario created to learn CPR protocol affects student nurses performance

---

The second goal of this thesis is focused on how serious games can improve first-aid teaching. In this chapter, an study of how character gender of a victim in a simulation scenario created to practice the cardiopulmonary resuscitation protocol influences the performance of students from the Nursing Faculty is presented. To carry out the study different virtual scenarios where victims have been modeled as males or females have been created and integrated in the LISSA serious game [Wattanasoontorn 2013]. Students have solved the emergencies and different parameters such as time to remove clothes and hands positions have been evaluated. From the study it has been seen that performance is not influenced by victim gender.

How the gender of a victim character in a virtual scenario created to learn CPR protocol affects student nurses performance, Imma Boada, Antonio Rodriguez, Santiago Thió-Henestrosa, Josep Olivet, and Josep Soler, Computer Methods and Programs in Biomedicine, August (162), Pp:233-241 (2018), doi: 10.1016/j.cmpb.2018.05.019. JCR-Computer Science interdisciplinary applications, position:25/106; IF:3,424; Quartile Q1

Computer Methods and Programs in Biomedicine 162 (2018) 233–241

Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

How the gender of a victim character in a virtual scenario created to learn CPR protocol affects student nurses' performance

Imma Boada[a,*], Antonio Rodriguez-Benitez[a], Santiago Thió-Henestrosa[b], Josep Olivet[c], Josep Soler[a]

[a] Graphics and Imaging Laboratory, Spain
[b] Departament Informàtica, Matemàtica Aplicada i Estadística, Spain
[c] Nurse Faculty, University of Girona, Spain

ARTICLE INFO

Article history:
Received 23 November 2017
Revised 17 April 2018
Accepted 16 May 2018

Keywords:
Virtual environments
Cardiopulmonary resuscitation
Nursing informatics
Character gender

ABSTRACT

Background and objective: Virtual simulations recreate scenarios where student nurses can practice procedures in a safe and supervised manner and with no risk to the patient. Virtual scenarios include digital characters that reproduce human actions. Generally, these characters are modeled as males and restricted roles are assigned to females. Our objective is to evaluate how the character gender of a victim in a scenario created to practice the cardiopulmonary resuscitation protocol (CPR) affects performance of student nurses.

Methods: Three virtual scenarios with cardiac arrest victims modeled as males or females were assigned to 41 students of the Nursing Faculty to practice the CPR protocol. We evaluated student performance with respect to the time to remove clothes, the time to perform the CPR maneuver, and the hands position for CPR. Chi-square, Fisher exact, and Mann–Whitney *U* were used to test primary outcome measures in the experimental design of victim character sex (male vs. female) and student sex (men vs. women).

Results: The analysis performed did not find statistically differences in time to remove clothes or in time to start CPR. With respect to hands placement we also did not find significant difference in any of the cases.

Conclusion: Nurse student actions are not influenced by the character gender of the victim. Excellent results with respect to hands placement to start CPR are obtained. Virtual scenarios can be a suitable strategy to reduce gender differences in gender sensitive situations such as CPR performance.

1. Introduction

Simulation-based learning recreates realistic experiences in controlled environments where students can practice to gain experience and develop problem solving skills [1]. It is applied in many different disciplines such as aviation, business, economics and medicine, to name a few. Focusing on nurse education, simulation techniques play a decisive role since they are suitable tools to provide students appropriate levels of clinical experience to become safe and competent practitioners [2]. These techniques have been long utilized to teach the principles and skills of nursing care and many studies have shown their effectiveness [3–8,11].

Simulation activities combine role play tasks with models of anatomical parts, whole body mannequins, and computer-based programs. These programs have increased in the last years leading to a large variety of e-simulation techniques [9–11]. Some e-simulation techniques are based on the creation of virtual environments that can be accessed via the Internet or downloaded as an application. Generally, the creation of these virtual scenarios requires time and effort, mainly due to the graphical interface that it requires and the narrative that is needed to support them. This complexity increases when the digital characters aim to realistically reproduce human actions. In this context, depending on the situations and the procedures that have to be simulated, achieving a realistic representation can lead to some sensitive issues such as the selection of the character's gender. For instance, consider the cardiopulmonary resuscitation (CPR) protocol that has to be applied when someone suffers a sudden heart attack. To simulate this situation, we can create a scene with an automatic external defibrillator (AED) and the characters representing the victim and the rescuer that will be manipulated by the user. One of the steps of the CPR protocol requires the rescuer to use the AED to analyze the patient's heart rhythm. To carry out this step, it is recommended to remove all clothing from the chest, abdomen and

* Corresponding author.
E-mail address: imma.boada@udg.edu (I. Boada).

https://doi.org/10.1016/j.cmpb.2018.05.019
0169-2607/

arms of the victim to properly place the defibrillator's patches [12]. These actions can be embarrassing if the victim is a female. In a recent study, Blewer et al. [13] evaluated 20.000 CPR cases and detected that rescuers were less likely to help women than man. They considered as a possible reason for these results the fact that people were less comfortable delivering CPR to a woman they do not know rather than a man because of the physical barriers. They think that reluctance to touch a woman's chest might be one reason since rescuers may worry about removing a woman's clothing to get better access, or touching breasts to do CPR. To avoid this situation, the majority of simulation scenarios model the victim as a male, although females can also be exposed to a sudden heart attack. The same case occurs when simulations are done with human mannequins which are always modeled as males. Studies of game content have shown that there are few female characters in computer games and that these characters have very restricted roles [14–16]. In this paper, we want to evaluate if the victim gender in a simulation scenario designed to practice the CPR procedure influences the student nurses's performance.

2. Background

Several studies have been carried out to evaluate how gender affects different aspects of CPR performance such as the effectiveness of training, the willingness to perform CPR, leadership during resuscitation, the quality of CPR, and the effect of failed resuscitative efforts on the provider [17]. Sipsma et al. [18] described that males reported greater confidence in performing CPR and greater willingness to start CPR while females were less likely to have undertaken CPR training. Axelsson et al. [19], in a Swedish survey of citizens trained in CPR, detected that females were less likely than males to perform CPR on an unkempt person while males were more confident than females in starting CPR. Focusing on chest compression maneuver, different studies have found that females are less likely than males to consistently achieve adequate chest compression depth during CPR [20,21]. These studies also detected that a higher body mass index on the males is also associated with more consistently achieving adequate chest compression depth. Kitamura et al. [22] detected that female helpers were more willing to perform telephone prompted chest compressions than males, but were less willing to make an emergency call or use an automated external defibrillator.

Note that all related studies were focused on the gender of the helper. As far as we know, there are only two studies that focused on the gender of the victim. The first one, by Kramer et al. [23], evaluated if the sex of a mannequin affects CPR performance. In their experiment, a sample population applied the CPR protocol to two different mannequins, a male and a female created by adding female physical attributes to a male one. They analyzed different actions such as hands placement on the victim's chest, or the compressions quality. They concluded that rescuers removed significantly more clothing from the male than the female, with men rescuers removing less clothing than the female ones. They also observed that more rescuers initial hands placement for CPR was centered between the female's breasts compared to the male, on which placement was distributed across the chest towards the nipples. The second study, conducted by Blewer et al. [13], analyzed 20.000 CPR cases collected from 2011 to 2015 and examined gender differences in receiving heart help from non-professional responders in public locations. They observed that males had an increased likelihood of receiving CPR compared to females. Particularly, only 39% of women suffering cardiac arrest in a public place were given CPR versus 45% of men. Although, they do not know exactly why rescuers were less likely to help women, they think that maybe the cause is fear of touching unknown women since

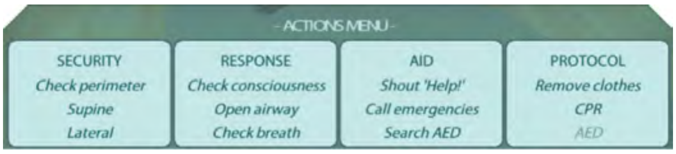


Fig. 1. Main menu of LISSA with all the actions of the CPR protocol.

there was no difference in CPR rates for women who had a cardiac arrest at home, where the victim knew the rescuer.

In the context of virtual scenarios, several applications have been proposed to improve CPR performance. Below, we describe some of them. JUST [24], an immersive virtual reality situation training system for non-professional health emergency operators, MicroSim Prehospital [25] designed for pre-hospital training on emergency medical services, and Staying alive [26], an online 3D simulator which provides a learning experience of saving a virtual patient from cardiac arrest in four minutes. LISSA [27] presents an emergency situation to the user who has to save the victim applying the CPR actions selected from a menu. In the context of serious games, Relive [28], a first person 3D adventure where the player faces different rescue situations and can test the quality of his CPR directly, Viva!Game [29], a Web-based serious game designed to create awareness on cardiac arrest and cardiopulmonary resuscitation and HeartRun [30], a mobile simulation game to train resuscitation and targeted at giving school children an understanding of CPR and getting them to take action.

Currently, no literature exists that evaluates how character gender of virtual scenarios affects the CPR performance of student nurses. Our aim is to evaluate this effect considering different emergency scenarios specifically designed for the experiment. We want to know if a patient's sex influences student nurses when resuscitating a female versus a male victim during a simulated cardiac arrest in a virtual scenario. To do that we measure the time spent removing the victim's clothes and the time passed before starting the CPR, and we hypothesized that both times are equally distributed (null hypothesis) or not (alternative hypothesis) if the victim is male or female. The test will be carried out at the Nursing Faculty of our university with 41 students.

3. Material and methods

3.1. Emergency scenarios

For the experiment, we used LISSA, which stands for Life Support Simulation Activities. LISSA is a simulation software designed to complement teaching on CPR and AED use [27,31]. LISSA provides an emergency situation represented in a 3D virtual environment with characters representing the victim, the rescuer, and all the auxiliary tools that may be required in the emergency. The student controls the rescuer character by selecting actions from a menu that appears at the bottom of the screen (see Fig. 1). The student selects the actions which trigger character animations. Selected actions are automatically evaluated by the system. The student has several attempts to perform the correct actions. The simulation ends when there are no more attempts or the victim has recovered. At this point, LISSA returns a performance report to check all the student's actions. LISSA has been used to complement CPR teaching [31]. For a more detailed description of the system see [27,31].

LISSA provides teachers an interface to create the emergency scenario. This allows them to select: the victim and rescuer characters, the place where the emergency will take place, if the victim will recover or not, the number of CPR sequences (30 compressions plus 2 ventilations) that have to be applied before the victim recovers or dies, and if AED will be used and when. To carry out our experiment we created the three scenarios presented in Fig. 2 and described below.

- Scenario 1. The victim is a man and the helper is a woman. The emergency takes place in the hall of an office center. The victim will recover after applying a complete sequence of 30 compressions and 2 ventilations plus one AED discharge. The images of Fig. 2(a) correspond to this scenario.
- Scenario 2. The victim is a man and the helper is a woman. The emergency takes place in a street of a city. The victim will recover after applying a complete sequence of 30 compressions and 2 ventilations plus one AED discharge. Fig. 2(b) corresponds to this scenario.
- Scenario 3. The victim is a woman and the helper is a man. The emergency takes place in a street of a city, the same as scenario 2. The victim will recover after applying a complete sequence of 30 compressions and 2 ventilations plus one AED discharge. Fig. 2(c) corresponds to this scenario.

3.2. Participants

The population of our testing scenario is composed of 41 nursing undergraduate students enrolled in the second year of the Nursing degree of our university. From the 128 students in this course only 15 are men. We selected all of them and then, we randomly selected 27 women from the rest. At the end of the experiment, one of the men did not perform the tasks so we have a sample population of 14 men and 27 women.

The undergraduate nursing program consists of four years with a spring and fall semester each year. Basic CPR skills are taught in the second year, in the subject of Performance in Emergencies. CPR is introduced at the beginning of the semester. Teachers provide students the European Resuscitation Council (ERC) guidelines and a set of tests that have to be solved via Moodle. A self-directed learning methodology is used to acquire these theoretical contents. In addition, students have to solve different tests sequentially. A test can only be solved when the previous one has been correctly solved. To complement the theory, teachers assign to all the students two emergency cases considering the LISSA scenarios previously described. The first case corresponds to Scenario 1 and is assigned to all the students. The second case is created considering Scenario 2 or Scenario 3 and is randomly assigned to the students in such a way that 6 men and 15 women have a case with a male victim and the rest have a case with the female victim. The students have an on-line LISSA tutorial and no teacher instruction is given, although a mail contact is given for possible doubts. After solving LISSA cases, they start laboratory sessions. Students are separated into small groups and continue their studies in the simulation laboratory under lecturer supervision. The laboratory is equipped with a Resusci Anne Simulator mannequin, by Laerdal Medical Incorporation from Norway.

3.3. Experimental design and statistical analysis

At the beginning of the course, students filled in the questionnaire presented in Table 1 to determine their previous knowledge of CPR.

LISSA provides functionalities to register any action performed by the student and we use them for the experiment. In particular, when the student selects one action from the menu we register the clock time. Since the CPR maneuver is the key point of the rescue procedure we focused on the following information related with the CPR maneuver

- The time between *Remove Clothes action* and *CPR action*. This is the time the student spends in front of the victim with the uncovered thorax (see Fig. 3(a)).
- The time to select correct hands positions from the menu represented in Fig. 3(b). This menu appears after selecting *CPR action*.
- The position selected to start CPR. After selecting hands position. A frontal plane of the victim thorax appears (see Fig. 3(c)), the student presses on a thorax position to start the maneuver. This position is classified according to the Dioszeghy et al. proposal [32] as green, yellow or red (see Fig. 3(d)). The green area, corresponding to the middle and lower part of the sternum, is the location of correct compression; the yellow area, corresponding to 20 mm surrounding the green one, is the less desirable area; and the red area is incorrect. The surface outside the correct area is unsafe, and yellow and red areas are more dangerous since the chance of rib fractures or other injury might be higher.

Finally, compressions and ventilations are done by pressing *space* and *enter* keys, respectively. In Fig. 3(e) we can see the interfaces that illustrate the compressions and ventilations performance.

Chi-square, Fisher exact, and Mann–Whitney *U* were used to test primary outcome measures in the experimental design of character sex (male vs. female) and student sex (men vs. women) (Figs. 4–6).

4. Results

We assigned two cases to all participants. The first case corresponds to a male victim (see Fig. 2(a)) and is the same for all the students. This case is not considered for evaluation. It is just considered as a training case to make student familiar with LISSA. The second case has a male or a female victim depending on the selected scenario (see Fig. 2(b) and (c)). We grouped students according to the gender of the victim. The first group interacts with a female victim and the second group with a male one.

4.1. Participants characteristics

Table 2 shows the characteristics of our sample of participants grouped according to the gender of the victim character (21 participants rescued a female victim and 20 a male victim). There are no group differences either for First Aid Course, or Previous knowledge of CPR, or Previous Heath education, or Previous work experience or Previous CPR course.

4.2. Time of response

We measured if the sex of the victim affects the time of response when the user removes the clothes and when the user starts applying CPR. In Table 3, response time to remove clothes and to start CPR grouped by student sex are presented. In both cases, according to the Mann–Whitney *U* test, the analysis performed was not able to find statistically significant differences in these times ($p = 0.90$ and $p = 0.82$ respectively), with a small effect size ($r = 0.24$ and $r = 0.25$, respectively).

The obtained results according to the sex of the victim are presented in Tables 4 and 5. In Table 4, when the victim is a male, $p = 0.57$ (with a small effect size, $r = 0.18$) to remove clothes, and $p = 0.97$ (with a small effect size, $r = 0.26$) to perform CPR; and in Table 5, when the victim is a female, $p = 0.57$ (with a small effect size, $r = 0.21$) to remove clothes, and $p = 0.73$ (with a small effect size, $r = 0.18$) to perform CPR. Note that we did not find statistically differences between the sex of victims or the sex of the participants in considered times.

Fig. 2. The three testing scenarios used for the experiment.

Table 1
Students questionnaire to determine their CPR background.

	Question	Answer
1	Do you have theoretical CPR knowledge?	Yes/No
2	Do you have previous studies in health?	Yes/No
3	Do you have working experience in the field of health?	Yes/No
4	How many years of experience do you have in the field of health?	...
5	Do you have practical CPR knowledge?	Yes/No
6	How many years ago was your last course on CPR?	...
7	Do you have experience in first aid?	Yes/No
8	Where did you receive instruction?	University or others
9	Assess your ventilation performance	[1...10]
10	Assess your compressions performance	[1...10]
11	Assess your capability to use of AED	[1...10]
12	Assess your capability to perform CPR in a real situation	[1...10]

Table 2
Study participants experience.

Victim gender of emergency case	Female ($N = 21$)		Male ($N = 20$)		
	Yes	%	Yes	%	Significance
Previous knowledge of RCP	9	42.9.%	6	30.0%	NS($p = 0.39$)
First aid course	6	28.6%	5	25.0%	NS($p = 0.80$)
Previous RCP course	6	28.6%	4	20.0%	NS($p = 0.52$)
Previous heath education	6	28.6%	7	35.0%	NS($p = 0.66$)
Previous work experience	6	28.6%	4	20.0%	NS($p = 0.52$)

Table 3
Response time in seconds to remove clothes and to start CPR grouped by the sex of the student.

Student	Time to remove clothes (s)			Time to start CPR (s)		
	Md	IQR	Mann–Whitney U p-value (size effect)	Md	IQR	Mann–Whitney U p-value (size effect)
Men = 14	1.34	1.09	0.90 ($r = 0.24$)	2.02	0.44	0.82 ($r = 0.25$)
Women = 27	1.08	1.24		2.10	0.66	

Table 4
Response time in seconds to remove clothes and to start CPR on male victim by the sex of student.

Student	Time to remove clothes male victim (s)			Time to start CPR male victim(s)		
	Md	IQR	Mann–Whitney U p-value (size effect)	Md	IQR	Mann–Whitney U p-value (size effect)
Men = 6	1.59	1.42	0.57 ($r = 0.18$)	2.00	0.32	0.97 ($r = 0.26$)
Women = 15	1.16	1.15		2.24	1.09	

Table 5
Response time in seconds to remove clothes and to start CPR on female victim by the sex of student.

Student	Time to remove clothes female victim (s)			Time to start CPR female victim (s)		
	Md	IQR	Mann–Whitney U p-value (size effect)	Md	IQR	Mann–Whitney U p-value (size effect)
Men = 8	1.13	0.96	0.57 ($r = 0.21$)	2.03	0.75	0.73 ($r = 0.18$)
Women = 12	0.99	1.54		2.27	0.76	

We are conscious that our sample is small and not well balanced due to the fact that only a few number of men students enrolled in the nursing faculty. Consequently, with a bigger and well balanced sample some difference in the results could be found.

4.3. Hands placement

With respect to the hands placement to start the CPR maneuver, according to Fisher's exact test we do not find astatistically significant difference between hands location on green and yellow zones versus red zone and beyond on male versus female victim ($p = 0.10$) (see Fig. 7). The same pattern occurs when comparing the sex of a student in a man victim ($p = 0.88$) (see Fig. 8) and women victim ($p = 0.32$) (see Fig. 9). Approximately 80% of either all participants, men and women placed their hands inside green and yellow zones.

5. Discussion

Nursing education has a long tradition of using clinical simulation as a complement to traditional methods of teaching. Whole-body, body-parts and computer controlled mannequins provide realistic environments where critical thinking and clinical skills can be promoted with no harm to the patient. Computer simulations in particular are widely regarded as an effective and cost efficient mixed method and many universities use virtual environments to teach a wide range of professional practice skills [33–36]. Although many studies in nursing have evaluated the effectiveness

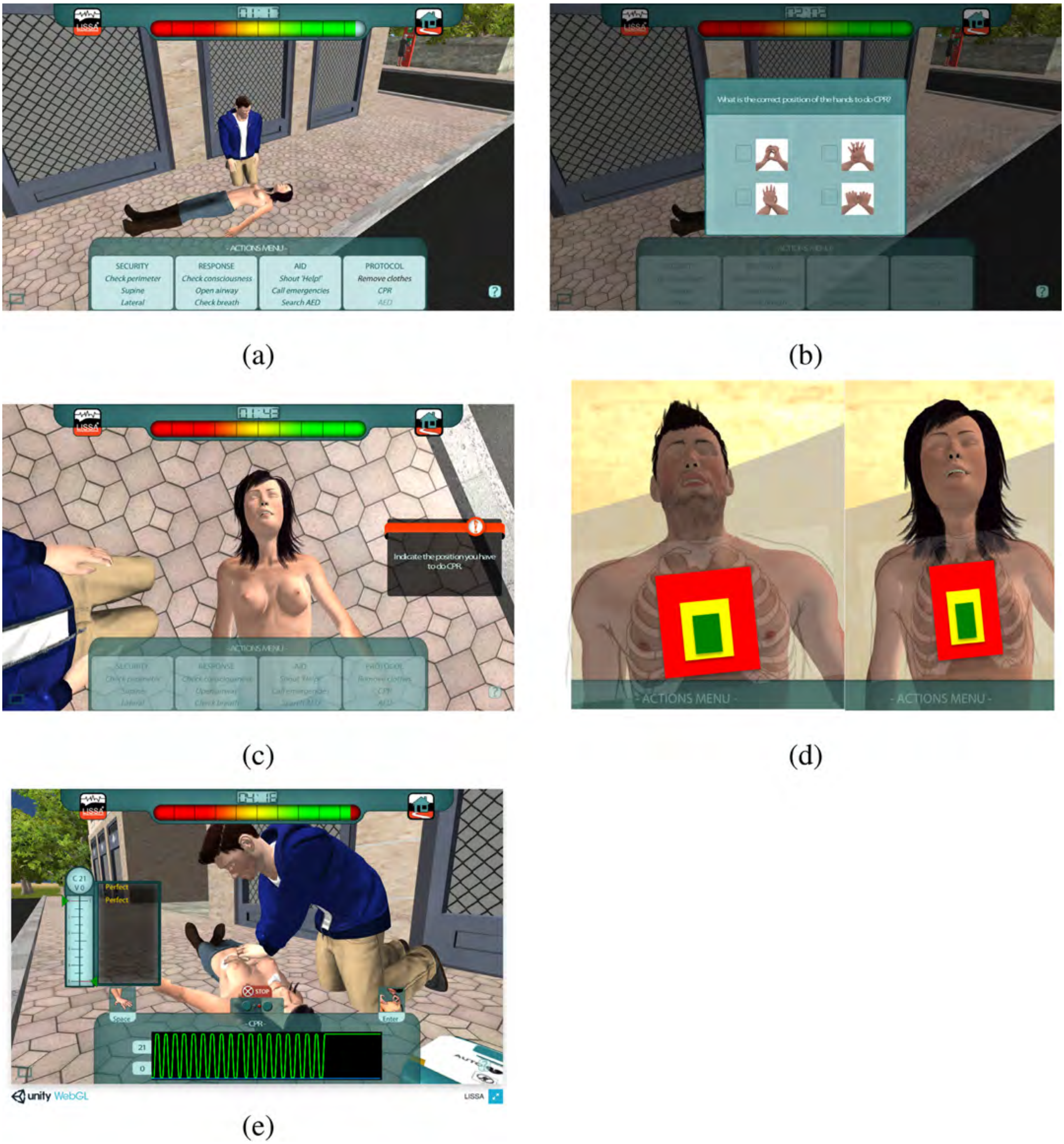


Fig. 3. LISSA interfaces related to CPR maneuver (a) after Remove Clothes action (b) menu to select hands position; (b) selection of thorax position to start CPR maneuver; (c) classification of compression position according to Dioszeghy et al. proposal [32]; and (d) Performance of CPR compressions and ventilations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of simulation-based educational interventions, as far as we know, none of them has focused on the effect of the victim's character gender on the students' performance.

In this paper, we have evaluated if the gender of a victim's character in a virtual environment designed to practice CPR influences the performance of student nurses. To carry out the experiment we used LISSA, a simulation scenario that presents a 3D emergency situation with a victim and a rescuer that has to apply the CPR protocol to rescue the victim. The student controls the rescuer's actions and LISSA registers student performance for posterior evaluation. We selected 41 undergraduate students from the Nursing Faculty of our university (14 males and 27 females). We assigned two cases to all the students. The first one with a male victim was used to make students familiar with LISSA. The second case, used for the

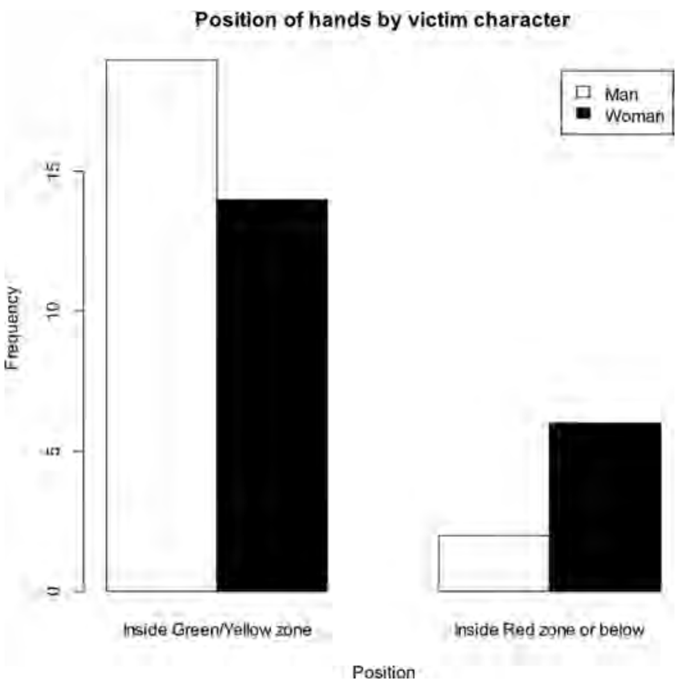


Fig. 4. Frequency of initial hand placement within the green and yellow zones and the red zone on male and female victims.

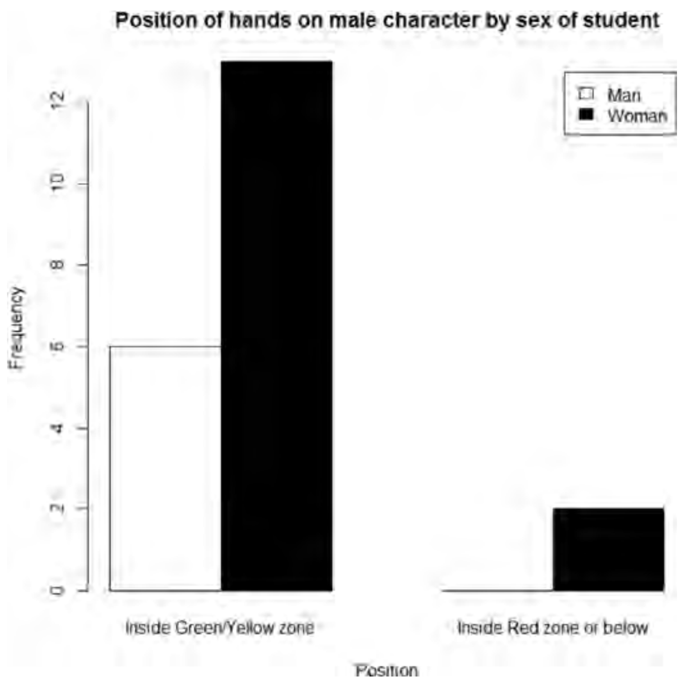


Fig. 6. Frequency of initial hand placement within the green and yellow zones and the red zone and beyond on female victim by sex of student.

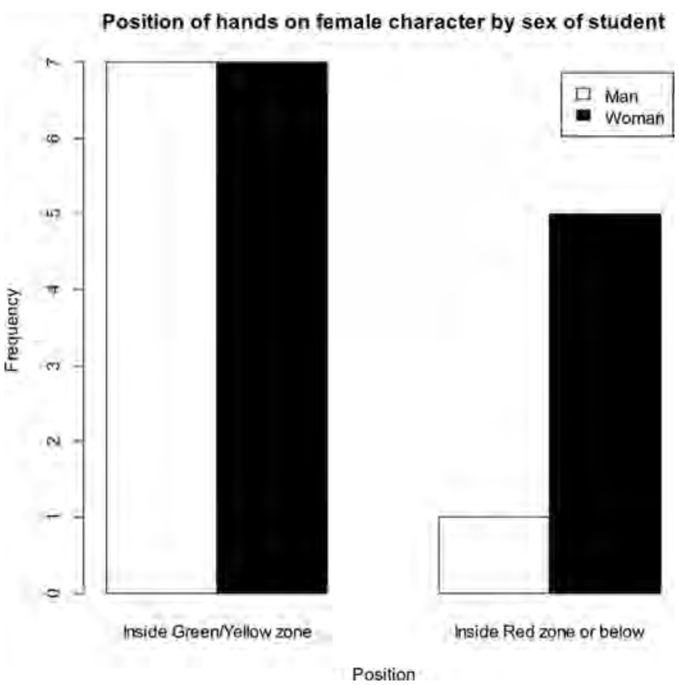


Fig. 5. Frequency of initial hand placement within the green and yellow zones and the red zone and beyond on man victim by sex of student.

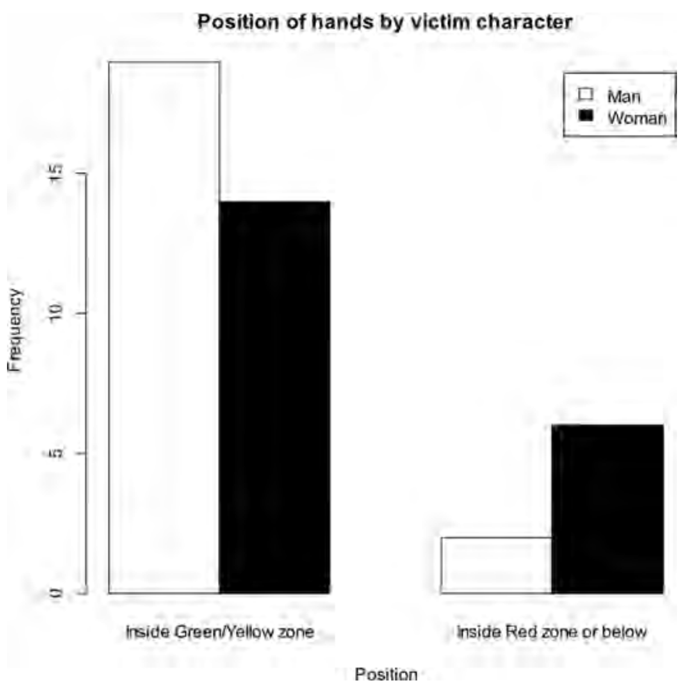


Fig. 7. Frequency of initial hand placement within the green and yellow zones and the red zone on male and female victims.

evaluation, has the same scene but with a male or a female victim. We randomly assigned this case to our population (8 men and 12 women have a female victim and 6 men and 15 women have a female victim). Focusing on this second case, we evaluated the time to remove the clothes of the victim, the time to place hands to start the CPR maneuver, and also the position of the hands. We statistically analyzed data considering student sex and also the sex of the victim. We did not find a statistical difference between men and women either on removal clothes time or time to perform CPR. The obtained results differ from the results obtained by Kramer et al. [23]. They experimented with a mannequin and detected that men and women were reluctant to remove the mannequin's female clothing. Although in our case the clothes removal is not as realistic as the mannequin case we consider that the obtained results are very satisfactory, since virtual environments can be seen as a tool to reduce differences across gender detected in other contexts. With respect to hand placement to perform CPR, we do not detect significant differences between men and women. In the study carried out by Kramer et al. [23] placement of participants' hands on the chest differed if the simulated patient was

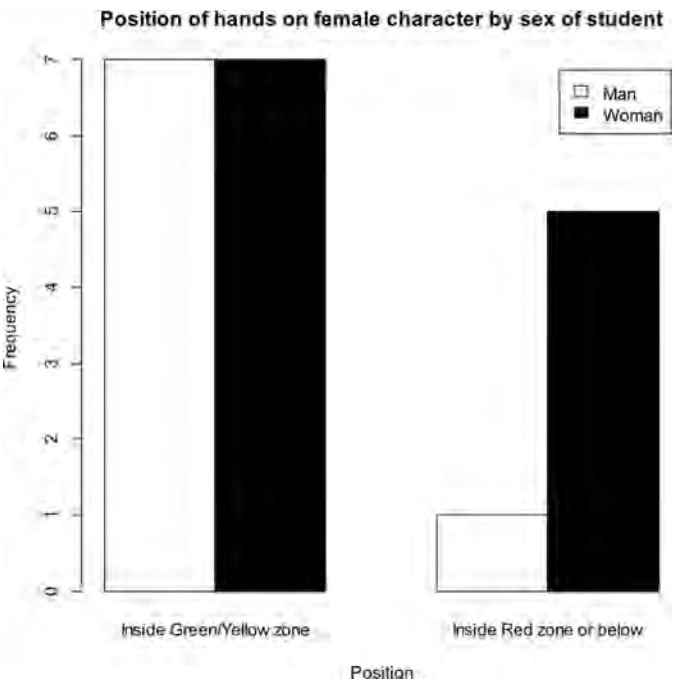


Fig. 8. Frequency of initial hand placement within the green and yellow zones and the red zone and beyond on man victim by sex of student.

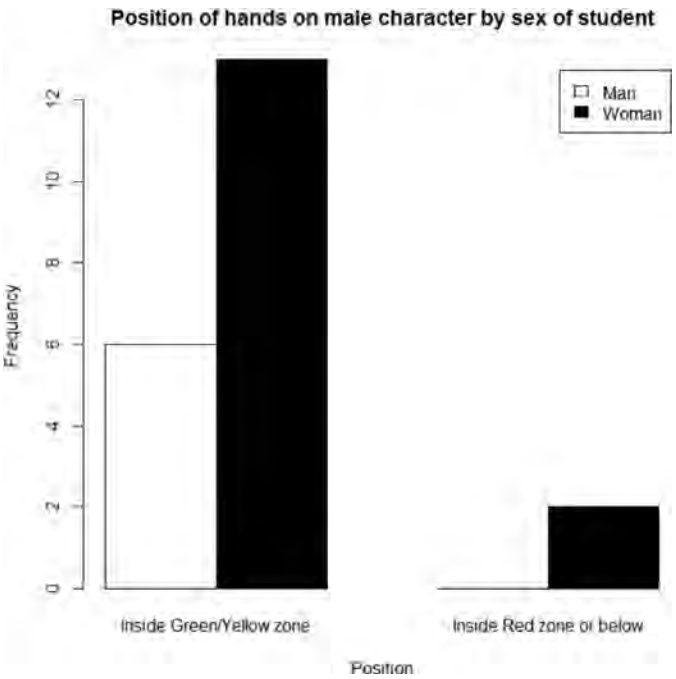


Fig. 9. Frequency of initial hand placement within the green and yellow zones and the red zone and beyond on female victim by sex of student.

a male or a female. In our case, almost 80% of the participants who performed CPR placed the hands inside the green and yellow zones. This result is better than the Kramer et al. where less than 50% of rescuers placed their hands correctly. To determine the causes of our better results will require a further study since many factors can contribute to this. On the one hand, we suppose that there is a predisposition of nursing students to perform CPR. Generally, these students have excellent knowledge about the importance and purpose of CPR [37]. Therefore, they should feel more confident when practicing CPR. On the other hand, the experimented sensations when working on a virtual scenario or with a mannequin should also have an impact on the results. Focusing on touch, for instance, the fact that practicing on a virtual scenario is less realistic than interacting with a mannequin could also influence the results. Participants do not directly touch the victim and maybe it is easy for them to perform the maneuvers leading to better results. However, all these assumptions require a new study to evaluate them. From our first results, we consider that virtual simulation scenarios are suitable environments to improve CPR skills and this can be taken into consideration when preparing CPR training courses. Moreover, according to Blewer et al. [13] who detected that male victims had an increased likelihood of receiving CPR compared to females in public locations, we consider that virtual scenarios can be used not only for student nurses but also for laypersons to introduce the protocol and also to reduce the reluctance to interact with female victims.

The advantages of simulation-based educational interventions include the ability to provide immediate feedback, repetitive practice learning, the integration of simulation into the curriculum, the ability to adjust the difficulty level, opportunities for individualized learning, and the adaptability to diverse types of learning strategies [38,39]. From our study, we can conclude that virtual scenarios should also be considered as a tool to reduce differences across gender.

5.1. Limitations and future research

In this study we focused our interest on nursing faculty students, which is a limiting factor due to the low number of men in our sample population. Unfortunately, this is a common fact in all Nursing Faculties [40]. To overcome this limitation, our idea is to extend the study to first aid courses carried out in hospitals, police or fire stations. Another limitation of our study is the *Remove Clothes* action implemented in our simulation environment. In the current version, once the user selects this option from the menu all the clothes are removed revealing the bare thorax of the victim. We consider that it would be more interesting to recreate the procedures to remove the clothes one by one, in this way we would evaluate if users remove all the clothes or not and the time to do this. Therefore, our next step will be the implementation and integration in the system of the clothes removal procedures. In addition, from our study we have also detected other issues that require specific studies such as the reproduction of the experiment with laypersons or the comparison of mannequin-based methodologies and virtual techniques considering female and male victims.

6. Conclusions

We have analyzed how the character gender of a victim in a simulation scenario created to practice CPR influences the performance of student nurses. Our results show that the sex of the victim character does not affect student performance when applying the CPR protocol. Our results recommend the use of virtual environments as a way to reduce differences across genders.

Conflict of interest

There are no conflicts of interests.

Acknowledgments

This work was supported by the Catalan Government (Grant No. 2017-SGR-1101) and by the Spanish Government (Grant No. TIN2016-75866-C3-3-R).

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cmpb.2018.05.019.

References

[1] D.M. Gaba, The future vision of simulation in health care, Qual. Safe Health Care 13 (1) (2004) i2–i10, doi:10.1136/qhc.13.suppl-1.i2.
[2] P. Baxter, N. Akhtar-Danesh, R. Valaitis, W. Stanyon, S. Sproul, Simulated experiences: nursing students share their perspectives, Nurse Educ. Today 29 (8) (2009) 859–866, doi:10.1016/j.nedt.2009.05.003.
[3] M.J. Shapiro, J.C. Morey, S.D. Small, V. Langford, C.J. Kaylor, L. Jagminas, Simulation based teamwork training for emergency department staff: does it improve clinical team performance when added to an existing didactic teamwork curriculum? Qual. Safe Health Care 13 (6) (2004) 417–421, doi:10.1136/qshc.2003.005447.
[4] D. Gaba, S.K. Howard, K. Fish, Simulation based training in anaesthesia crisis resource management: a decade of experience, Simul. Gaming 32 (2) (2001) 175–193, doi:10.1177/104687810103200206.
[5] T.P. Grantcharov, V.B. Kristiansen, J. Bendix, L. Bardram, J. Rosenberg, P. Funch-Jensen, Randomized clinical trial of virtual reality simulation for laparoscopic skills training, Br. J. Surg. 91 (2) (2004) 146–150, doi:10.1002/bjs.4407.
[6] A. Gupta, B. Peckler, D. Schoken, Introduction of hi-fidelity simulation techniques as an ideal teaching tool for upcoming emergency medicine and trauma residency programs in india, J. Emergency Trauma Shock 1 (1) (2008) 15–18, doi:10.4103/0974-2700.41787.
[7] S. Decker, S. Sportsman, L. Puetz, L. Billings, The evolution of simulation and its contribution to competency, J. Contin. Educ. Nurs. 39 (2) (2008) 74–80.
[8] Health Workforce Australia, Use of Simulated Learning Environments in Nursing Curricula, 2010.
[9] F. Ricciardi, L.T. De Paolis, A comprehensive review of serious games in health professions, Int. J. Comput. Games Technol. (2014), doi:10.1155/2014/787968.
[10] M. Graafland, J.M. Schraagen, M.P. Schijven, Systematic review of serious games for medical education and surgical skills training, Br. J. Surg. 99 (10) (2012) 1322–1330, doi:10.1002/bjs.8819.
[11] R.P. Cant, S.J. Cooper, Simulation in the internet age: the place of web-based simulation in nursing education. an integrative review, Nurse Educ. Today 34 (12) (2014) 1435–1442, doi:10.1016/j.nedt.2014.08.001.
[12] D. Eisenberg, H. Meischke, I. Painter, T.D. Rea, Should dispatchers instruct lay bystanders to undress patients before performing CPR? A randomized simulation study, Resuscitation 84 (7) (2013) 979–981, doi:10.1016/j.resuscitation.2012.12.010.
[13] A.L. Blewer, S.K. McGovern, R. Schmicker, L.J. Morrison, S. May, T.P. Aufderheide, M. Daya, A.H. Idris, C.W. Callaway, P.J. Kudenchuk, G.M. Vilke, B.S. Abella, Gender disparities among patients receiving bystander cardiopulmonary resuscitation in the United States circulation, 2017, 136:A16409.
[14] E. Boyle, T.M. Connolly, T. Hainey, The role of psychology in understanding the impact of computer games, Entertain. Comput. 2 (2) (2011) 69–74, doi:10.1016/j.entcom.2010.12.002.
[15] B. Beasley, T.C. Standley, Shirts vs. skins: clothing as an indicator of gender role stereotyping in video games, Mass Commun. Soc. 5 (2002) 279–293, doi:10.1207/S15327825MCS0503-3.
[16] K.E. Dill, The Oxford Handbook of Media Psychology, 2014. ISBN 9780195398809, doi:10.1093/oxfordhb/9780195398809.001.0001. Chapter 15
[17] J.G. Wigginton, S.M. Perman, G.C. Barr, A.J. McGregor, A.C. Miller, A.F. Napoli, B. Safdar, K.R. Weaver, S. Deutsch, T. Kayea, L. Becker, Sex and gender specific research priorities in cardiovascular resuscitation:, in: Proceedings from the 2014 Academic Emergency Medicine Consensus Conference, 21(12), 2014, pp. 1343–1349, doi:10.1111/acem.12541.
[18] K. Sipsma, B.A. Stubbs, M. Plorde, Training rates and willingness to perform CPR in king county, washington: a community survey, Resuscitation 82 (5) (2011) 564–567, doi:10.1016/j.resuscitation.2010.12.007.
[19] A. Axelsson, A. Thoren, S. Holmberg, J. Herlitz, Attitudes of trained swedish lay rescuers toward CPR performance in an emergency. a survey of 1012 recently trained CPR rescuers, Resuscitation 44 (1) (2000) 27–36.
[20] A. Ashton, A. McCluskey, C.L. Gwinnutt, A.M. Keenan, Effect of rescuer fatigue on performance of continuous external chest compressions over 3 min, Resuscitation 55 (2) (2002) 151–155.
[21] M.A. Peberdy, A. Silver, J.P. Ornato, Effect of caregiver gender, age, and feedback prompts on chest compression rate and depth, Resuscitation 80 (2009) 1169–1174, doi:10.1016/j.resuscitation.2009.07.003.
[22] T. Kitamura, T. Iwami, G. Nichol, T. Nishiuchi, Y. Hayashi, C. Nishiyama, T. Sakai, K. Kajino, A. Hiraide, H. Ikeuchi, H. Nonogi, T. Kawamura, Reduction in incidence and fatality of out-of-hospital cardiac arrest in females of the reproductive age, Eur. Heart J. 31 (2010) 1365–1372.
[23] C.E. Kramer, M.S. Wilkins, J.M. Davies, J.K. Caird, G.M. Hallihan, Does the sex of a simulated patient affect CPR? Resuscitation 86 (2015) 82–87, doi:10.1016/j.resuscitation.2014.10.016.
[24] M. Ponder, B. Herbelin, T. Molet, S. Scherteneib, B. Ulicny, G. Papagiannakis, N. Magnenat-Thalmann, D. Thalmann, Interactive scenario immersion: health emergency decision training in just project, in: International Workshop on Virtual Reality Rehabilitation, 2002, pp. 87–101.
[25] Laerdal Medical, Microsim prehospital, 2012, http://www.laerdal.com/gb/docid/12984879/MicroSimPrehospital.
[26] Ilumens, 2011, StayingAlive3D. http://www.stayingalive.fr/index?uk.html.
[27] V. Wattanasoontorn, I. Boada, M. Sbert, LISSA: A serious game to learn cardiopulmonary resuscitation, Resuscitation 85 (S1) (2014) S72, doi:10.1016/j.resuscitation.2014.03.182.
[28] F. Sameraro, A. Frisoli, G. Ristagno, C. Loconsole, L. Marchetti, A. Scapigliati, T. Pellis, N. Grieco, E. L. Cerchiari, Relive: a serious game to learn how to save lives, Resuscitation 85 (7) (2014) e109–10, doi:10.1016/j.resuscitation.2014.03.306.
[29] Viva!Game http://www.viva2013.it/viva-game.
[30] B. Schmitz, R. Klemke, J. Walhout, M. Specht, Attuning a mobile simulation game for school children using a design- based research approach, Comput. Educ. 81 (2015) 35–48, doi:10.1016/j.compedu.2014.09.001.
[31] I. Boada, A. Rodriguez, J.M. Garcia, J. Olivet, V. Carreras, M. Sbert, Using a serious game to complement CPR instruction in a nurse faculty, Comput. Methods Programs Biomed. 122 (2) (2015) 282–291, doi:10.1016/j.cmpb.2015.08.006.
[32] C. Dioszeghy, D. Kissa, G. Frituzb, G. Szekelya, G. Elob, Comparison of effects of different hand positions during cardiopulmonary resuscitation, Resuscitation 66 (3) (2005) 297–301, doi:10.1016/j.resuscitation.2005.03.010.
[33] M. Broom, M. Lynch, W. Preece, Using online simulation in child health nurse education, Paediatr. Nurs. 21 (8) (2009) 32–36, doi:10.7748/paed.21.8.32.s26.
[34] E. Codier, E, A. Holt, Virtual clinical rounds in a multi-user virtual environment (MUVE), J. Nurs. Educ. 51 (10) (2012) 595–596, doi:10.3928/01484834-20120920-02.
[35] J.F. Giddens, G. Shuste, N. Roehrig, Early student outcomes associated with a virtual community for learning, J. Nurs. Educ. 49 (6) (2010) 355–358, doi:10.3928/01484834-20100217-03.
[36] C. Kilmon, L. Brown, S. Ghosh, A. Mikitiuk, Immersive virtual reality simulations in nursing education, Nurs. Educ. Perspect. 31 (5) (2010) 314–317.
[37] M. Vural, M.F. Kosar, O. Kerimoglu, F. Kizkapan, S. Kahyaoglu, S. Tugrul, H. B. Isleyen, Cardiopulmonary resuscitation knowledge among nursing students: a questionnaire study, Anatolian J. Cardiol. 17 (2) (2017) 140–145, doi:10.14744/AnatolJCardiol.2016.7156.
[38] S.B. Issenberg, W.C. McGaghie, E.R. Petrusa, D.L. Gordon, R.J. Scalese, Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review, Med. Teach. 27 (2005) 10–28, doi:10.1080/01421590500046924.
[39] K. Junghee, P. Jin-Hwa, S. Shin, Effectiveness of simulation-based nursing education depending on fidelity: a meta-analysis, BMC Med. Educ. 16 (2016) 152, doi:10.1186/s12909-016-0672-7.
[40] R.J. Meadus, J.C. Twomey, Men student nurses: the nursing education experience, Nurse Forum 46 (4) (2011), doi:10.1111/j.1744-6198.2011.00239.x.

Chapter 4

30:2, A Game Designed to Promote the Cardiopulmonary Resuscitation Protocol

---

In the context of the second goal of the thesis focused on the use of serious games to improve first-aid teaching, in this chapter, a video game designed to disseminate and promote cardiopulmonary resuscitation (CPR) protocol to non-experts is presented. The game is composed of different mini-games representing the main steps of the CPR protocol. A detailed description of all these mini-games as well as the tests that have been carried out are given.

30:2 a Game Designed to Promote the Cardiopulmonary Resuscitation Protocol, Imma Boada,Antonio Rodriguez-Benitez, Juan Manuel Garcia-Gonzalez, Santiago Thió-Henestrosa, and Mateu Sbert, International Journal of Computer Games Technology, 2016 ISSN: 1687-7047. Scopus-Computer Graphics and Computer-Aided Design , position: 24/64-IF:1,54.

Hindawi Publishing Corporation
International Journal of Computer Games Technology
Volume 2016, Article ID 8251461, 14 pages
http://dx.doi.org/10.1155/2016/8251461

Research Article

30 : 2: A Game Designed to Promote the Cardiopulmonary Resuscitation Protocol

Imma Boada,[1] Antonio Rodriguez-Benitez,[1] Juan Manuel Garcia-Gonzalez,[1] Santiago Thió-Henestrosa,[2] and Mateu Sbert[1,3]

[1]*Graphics and Imaging Laboratory, University of Girona, 17071 Girona, Spain*
[2]*Departament Informatica, Matemàtica Aplicada i Estadística, University of Girona, 17071 Girona, Spain*
[3]*School of Computer Science and Technology, Tianjin University, Tianjin 300072, China*

Correspondence should be addressed to Imma Boada; imma.boada@udg.edu

Received 8 January 2016; Accepted 11 April 2016

Academic Editor: Michela Mortara

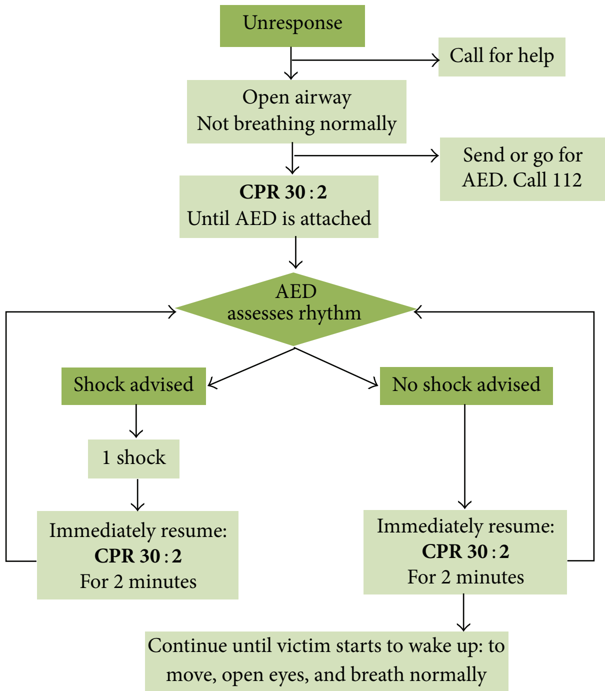
Cardiopulmonary resuscitation (CPR) is a first-aid key survival technique used to stimulate breathing and keep blood flowing to the heart. Its effective administration can significantly increase the survival chances of cardiac arrest victims. We propose 30 : 2, a videogame designed to introduce the main steps of the CPR protocol. It is not intended for certification and training purpose. Driven by the 2010 European Resuscitation Council guidelines we have designed a game composed of eight mini games corresponding to the main steps of the protocol. The player acts as a helper and has to solve a different challenge. We present a detailed description of the game creation process presenting the requirements, the design decisions, and the implementation details. In addition, we present some first impressions of our testing users (25 children, five of each age from 8 to 12 years old and 12 males and 13 females). We evaluated clarity of instructions and three settings of the game: the aesthetics of scenarios, the playability, and the enjoyability of each mini game. All games were well punctuated, and there are no significantly differences between their sex. The proposed game can be a suitable tool to disseminate and promote CPR knowledge.

1. Introduction

In the last years, computer-based learning has emerged as an effective tool to promote learning and develop cognitive skills [1]. This approach combines serious learning with interactive entertainment providing many benefits in terms of learning and motivation [2–5]. According to Kebritchi and Hirumi [6], there are five main reasons for the effectiveness of computer-based learning: first, it uses action instead of explanation; second, it creates personal motivation and satisfaction; third, it accommodates multiple learning styles and skills; fourth, it reinforces mastery of skills; and fifth, it provides an interactive and decision-making context. In addition, computer games provide other benefits such as complex and diverse approaches to learning processes and outcomes, interactivity, ability to address cognitive as well as affective learning issues, and motivation for learning [7]. If we consider all these benefits and also that there is an extended use of portable gaming platforms among young people, we can conclude that computer-based games are a perfect channel to promote learning contents [8, 9]. In this context, we propose 30 : 2, a computer game designed to promote the cardiopulmonary resuscitation protocol among citizens and especially among children. The game is not intended for certification and training purpose but to increase awareness and improve knowledge about cardiopulmonary resuscitation.

Cardiopulmonary resuscitation (CPR) is an emergency lifesaving procedure that is done when someone's breathing or heartbeat has stopped. The procedure combines rescue breathing, to provide oxygen to the lungs, and chest compressions to keep oxygen-rich blood flowing until the heartbeat and breathing can be restored. Permanent brain damage or death can occur within minutes if blood flow stops. However, immediate CPR can double or triple survival rates and, CPR plus defibrillation within 3 to 5 minutes of collapse, can produce survival rates as high as 49 to 75% [10–14].

Since 1960, when Kouwenhoven et al. [15] published an article stating that anyone, anywhere, could perform CPR, providing CPR has become an essential competency not only for expert but also for lay people. Different organizations, such as the European Resuscitation Council (ERC) [14], the Red Cross, and the American Heart Association [16], have defined guidelines that describe how resuscitation should be undertaken both safely and effectively. In addition, many countries have initiated CPR programmes to train lay rescuers in CPR and several strategies have been used to teach it including mass training [17], or video self-instruction [18], among others. Unfortunately, the rate of bystander CPR at cardiac arrest is still very low, less than 20% [19]. There is a lack of awareness of the availability of CPR training for the public and lack of interest [20]. Therefore, any proposal that enhance CPR dissemination and promotion will be welcome. With this idea in mind, we created 30 : 2 a computer game designed to introduce, in an enjoyable way, the main steps of the CPR protocol to children and lay people. The game is composed of eight mini games corresponding to the main steps of the CPR protocol proposed by the ERC 2010 [14]. Each mini game presents a different challenge and different levels of difficulty to maintain the attention of the player. The game name, 30 : 2, comes from the key step of the CPR protocol that performs 30 compressions and 2 ventilations.



Figur e 1: Automated external defibrillator algorithm according to 2010 ERC guidelines.

2. Related Work

In this section, we briefly describe the CPR protocol which is the basis of our game. Then, we review different applications that have been proposed to learn this protocol and some of the studies that have been carried out to promote it among nonexpert audience.

2.1. The Basic Life Support Protocol. The basic life support protocol defines the procedures that have to be carried out when a victim of a cardiac arrest is found. We will follow the protocol defined by the ERC 2010 [14] and represented in Figure 1. According to this protocol we have to proceed as follows. (1) Check the perimeter to make sure the situation is safe. (2) Check the victim for a response by gently shaking his shoulders and asking loudly if he is all right. (3a) If the victim responds, leave him in the position in which you found him ensuring there is no further danger; try to find out what is wrong with him/her and get help if needed. (3b) If he victim does not respond, shout for help, turn the victim onto his back, and then, open the airway placing your hand on his forehead and gently tilt his head back with your fingertips under the point of the victim's chin; lift the chin to open the airway. (4) Keeping the airway open, look, listen, and feel for breathing. (5a) If he is breathing normally, turn him into the recovery position. Send or go for help (call 112or local emergency number for an ambulance) and continue to assess that breathing remains normal. (5b) If the breathing is not normal or absent, send someone for help and to find and bring an automatic external defibrillator (AED) if available; or if you are on your own, use your mobile phone to alert the ambulance service. Leave the victim only when there is no other option. (6) Start chest compression and rescue breaths in a ratio of 30 : 2. To perform compressions, you must place your hands vertically above the victim's chest and press down on the sternum. Pressure depth has to be between 5 and 6 cm and at a rate of at least 100 compressions per minute, but not exceeding 120. After 30 compressions open the airway again and perform two rescue breaths, blowing steadily into the mouth while watching for the chest to rise, taking about 1 second as in normal breathing. Continue with chest compressions and rescue breathes, in a ratio of 30 : 2, and stop to recheck the victim only if he starts to wake up: to move, open eyes, and breathe normally. Otherwise, do not interrupt resuscitation. (7) If the victim recovers, put him in the lateral security position.

2.2. State of the Art on CPR Applications. Different methods have been proposed to teach CPR. Below we describe some of them (see Table 1 for a summary).

On the one hand, there are video training applications such as Save-a-Life simulator [21], an interactive online video simulation that tests the player knowledge of helping someone suffering from sudden cardiac arrest, and CPR-and-Choking [22], an application that provides instant information on how to perform CPR and how to aid a choking victim. On the other hand, there are handheld device applications such as CPR Game [23], a cardiac arrest simulator on iOS platform focused on advanced CPR training; iResus [24], an application for smart phone, designed to improve

Table 1: Some of the proposed applications to introduce CPR or some of the steps of the protocol.

Application type	
Video training	Save-a-Life simulator [21],CPR-and-Choking [22]
Handheld device	CPR Game [23], iResus [24], iCPR [25, 26], M-AID [27], CPR simulator [21],and LifeSaver [28]
PC platform	Mini-VREM [29], AED Challenge [30]
Serious games	JUST [31],MicroSim [32], Staying Alive [33], LISSA [34], Relive [35], Viva!Game [36], and HeartRun [37]

the performance of an advanced life support provider in a simulated emergency situation; iCPR [25, 26], an iPhone application designed for both lay persons and healthcare professionals able to detect the rate of chest compressions performance by using the built-in accelerometer; M-AID [27], a first-aid application for mobile phones that uses yes or no questions to judge an ongoing situation giving to the user detailed instructions of how to proceed; CPR simulator [21],a set of CPR exercises including adult, child, and infant CPR simulator that runs through the CPR sequence; and LifeSaver [28] a simulator proposed by the UK Resuscitation Council that fuses interactivity with live-action film. In addition, some applications for PC platforms are Mini-Virtual Reality Enhanced Mannequin (Mini-VREM) [29] which is a CPR feedback device with motion detection technology including Kinect, sensor and software specifically designed to analyse chest compression performance and provide real-time feedback in a simulation training setting; and AED Challenge [30], an application that provides online automated external defibrillation and CPR skill practice and testing with realistic scenarios. Finally, in the serious games context, some games for CPR training are JUST [31],an immersive virtual reality situation training system for nonprofessional health emergency operators; MicroSim Prehospital [32] designed for prehospital training on emergency medical services; and Staying Alive [33], an online 3D simulator which provides a learning experience of saving a virtual patient from cardiac arrest in four minutes. LISSA [34] is a serious game with actions turning around an emergency situation represented in a 3D virtual environment with the victim, the helper, and all the auxiliary tools that may require the emergency. The player has to save the victim applying the CPR actions that are evaluated and used to update the game score. When game is over LISSA returns a performance report. This game is used to complement CPR teaching. Other serious games are Relive [35], a first person 3D adventure where the player faces different rescue situations and can test the quality of his CPR directly; Viva!Game [36], a Web-based serious game designed to create awareness on cardiac arrest and cardiopulmonary resuscitation; and HeartRun [37], a mobile simulation game to train resuscitation and targeted at giving school children an understanding of CPR and getting them to take action.

Focusing on the audience, different experiences have been carried out to introduce CPR among children. Uray et al. evaluated the feasibility of life supporting first-aid training as a mandatory subject for 6-7-year-old children of primary schools [38]. They stated that resuscitation skills should be learnt at school, since children are easily motivated, learn quickly, and retain skills [39]. Jones et al. indicated that children of 9 years should be taught to perform CPR, including chest compressions [40]. In addition, the good results obtained in different experiences that have been carried out all over the world have motivated associations such as the ERC, the American Heart Association, and the American Academy of Pediatrics to recommend teaching resuscitation to school children [41–43].

From previous experiences, it makes sense to consider the development of a new game to introduce the CPR protocol to children. In addition, considering the current state of the art, we have seen that most of reported methods are based on multimedia approaches where video, text, and audio are combined to reproduce in a practical case the CPR protocol. In some cases, users can also interact by answering questions that drive them to the correct sequence of the protocol. A similar approach is followed in the case of serious games where instead of real actors they use avatars. Finally other applications just focus on the CPR maneuver. In our case, we propose a different approach to engage children attention on CPR. The axis of our game is also the CPR protocol but we consider the protocol steps independently. For each step, we create a mini game with a challenge that helps the user to retain the key procedure of the step, with enough variety of challenges to maintain the attention of the player and avoid boring him doing the same action for a long time.

3. Game Description

To describe the 30 : 2 videogame, we are going to follow the educational game development approach (EGDA) proposed by Torrente et al. [44]. This approach covers all tasks from game design to implementation and evaluation. It is built around four basic principles. The first is a procedure-centric approach that gives importance to capturing the procedural knowledge of the domain. In our case, this knowledge is provided by the ERC protocol that determines the steps that have to be carried out in case of sudden heart attack (see Section 2.1).The second is the collaboration between experts. In our case, the development team works in close collaboration with physicians specialized in cardiopulmonary resuscitation. The third is the agile development with agile tools. In our case, we apply an iterative process that includes analysis, game design, implementation, and quality assurance. The fourth is the low-cost game model. In our case, due to budget restriction our proposal considers 2D animations instead of 3D realistic models that require a much bigger budget. Below, we give a more detailed description of the main steps of the development process.

3.1. Analysis. The analysis phase was done in collaboration with experts on CPR that are in charge of CPR instruction

Figur e 2: The steps of the basic life support protocol that have been selected to define the proposed game. We will create one mini game per selected step.

at our university and also at middle schools. For the school courses, they present the ERC guidelines to children, using the material provided by the ERC, and they also use a mannequin to practice. The purpose of the courses is to make children familiar with CPR concepts. The 30 : 2 game was conceived as a complement to these classes and as a way to preserve the acquired CPR knowledge. With this idea in mind, to delineate the objectives of our game, we considered the ERC guidelines presented in Section 2.1 and, assessed by the experts, we identified the steps and the key procedures of the protocol to be considered. The selected steps are represented in Figure 2 and correspond to the main case of the protocol in which the victim requires the CPR maneuver. We do not take into account the situations described in step (3a) or (5a).

The pedagogical approach used to design the game is based on the experiential learning theory, where educators aim engaging learners in direct experience to increase their knowledge, skills, and values [45]. Experience occurs as a result of interaction between human beings and an environment in forms of thinking, seeing, feeling, handling, and doing [45]. In our case, this experience is going to take place in an artificial environment where a victim has to be recovered from a heart attack by applying the CPR protocol. There are five instructional strategies rooted in the concept of learning through experiences. These are learning by doing, experiential, guided experiential, case-method teaching, and combination of experiential and inquiry-based learning [6]. In our case, we considered the learning by doing strategy. Schank et al. [46] posited seven instructional events to facilitate this experience. In the analysis phase, we defined these instructional events as follows:

(1) Goals definition: our objective is to introduce the main steps of the CPR protocol to the children. With this purpose we decided to create eight mini games, one for each CPR step.

(2) Mission: the mission is to save a heart attack victim by correctly applying the CPR steps. This mission is decomposed in eight submissions one for each CPR step.

(3) Cover story: there is a heart attack victim in a park and the player has to save him. We decided to create a common scenario for all the mini games and we adapted it to each mini game's requirements.

(4) Roles: the player who acts as a rescuer.

(5) Operation scenarios: all mini games take place in a park; we will provide different views of the park depending on the actions to be carried out.

(6) Provided resources: each mini game has a different challenge. Provided resources will be adapted to it. Game instructions will be given using the keywords of the protocol steps.

(7) Provided feedback: when the challenge is achieved a well done message will appear as well as the keywords of the protocol step.

In addition, we will support different levels of difficulty to keep a high level of engagement. We will support two playing modes. In the first mode, the player will play mini games individually, one by one to reach the maximum level of each mini game. In the second mode, the player will follow the complete sequence of mini games at the same level to see the whole protocol each time. For the CPR courses, we consider that the second mode is the most suitable. To increase the chance to perform the whole CPR process, we give five lives to the player, represented as hearts. In this way if the player fails in one step he has the chance to repeat it. Having several lives, we consider that players engagement in the game will increase as well as, in turn, their intrinsic motivation [47, 48]. In addition, we also use written positive feedback to increase feelings of competence and autonomy, which in turn lead to increased motivation [49].

3.2. Game Design. To design the game, we considered that the player acquires the role of a helper who has to save the victim of a cardiac arrest by applying the main steps of the CPR protocol. To guide the player between mini games at the beginning of each one we present the instructions of the step protocol as highlighted keywords, with the goal that the player could retain them easily. In addition, at the end of the mini game, we show the obtained score and the achieved steps. The player has five lives represented as five hearts. To solve the mini game challenge we have a predefined time that is defined according to the level of difficulty. Below we describe the different mini games. For each mini game, we will describe its pedagogical objective which is related with some procedure of the protocol, the scenario, the challenge, the interaction required to achieve the challenge, how we create the different levels of difficulty, and the messages with keywords.

3.2.1. Mini Game 1 (Isolate Victim). This mini game is related with step (1) of the protocol. Its pedagogical objective is to transmit to the player that when there is a victim the helper has to check the perimeter to make sure the situation is safe. We designed a game where the main scene is a park with a lot of people. People are represented as hearts of different colours and the victim as a broken heart. All hearts are on movement and the player has to press on the broken heart. Then, it will appear a security perimeter represented as a circle around the victim. The player has to move hearts out from the perimeter to isolate the victim. In this case, the player interacts by pressing on the broken heart and dragging and dropping on the hearts inside the security position. To create the different levels of difficulty we increase the number of hearts and also the used colours. At the beginning, all hearts have the same colour and then, as level of difficulty increases, new colours are added. In addition, time will be adapted to the level, allotted time decreases when difficulty level increases.

The text that appears in the game corresponds to keywords of the represented step. Before starting the game, a screen appears with the current score, the level of difficulty, and the game instructions. In this case, the text is *find and isolate the victim*. Once the game starts, the message *find the victim* and *isolate it* appears. At the end, the message *victim is in a secure position* appears.

3.2.2. Mini Game 2 (Check Conscious). This mini game is related with step (2) of the protocol. Its pedagogical objective is to transmit that to check the victim conscious; the helper has to shake his shoulder and ask if he is all right. We designed a game where the scene is a frontal view of the victim with the helper hand on the victim shoulder. In addition, there are glyphs with a question mark on the screen. These are of different colours and shapes; some icons add points and others subtract. Each time we click on a correct glyph, the hand will move victim shoulder to simulate the shaking procedure. The player has to achieve as much points as possible by pressing the correct glyphs. In this case, the player interacts by pressing on the correct icons. The levels of difficulty are related with the number of glyphs that appear and also their speed; the greater the difficulty, the greater the number of glyphs and speed. In addition, playing time will be adapted to the level; allotted time decreases when difficulty level increases.

As in the previous mini game the text that appears in the game corresponds to keywords of the represented step. Before starting the game, a screen appears with the current score, the level of difficulty, and the game instructions which are *check victim's response*. Once the game starts the message *press blue and yellow glyphs* appears. In the middle of the game the message *are you all right* appears and at the end, the message *victim is unconscious* appears.

3.2.3. Mini Game 3 (Ask for Help). This mini game is related with the first part of step (3b) of the protocol. Its pedagogical objective is to transmit that if the victim is not conscious, the helper has to shout for help. We designed a game where the scene represents a helper beside the victim. The helper has a speech balloon that has to be completed with the word *help*. Glyphs with letters fall down from the top of the screen and the player has to select the letters to write help. If letters are not selected in the correct order, he has to start again. The player has to complete the *help* word in the available time. In this case, the player interacts by pressing on the glyphs with the correct letters. The levels of difficulty are related with the falling speed of icon letters. In addition, time will be adapted to the level; allotted time decreases when difficulty level increases.

Again the text that appears in the game corresponds to keywords of the represented step. Before starting the game, a screen appears with the current score, the level of difficulty, and the game instructions which are *Ask for Help*. When the game starts the text *press the correct letters* appears as well as, at the end, *well done! Help is on the way!*

3.2.4. Mini Game 4 (Check Breath). This mini game is related with the first part of step (3b) and step (4) of the protocol. Its pedagogical objective is to transmit that if the victim is not conscious, in order to check breath the helper has to perform the tilt and chin lift by correctly placing hands on the head and move the victim's head back to open air way. Then, look at the thorax to see if it is moving and, finally, listen if the victim is breathing. We designed a game with the victim lying on the floor. We have a lateral view of his body and different glyphs representing right and left hands, ears, and eyes that will appear on the screen. The player has to select the hands and drop them to the correct head position to perform the tilt and chin lift. Then, place an eye glyph on the thorax and the ear near the victim's face. In this case, the player interacts by pressing on the glyph and dragging it to the correct position. The levels of difficulty are related with the number of glyphs and their speed. In addition, time will be adapted to the level; allotted time decreases when difficulty level increases.

The message that appears before starting the game is *check breath by performing tilt-chin maneuver*; *look at the thorax and listen respiration*. Once the game starts the messages *drag hands to correct positions* and *place eye on the thorax and ear on the face* appear. The final message is *victim is not breathing*.

3.2.5. Mini Game 5 (Call Emergency). This mini game is related with step (5b) of the protocol. Its pedagogical objective is to transmit that if the victim is not breathing, the helper has to call emergency number and ask for a defibrillator. We designed a game where the scene represents the front face of a mobile showing the numbers and the screen to see the dialed numbers. The player has to dial the correct emergency number in the available time. In this case, the player interacts by pressing on the phone numbers. To obtain different levels of difficulty the phone numbers change their position. In addition, time will be adapted to the level; allotted time decreases when difficulty level increases.

The message that appears before starting the game is *call emergency and ask for a defibrillator*. Once the game starts the message *call emergency* appears as well as, at the end, *well done! Emergency is on the way*.

3.2.6. Mini Game 6 (Remove Clothes). This mini game is related with step (6) of the protocol. Its pedagogical objective is to transmit that we need to uncover the thorax of the victim to perform the CPR maneuver. We designed a game where the scene represents a front plane of the victim with different layers of clothes (a scarf, a jacket, a shirt, etc.). The player has to remove, in the available time, all the clothes until thorax is uncovered. In this case, the player interacts by pressing on the screen following the shape of the scarf and the zip or pressing on the buttons. The levels of difficulty are related with the layers of clothes, which increase with the level of difficulty. In addition, allotted time will be adapted to the level; allotted time decreases when difficulty level increases.

The message that appears at the beginning is *remove clothes to uncover thorax*. Once the game starts, the message *remove clothes appropriately* appears as well as, at the end, *well done! Thorax uncovered*.

3.2.7. Mini Game 7 (Perform CPR). This mini game is related with step (6) of the protocol. Its pedagogical objective is to show the key maneuver of the CPR protocol. The player should learn how to place hands position and where, the rhythm, and the number of compressions that has to be done. In addition, he has to learn that after compressions he has to perform two rescue breaths in a ratio of 30 : 2. Moreover, he has to learn that compressions are at least of 5 cm. We designed a game with a set of icons to select correct hand positions and placement. In addition, there is a central menu with two icons one for compressions and the other for ventilations, an indicator to show compression depth and another to indicate ventilation degree. This menu has a central board to indicate if maneuver is correct or not. The four considered degrees of correctness are critic, bad, good, and perfect. The player has to perform compressions and ventilations correctly. The player interacts pressing on the correct icons. In this case, the levels of difficulty are related with the accuracy at which CPR maneuver is performed.

The message that appears at the beginning is *perform CPR maneuver*. Once the game starts, the messages that appear are *select correct hands position*, *perform 30 : 2,* and *put defibrillator patches*. At the end, the final message is *well done! The victim has recovered.*

3.2.8. Mini Game 8 (Security Position). This mini game is related with the last step of the CPR protocol. Its pedagogical objective is to show the movements that have to be done to place the victim in the lateral security position. In this position, the mouth is downward so that fluid can drain from the patient's airway; the chin is well up to keep the epiglottis opened. Arms and legs are locked to stabilize the position of the patient. We designed a game where the scene represents a lateral view of the victim. The player has to press on the correct parts of the body and perform the correct movements to place the victim in the security position. The player interacts by pressing on the correct part of the victim's body and dragging it to the correct position. In this case, the levels of difficult are related with the available time which decreases when difficulty level increases.

The message that appears at the beginning is *place the victim in the lateral security position.* Once the game starts the message that appears is *press on the body parts and move* and at the end *well done! Victim is in lateral security position*.

3.3. Implementation. To implement the game we used Unity3D, a cross-platform game engine, that can support Mac OSX and WindowsXP/Vista/7/8. It supports three scripting languages: JavaScript, C#, and a dialect of Python called Boo. All three are equally fast and interoperate, and can use the underlying. NET libraries support databases, regular expressions, XML, file access, and networking. Although scripting is frequently considered as limited and slow, in Unity3D scripts are compiled to native code and run nearly as fast as C++. In the project, all the game scripts have been programmed in C#.

The proposed game has been programmed as a finite state machine, where each state can contain different state machines. We used a generic home-implemented state machine library to implement the game flow. This library allows the definition of each state machine, the states that compose it, the actions each state will perform, and its transitions, in a very detailed way. The library only needs

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

Figure 3: Game screens corresponding to (a) the main page and the menus to select (b) the playing mode, (c) the mini game, and (d) the difficulty level.

the user to define what a particular element requires: (i) for each state machine, we have to define the first state to be executed; (ii) for each action, we define the actual action that it will perform; (iii) for each transition, we define the condition for the transition and the next state to which it will move if condition is true (this allows the reutilization of transitions if the condition and destination match); and (iv) in each state, we define the list of actions that it will perform, the substate machines it contains (if any), the transitions it has, and if it is a final state. All the implementation references are generic and are checked during compilation. In this way, we ensure that all references are correct and avoid the continuous errors search. In addition, since elements are not instantiated until they are needed, performance increases considerably. The library also contains a static class that is used as a log. This class allows the subscription of delegates to the class, so that subscribed functions receive the log messages. We have also implemented a library to control scores. This library stores the score independently for each level, allowing us to personalize each level and how it calculates its score and stores them in a manager that allows us to determine what to do with the obtained scores. An important feature of the proposed implementation is that it can be easily upgradable to new CPR guidelines.

When the user starts the game, the general state machine will be initialized and this will initialize player information such as the score. The first state of this machine is the first mini game, Isolate Victim. When the Isolate Victim mini game starts, the difficulty level information and the submachine of the selected level are initialized. In the first state of this submachine, the user has to press on the broken heart. The action that allows pressing on all the hearts will be activated. When the player presses a heart it checks if it is the broken one or not. If it is an unbroken one, it will remain in the same state; otherwise, it will activate the transition to go to the next state. In the new state, the action to remove unbroken hearts from the perimeter of the broken one will be activated. In this state, we continuously control that no hearts are into the perimeter. If there are, it remains in the same state. Once no more hearts are into the perimeter no more transitions are possible. Since this state is the last one, the submachine will finish and will inform its father state that it has finished. The father state will notify the score of the completed level to be stored in the score manager. Then, according to the game mode and the level, it will go to the next mini game or to the next level of the same mini game.

3.4. Quality Assurance. To ensure the game was stable and free of programming errors we continuously perform tests at different levels. We also used as testers members of our laboratory not related with the project but familiar with video games. Once all mini games were approved by our team, we performed tests with nonexperimented users with special attention to children. During tests we analysed playful experience to ensure that mini games were enjoyable enough. During these tests different proposals were done by the users and these led to different modifications on the mini games. To test the educational value after a testing session, we asked users to write the eight steps of the protocol to evaluate if they were able to reproduce them. In all the tests, they were able to do it.

4. Results

To present the results we will show different screens of the game grouped by mini games. For a complete demo of the game you can visit http://gilabparc.udg.edu/jocs/30_2/trailer.mov.

First images corresponding to some of the menus are presented in Figure 3. From (a) to (d), we can see the main screen with the game logo (see Figure 3(a)); the menu to select the playing modes (*Full* to play all the steps of the protocol, *Survival* to achieve the upper level of one mini game before

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

Figur e 4: Screens of the Isolate Victim mini game. (a) Init screen with game instructions. (b) Before detecting the broken heart. (c) After detection of victim with the security perimeter from which hearts have to be removed. (d) Final screen where we can see the game score and the message that victim and helper are in a secure position.

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

Figur e 5: Screens of the Check Conscious mini game. (a) Init screen with game instructions. (b) and (c) scenes with the icons that have to be pressed to shake shoulder, only blue and yellow icons add points. (d) Final screen with the game score and the message that the victim is unconscious.

playing the next mini game, *Scores* to check the score, and *Exit* to exit the game); the menu to select the mini game we want to play (see Figure 3(c)); and the selector of the difficulty level once the game has been selected (see Figure 3(d)).

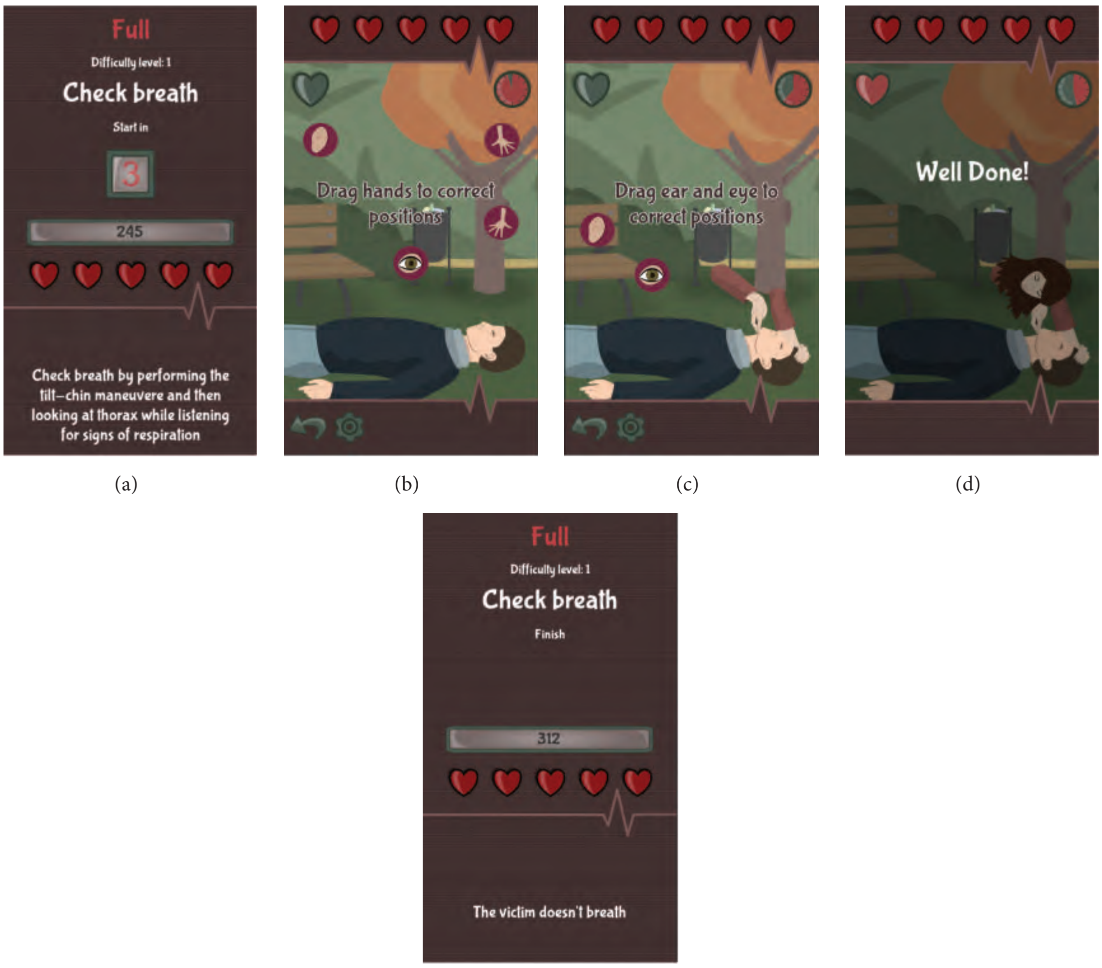
Figure 4 corresponds to the Isolate Victim mini game. From (a) to (d), we can see the init screen with game instructions and a timer that indicates when the game will start. We can also see the number of lives that the player has, in this case five hearts (see Figure 4(a)). This screen configuration is the same for all the mini games. The second image indicates what we have to do to isolate the victim. Note that we have hearts of different colours (see Figure 4(b)). Once we have pressed on the broken heart, the security perimeter appears and we have to isolate the victim as the message indicates (see Figure 4(c)). The last screen is the one that appears when the game is over. It indicates that the victim and the helper are in a secure position (see Figure 4(d)).

Figure 5 corresponds to the Check Conscious mini game. From (a) to (d), we can see the init screen with game instructions (see Figure 5(a)). The second image indicates what we have to do to check consciousness: press blue and yellow icons (see Figure 5(b)). Once we have pressed on the correct icons we will see how the hand moves the victim's shoulder (see Figure 5(c)). The last screen indicates that victim is unconscious (see Figure 5(d)).

Figure 6 corresponds to the Ask for Help mini game. From (a) to (d), we can see the init screen with game instructions (see Figure 6(a)). The second image indicates what we have to do to ask for help and also the icons with letters falling in the screen (see Figure 6(b)). Once correct

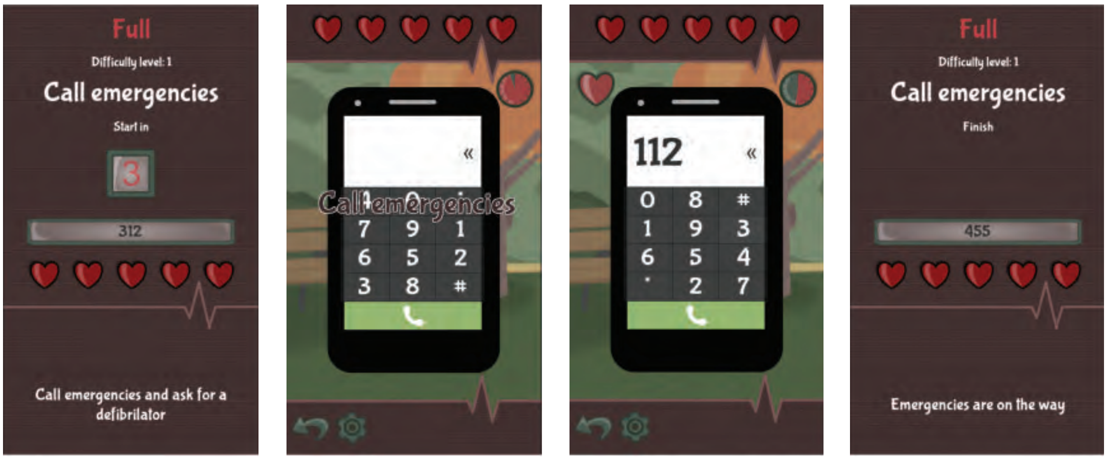
(a) (b) (c) (d)

Figure 6: Screens of the Ask for Help mini game. (a) Init screen with game instructions. (b) Scene with the empty balloon and falling letters. (c) Scene with some of the help letters completed. (d) Final screen with the game score and the message that help is on the way.



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

Figure 7: Screens of the Check Breath mini game. (a) Init screen with game instructions. (b) Scene with the icons that have to be placed in the correct positions. (c) Tilt-chin maneuver once hands have been correctly placed. (d) Look and listen for breath once eye and ear icons have been correctly placed. (e) Final screen with the score and the message that the victim is not breathing.



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

Figure 8: Game screens corresponding to the Ask for Help. (a) Init screen with game instructions. (b) Main screen with phone numbers and (c) once the player has dialed the correct number. (d) Final screen with the obtained score and the message that help and defibrillator are on the way.

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

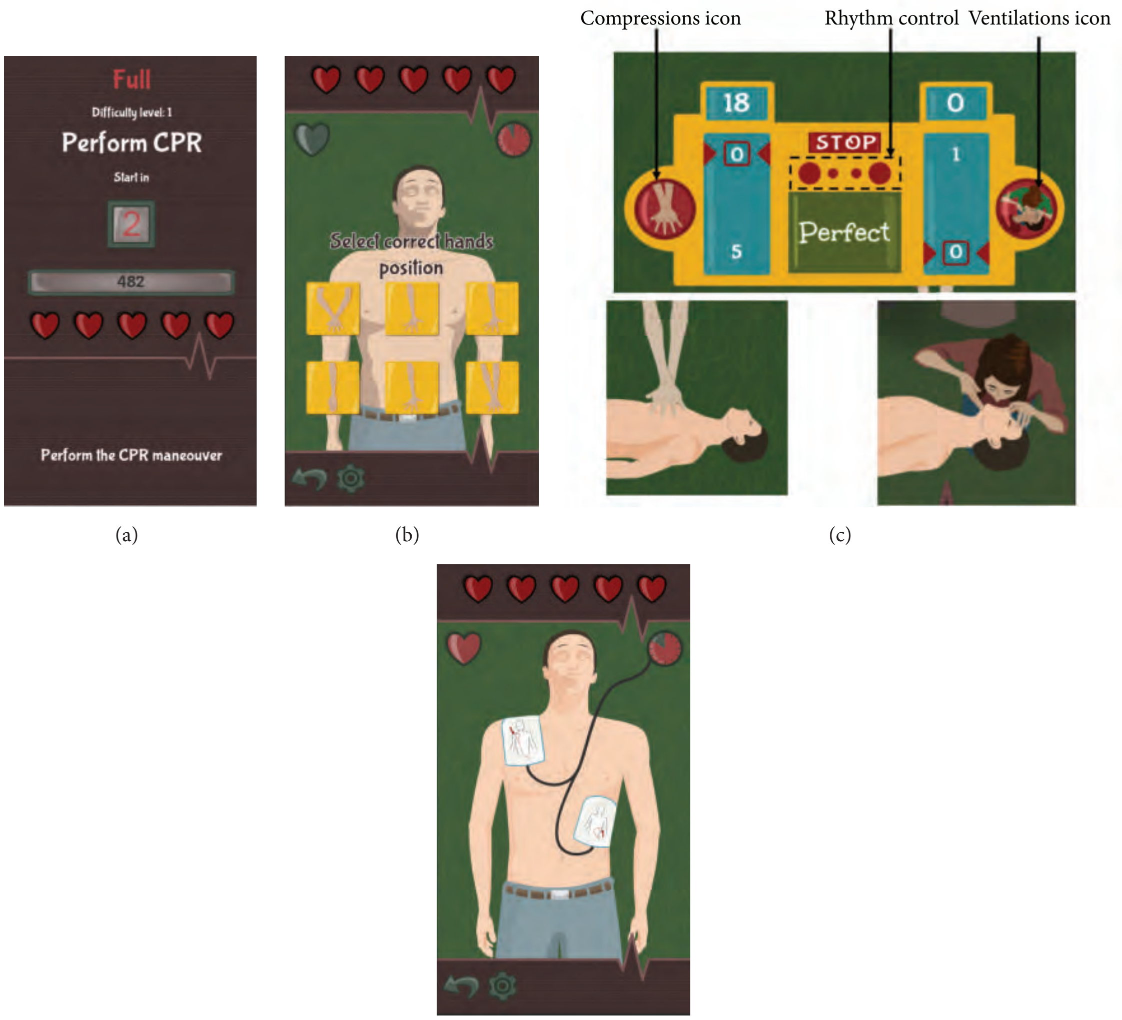
Figure 9: Game screens corresponding to the Remove Clothes mini game. (a) Init screen with game instructions. (b) Main scene with the victim wearing all the clothes. (c) After removing the scarf and the jacket. (d) Victim with the uncovered thorax.

letters are selected they appear in the speech balloon (see Figure 6(c)). The last screen indicates that help is on the way (see Figure 6(d)).

Figure 7 corresponds to the Check Breath mini game. From (a) to (e), we can see the init screen with game instructions indicating that we have to perform the tilt-chin maneuver and look and listen for breath (see Figure 7(a)). The second image shows the different icons of the game. As you can see, there are left and right hands to perform the tilt-chin maneuver and eyes and ears to look and listen. The icons have to be placed in the correct parts of the body victim (see Figure 7(b)). Once hands are correctly placed, the helper hands appear to show the correct hands placement on the victim (see Figure 7(c)). The next screen shows the helper head position which appears once eye and ear icons are correctly placed (see Figure 7(d)). The last screen indicates that the victim is not breathing (see Figure 7(e)).

Figure 8 corresponds to the Call Emergencies mini game. From (a) to (d), we can see the init screen with game instructions (see Figure 8(a)). The second image shows the phone with all the numbers (see Figure 8(b)). During the game, the numbers change their positions (see Figure 8(c)). The last screen indicates that emergencies are on the way (see Figure 8(d)).

Figure 9 corresponds to the Remove Clothes mini game. From (a) to (d), we can see the init screen with game instructions that indicate we have to uncover the victim thorax (see Figure 9(a)). The second image shows the victim with all the clothes (see Figure 9(b)). The next one shows the victim once the scarf and the jacket have been removed



(d)

Figur e 10: Game screens corresponding to the Perform CPR mini game. (a) The init screen. (b) The icon to select correct hand positions. (c) The menu to perform compressions and ventilations. (d) Defibrillator patches after performing CPR maneuver.

(see Figure 9(c)). The last one shows the victim with the uncovered thorax (see Figure 9(d)).

Figure 10 corresponds to the Perform CPR mini game which represents the key point of the protocol. From (a) to (d), we can see the init screen with game instructions (see Figure 10(a)). To start the game, the player has to select the correct hand positions. There will appear icons with different hands positions and the player has to select the correct one (see Figure 10(b)). Figure 10(c) represents the menu designed to control compressions and ventilations performance. In the middle of this board we can see if the performed action has been correct or not. Note that in the board we can also see the number of compressions and ventilations that have been performed and also indicators of the compression depth and ventilation degree. Once the maneuver has finished the defibrillator arrives and the player has to place the patches in the correct place (see Figure 10(d)).

Figure 1 1corresponds to the Security Position mini game. From (a) to (e), we can see the init screen with game instructions (see Figure 11(a)).To start the game, the player has to move the victim by pressing on arms or legs of his body (see Figure 11(b)).Once the correct part is pressed, an icon appears as the one showed at the bottom of Figure 11(c). In next figure, we can see the victim after moving his arm (see Figure 11(d)).The last image represents the victim in the lateral security position (see Figure 11(e)).

4.1. First Users' Impressions. To test the game we selected 25 children, five of each age from 8 to 12 years old, and 12 males and 13 females. They played the game as many times as they wanted and then, we asked for clarity of instructions and three settings of the game: the aesthetics of scenarios, the playability, and the enjoyability of each mini game. For all four questions users should answer their impression in a scale

Figure 11: Game screens corresponding to the Security Position mini game. (a) The main scene. (b) The icon that appears to move the arm. (c) After moving the arm. (d) The victim in the lateral security position.

from 1 to 5 where 1 recalls to *I do not like at all* and 5 to *I like a lot*. In order to summarize the results, a mean of all three settings was calculated. Table 1 shows mean and standard deviation of answers. Regarding the clarity of instructions, all 8 mini games have values higher than 3 and 6 of them (1, 2, 3, 5, 6, and 7) even higher than 4. On the other hand, the settings mean presents the same results except in Game 8 with a mean of only 2,43. The last column of Table 2 shows there is no significant difference between sexes on the answer, according the p values obtained by a Mann-Whitney U test. Due to the low size of our sample we plan to repeat the experiment with a larger one.

5. Conclusions and Future Work

The correct application of cardiopulmonary resuscitation protocol can increase the chances of survival for victims of cardiac arrest. Due to the importance of this procedure, many initiatives have been proposed to disseminate it. However, it is still unknown for a large number of people, and new strategies to promote it are needed. In this paper, we have proposed a game with this purpose and specially targeted to children. Following the cardiopulmonary resuscitation guidelines proposed by the European Resuscitation Council 2010 and assessed by experts, we have converted the main procedures of these guidelines into eight different mini games. Each mini game represents one of the key processes of the protocol and is presented to the player as a challenge. Playing with them makes the player learn the protocol. Our first experiments show us the suitability of the game as a channel to disseminate the protocol, mainly among children. As an immediate work we will update the game to adapt it to the ERC guidelines proposed in 2015 and we will create/improve the scenarios and challenges to preserve the player interest. For instance, in mini game five, we will include the dispatcher assisted CPR instruction. Moreover, we will carry out a further evaluation with a larger sample. In addition, we will evaluate the efficacy of the game to improve the willingness and quality of basic life support in a clinical setting.

Table 2: Mean and standard deviation of 25 testers' answers related to clarity of instructions and three settings of the game: the aesthetics of scenarios, the playability, and the enjoyability of each mini game.

		Mean	Standard deviation	Mann-Whitney U p value
Game 1	Clarity	4,28	0,61	1,00
Isolate Victim	Settings mean	4,16	0,43	0,17
Game 2	Clarity	4,36	0,57	0,53
Check Conscious	Settings mean	4,12	0,41	0,96
Game 3	Clarity	4,56	0,51	0,08
Ask for Help	Settings mean	4,24	0,35	0,59
Game 4	Clarity	3,68	0,75	0,81
Check Breath	Settings mean	3,52	0,42	0,40
Game 5	Clarity	4,56	0,51	0,85
Call Emergencies	Settings mean	4,45	0,29	0,61
Game 6	Clarity	4,46	0,51	0,85
Remove Clothes	Settings mean	4,19	0,36	0,41
Game 7	Clarity	4,16	0,55	0,51
Perform CPR	Settings mean	4,16	0,59	0,27
Game 8	Clarity	3,4	0,58	1,00
Security Position	Settings mean	2,43	0,46	0,91

Competing Interests

There are no competing interests.

Acknowledgments

This work has been funded in part by grants from the Spanish Government (no. TIN2013-47276-C6-1-R) and from the Catalan Government (no. 2014-SGR-1232).

References

[1] M. Prensky, *Digital Game-Based Learning*, McGraw Hill, New York, NY, USA, 2001.

[2] T. M. Connolly, E. A. Boyle, E. MacArthur, T. Hainey, and J. M. Boyle, "A systematic literature review of empirical evidence on computer games and serious games," *Computers and Education*, vol. 59, no. 2, pp. 661–686, 2012.

[3] J. P. Gee, "Learning by design: good video games as learning machines," *E-Learning*, vol. 2, no. 1, pp. 5–16, 2005.

[4] D. W. Shaffer, *How Computer Games Help Children Learn*, Palgrave Macmillan, New York, NY, USA, 2006.

[5] F. Ke, "A case study of computer gaming for math: engaged learning from gameplay?" *Computers and Education*, vol. 51, no. 4, pp. 1609–1620, 2008.

[6] M. Kebritchi and A. Hirumi, "Examining the pedagogical foundations of modern educational computer games," *Computers and Education*, vol. 51, no. 4, pp. 1729–1743, 2008.

[7] H. F. O'Neil, R. Wainess, and E. L. Baker, "Classification of learning outcomes: evidence from the computer games literature," *Curriculum Journal*, vol. 16, no. 4, pp. 455–474, 2005.

[8] M. Virvou and E. Alepis, "Mobile educational features in authoring tools for personalised tutoring," *Computers and Education*, vol. 44, no. 1, pp. 53–68, 2005.

[9] P. Lavín-Mera, P. Moreno-Ger, and B. Fernández-Manjón, "Development of educational videogames in m-learning contexts," in *Proceedings of the 2nd IEEE International Conference on Digital Game and Intelligent Toy Enhanced Learning (DIGITEL '08)*, pp. 44–51, Banff, Canada, November 2008.

[10] T. Kitamura, T. Iwami, T. Kawamura et al., "Nationwide improvements in survival from out-of-hospital cardiac arrest in Japan," *Circulation*, vol. 126, no. 24, pp. 2834–2843, 2012.

[11] T. Nishi, T. Maeda, K. Takase, T. Kamikura, Y. Tanaka, and H. Inaba, "Does the number of rescuers affect the survival rate from out-of-hospital cardiac arrests? Two or more rescuers are not always better than one," *Resuscitation*, vol. 84, no. 2, pp. 154–161, 2013.

[12] Y. Tanaka, J. Taniguchi, Y. Wato, Y. Yoshida, and H. Inaba, "The continuous quality improvement project for telephone-assisted instruction of cardiopulmonary resuscitation increased the incidence of bystander CPR and improved the outcomes of out-of-hospital cardiac arrests," *Resuscitation*, vol. 83, no. 10, pp. 1235–1241, 2012.

[13] J. Herlitz, J. Engdahl, L. Svensson, M. Young, K.-A. Ängquist, and S. Holmberg, "Characteristics and outcome among children suffering from out of hospital cardiac arrest in Sweden," *Resuscitation*, vol. 64, no. 1, pp. 37–40, 2005.

[14] G. Abbas, A. Alfonzo, H. R. Arntz et al., "European Resuscitation Council Guidelines for Resuscitation 2010 Section 1. Executive summary," *Resuscitation*, vol. 81, no. 10, pp. 1219–1276, 2010.

[15] W. B. Kouwenhoven, J. R. Jude, and G. Knickerbocker, "Closed-chest cardiac massage," *Journal of the American Medical Association*, vol. 173, no. 10, pp. 1064–1067, 1960.

[16] American Heart Association, "Emergency Cardiovascular Care online education," http://www.onlineaha.org.

[17] Y. T. Fong, V. Anantharaman, S. H. Lim, K. F. Leong, and G. Pokkan, "Mass cardiopulmonary resuscitation 99—Survey results of a multi-organisational effort in public education in

cardiopulmonary resuscitation," *Resuscitation*, vol. 49, no. 2, pp. 201–205, 2001.

[18] E. L. Einspruch, B. Lynch, T. P. Aufderheide, G. Nichol, and L. Becker, "Retention of CPR skills learned in a traditional AHA Heartsaver course versus 30-min video self-training: a controlled randomized study," *Resuscitation*, vol. 74, no. 3, pp. 476–486, 2007.

[19] C. Vaillancourt, J. Grimshaw, J. C. Brehaut et al., "A survey of attitudes and factors associated with successful cardiopulmonary resuscitation (CPR) knowledge transfer in an older population most likely to witness cardiac arrest: design and methodology," *BMC Emergency Medicine*, vol. 8, article 13, 2008.

[20] A.-B. Thoren, A. Axelsson, and J. Herlitz, "The attitude of cardiac care patients towards CPR and CPR education," *Resuscitation*, vol. 61, no. 2, pp. 163–171, 2004.

[21] Medtronic Foundation, CPR Simulator, 2012, http://www.cpr-sim.com/.

[22] CPR Choking, 2011, http://www.stonemeadowdevelopment.com/StoneMeadowDevelopment/CPR&Choking.html.

[23] EM Gladiators LLC, CPR Game, 2011,http://www.freenew.net/iphone/cpr-game-20/466678.htm.

[24] D. Low, N. Clark, J. Soar et al., "Does use of iResus© application on a smart phone improve the performance of an advanced life support provider in a simulated emergency?" *Resuscitation*, vol. 81, no. 2, supplement, p. S10, 2010.

[25] A. Alessandri, *iCPR—iPhone App for CPR Training*, 2009, http://www.icpr.it/.

[26] F. Semeraro, F. Taggi, G. Tammaro, G. Imbriaco, L. Marchetti, and E. L. Cerchiari, "ICPR: a new application of high-quality cardiopulmonary resuscitation training," *Resuscitation*, vol. 82, no. 4, pp. 436–441, 2011.

[27] R. Zanner, D. Wilhelm, H. Feussner, and G. Schneider, "Evaluation of M-AID, a first aid application for mobile phones," *Resuscitation*, vol. 74, no. 3, pp. 487–494, 2007.

[28] LifeSaver, 2012, https://life-saver.org.uk/.

[29] Indiegogo Inc. Mini-VREM, 2012, http://www.mini-vrem.it/.

[30] Insight Instructional Media, *AED Challenge*, 2011, http://aed-challenge.com/.

[31] M. Ponder, B. Herbelin, T. Molet et al., "Interactive scenario immersion: health emergency decision training in just project," in *Proceedings of the International Workshop on Virtual Reality Rehabilitation*, pp. 87–101, 2002.

[32] Laerdal Medical, "MicroSim Prehospital," 2012, http://www.laerdal.com/gb/docid/12984879/MicroSimPrehospital.

[33] Ilumens, *Staying Alive 3D*, 2011, http://www.stayingalive.fr/index_uk.html.

[34] V. Wattanasoontorn, I. Boada, and M. Sbert Lissa, "A serious game to learn cardiopulmonary resuscitation," in *Proceedings of the 8th International Conference on Foundations of Digital Games, Games for Learning Workshop (FDG '13)*, 2013.

[35] F. Semeraro, A. Frisoli, G. Ristagno et al., "Relive: a serious game to learn how to save lives," *Resuscitation*, vol. 85, no. 7, pp. e109–e110, 2014.

[36] Viva! Game, http://www.viva2013.it/viva-game.

[37] B. Schmitz, R. Klemke, J. Walhout, and M. Specht, "Attuning a mobile simulation game for school children using a design-based research approach," *Computers and Education*, vol. 81, pp. 35–48, 2015.

[38] T. Uray, A. Lunzer, A. Ochsenhofer et al., "Feasibility of Life-supporting First-aid (LSFA) training as a mandatory subject in primary schools," *Resuscitation*, vol. 59, no. 2, pp. 211–220, 2003.

[39] M. S. Link, "CPR for kids: please try this at home," *Journal Watch Cardiology*, vol. 28, pp. 234–239, 2007.

[40] I. Jones, R. Whitfield, M. Colquhoun, D. Chamberlain, N. Vetter, and R. Newcombe, "At what age can schoolchildren provide effective chest compressions? An observational study from the Heartstart UK schools training programme," *British Medical Journal*, vol. 334, no. 7605, pp. 1201–1203, 2007.

[41] D. L. Isbye, L. S. Rasmussen, C. Ringsted, and F. K. Lippert, "Disseminating cardiopulmonary resuscitation training by distributing 35 000 personal manikins among school children," *Circulation*, vol. 116, no. 12, pp. 1380–1385, 2007.

[42] American Academy of Pediatrics Committee on Injury, Violence, and Poison Prevention, "Prevention of drowning in infants, children, and adolescents," *Pediaitrics*, vol. 112, pp. 437–439, 2003.

[43] L. A. Pyles and J. Knapp, "Role of pediatricians in advocating life support training courses for parents and the public," *Pediatrics*, vol. 114, no. 6, pp. e761–e765, 2004.

[44] J. Torrente, B. Borro-Escribano, M. Freire et al., "Development of game-like simulations for procedural knowledge in healthcare education," *IEEE Transactions on Learning Technologies*, vol. 7, no. 1, pp. 69–82, 2014.

[45] J. Dewey, *Experience and Education*, Simon and Schuster, New York, NY, USA, 1938.

[46] R. C. Schank, T. R. Berman, and K. A. Macpherson, "Instructional-design theories and models: a new paradigm of instructional theory," in *Learning by Doing*, C. M. Reigeluth and N. J. Mahwah, Eds., pp. 633–651, Lawrence Erlbaum Associates, Mahwah, NJ, USA, 1999.

[47] E. L. Deci and R. M. Ryan, *Intrinsic Motivation and Self-Determination in Human Behavior*, Plenum, New York, NY, USA, 1985.

[48] E. L. Deci and R. M. Ryan, "The "what" and "why" of goal pursuits: human needs and the self-determination of behavior," *Psychological Inquiry*, vol. 11, no. 4, pp. 227–268, 2000.

[49] C. Burgers, A. Eden, M. D. van Engelenburg, and S. Buningh, "How feedback boosts motivation and play in a brain-training game," *Computers in Human Behavior*, vol. 48, pp. 94–103, 2015.

Appendix A. CPR protocol

According to ERC, the CPR protocol (or adult basic life support sequence) is composed of eight main steps that have to be applied sequentially. These steps and their corresponding actions are: (1) Safety. Make sure that the helper, the victim of cardiac arrest, and any bystanders are safe; (2)Response. Check the victim for a response; (3) Airway. Open airway using the head tilt and chin lift technique; (4) Breathing. Look, listen, and feel for normal breathing; (5)Alert. Call emergency services and send someone to get automatic external defibrillator; (6)Circulation. Start chest compressions combined with rescue breaths; (7)Defibrillator. If there is an assistant in the scene and also an AED, the assistant has to follow AED instructions while helper continue with compressions and rescue breaths. Repeat (6) and (7) until health professionals arrive or the victim recovers. In this last case, (8)Recovery position. Place the victim in the recovery position. For a more detailed description please see (Monsieurs et al. (2015)).

Appendix B. Supplementary tables

	Age			Sex			Previous CPR knowledge		
Blind	Mean	Sd	U Man-Whitney	Male	Female	χ^2	No	Yes	χ^2
No	37,75	13,23	0,43	50%	50%	1	75%	25%	0,13
Yes	35	14,78		50%	50%		100%	0%	

Table S1: Characterization of our sample population.

First Questionnaire		
Q1	Age	...
Q2	Sex	Male/Female
Q3	Do you have previous knowledge on CPR?	(Yes/No)
Q4	Degree of visually impairment	0% ... 100%
Q5	Do you use the smartphone to play games?	(Yes/No)
Q6	In case of Q5 answer is Yes, how many hours per week do you play?	

Table S2: Questions of the interviews.

Q1.Is it necessary to remove clothes from the thorax to apply the CPR protocol?
(a1) Yes, it is necessary to perform compressions and to use AED **(a2)** No, it is not necessary. AED can be used over the clothes
Q2. How can check breath of a non-conscious victim?
(a1) Placing the hand on the thorax to check if there is movement **(a2)** Doing the chin tilt technique and observe for breathing **(a3)** Not necessary to check
Q3. After using the AED, when we are waiting for ambulance how we have to place the victim?
(a1) Supine position **(a2)** Incorporated to recover conscious **(a3)** Lateral security position **(a4)** It doesn't matter the position
Q4.How many compressions have to be done in the CPR maneuver?
(a1) 15 **(a2)** 20 **(a3)** 30 **(a4)** 35 **(a5)** Continuoesly until AED arrives
Q5. How many ventilations have to be done in the CPR maneuver?
(a1).2 **(a2)**.4 **(a3)**.6 **(a4)**.10 **(a5)**.No ventilations needed
Q6. Using AED, determine number of patches and position to be placed
(a1).One/right breast **(a2)**.One/left breast **(a3)**.One/right **(a4)**. Two/breast and back **(a5)**.Two/ right upper and down left of thorax **(a6)**.Two/ center thorax and stomach **(a7)**.Three/ back and left and right of thorax
Q7. When is necessary to call emergencies?
(a1) When victim does not respond to stimulus and if breathing before starting CPR **(a2)** We have to wait for someone who helps us, we have to start CPR and we can not stop **(a3)** Before check breathing we have to call emergencies
Q8. If you find someone lying on the floor the first thing to do is
(a1) Call emergencies **(a2)** Create a security perimeter around the victim **(a3)** Ask for help **(a4)** Check conscious **(a5)** Check breath
Q9. When we have to ask for help?
(a1) After check conscious **(a2)** After check breath **(a3)** Not necessary to ask for help **(a4)** It is the first thing to be done
Q10. Can you tell the steps of the CPR protocol in the correct order?
(Open answer)

Table S3: CPR questionnaire.

Opinion Questionnaire		
Q1	I liked the game	(1 to 5)
Q2	I experienced frustation with the game	(1 to 5)
Q3	The game is boring	(1 to 5)
Q4	The game is difficult	(1 to 5)
Q5	The game is funny	(1 to 5)
Q6	I want to play again	(1 to 5)
Q7	The game is easy to use	(1 to 5)
Q8	The CPR protocol has been well explained	(1 to 5)
Q9	I know more on CPR than before playing	(1 to 5)
Q10	The aids are intuitive	(1 to 5)
Q11	The aids are effective	(1 to 5)

Table S4: Questions related to game experience.

Question	Blind	mean	sd	Q1	Md	Q3	U Man-Whitney
Q1. Game liked	No	3,625	1,061	3	3,5	4,25	0,151
	Yes	4,375	0,744	4	4,5	5	
Q2 Game frustred	No	3,625	1,061	3	3,5	4,25	0,151
	Yes	2,75	0,886	2,75	3	3	
Q3. Game bores	No	1,875	0,834	1	2	2,25	0,128
	Yes	1,375	0,517	1	1	2	
Q4. Game difficult	No	4,125	0,641	4	4	4,25	0,009
	Yes	2,75	0,886	2	2,5	3,25	
Q5.Game funny	No	4	0,925	4	4	4,25	0,030
	Yes	4,25	0,707	4	4	5	
Q6. Play again	No	4,125	1,126	3,75	4,5	5	0,444
	Yes	4,625	0,517	4	5	5	
Q7. Easy to use	No	2,375	1,061	1,75	2,5	3	0,680
	Yes	3,5	0,534	3	3,5	4	
Q8. CPR explanation	No	4,125	0,641	4	4	4,25	1,000
	Yes	4	1,069	3,75	4	5	
Q9. CPR knowledge	No	4,75	0,463	4,75	5	5	0,648
	Yes	4,625	0,517	4	5	5	
Q10. Aids intuitive	No	2,875	0,641	2,75	3	3	0,067
	Yes	3,5	0,534	3	3,5	4	
Q11. Aids effective	No	2,875	1,126	2	3	4	0,100
	Yes	3,875	0,834	3	4	4,25	

Table S5: Results of game experience questionnaire.

Mini-game	Blind	mean	sd	Q1	Md	Q3	U Man-Whitney
Locate victim	No	3,875	0,99	3	3,5	5	0,124
	Yes	4,625	0,52	4	5	5	
Isolate victim	No	4,5	0,53	4	4,5	5	0,349
	Yes	4,75	0,46	4,75	5	5	
Check response	No	4,5	0,53	4	4,5	5	0,030
	Yes	5	0	5	5	5	
Ask for Help	No	4	1,07	3	4	5	0,081
	Yes	4,875	0,35	5	5	5	
Tilt.chin tech.	No	2,5	1,41	1,75	2	3,25	0,020
	Yes	4,25	0,71	4	4	5	
Check Breath	No	2,75	1,04	2	3	3,25	0,019
	Yes	4,125	0,99	4	4	5	
Call 112	No	3,5	0,93	3	3,5	4	0,042
	Yes	4,5	0,76	4	5	5	
Uncover thorax	No	3,25	1,67	2,5	3	5	0,111
	Yes	4,5	0,93	4,5	5	5	
Circulation	No	2,625	1,41	1,75	2,5	3,25	0,027
	Yes	4,375	1,41	4,75	5	5	
Security position	No	4,125	0,83	3,75	4	5	0,571
	Yes	4,375	0,74	4	4,5	5	
Find DEA	No	4,25	0,89	3,75	4,5	5	0,109
	Yes	4,875	0,35	5	5	5	
Place Patches	No	3,625	1,06	3	3,5	4,25	0,027
	Yes	4,75	0,46	4,75	5	5	

Table S6: Results of questionnaire related to the enjoyability of mini-games.

Mini-game	Blind	mean	sd	Q1	Md	Q3	U Man-Whitney
Locate victim	No	3,375	1,19	3	3,5	4	0,025
	Yes	2	0,93	1	2	3	
Isolate victim	No	3,875	0,64	3,75	4	4	0,150
	Yes	2,875	1,46	1,75	3	4	
Check response	No	4	0,53	4	4	4	0,367
	Yes	3,25	1,49	2	3,5	4,25	
Ask for Help	No	4	1,07	3,75	4	5	0,111
	Yes	3,25	0,71	3	3	4	
Tilt.chin tech.	No	4,875	0,35	5	5	5	0,000
	Yes	3,125	0,35	3	3	3	
Check Breath	No	2,75	1,16	2	2,5	4	0,294
	Yes	2,125	1,25	1	2	2,5	
Call 112	No	3,5	1,07	3	3	4,25	0,042
	Yes	2,375	0,74	2	2,5	3	
Uncover thorax	No	4,75	0,46	4,75	5	5	0,027
	Yes	3,625	1,06	3	3,5	4,25	
Circulation	No	4,875	0,35	5	5	5	0,004
	Yes	3,75	0,71	3	4	4	
Security position	No	3,25	1,28	2,75	3,5	4	0,066
	Yes	2,125	0,83	1	2	3	
Find DEA	No	4	0,76	3,75	4	4,25	0,002
	Yes	1,875	0,83	1	2	2,25	
Place Patches	No	4,375	0,74	4	4,5	5	0,002
	Yes	2,25	0,89	2	2	2,25	

Table S7: Results of questionnaire related to the difficulty of mini-games.

Chapter 5

CPRforblind: A video game to introduce cardiopulmonary resuscitation protocol to blind people

The third goal of this thesis is focused on the design and evaluation of serious games to introduce the CPR protocol to blind players. In this chapter, a serious game designed to introduce the main steps of the CPR protocol to visually impaired people is presented. The game uses a set of mini-games and reduces all player interactions to sound, vibration and tactile input and output. A detailed description of the game and the different experiments that have been carried out are provided.

CPRforBlind, A videogame to introduce CardioPulmonary Resuscitation protocol to blind people, Antonio Rodríguez, Imma Boada, Santiago Thió-Henestrosa, Mateu Sbert, British Journal of Educational Technology, 2018, ISSN: 1467-8535, JCR- Education and Educational research, 31/243; IF:2,588; Quartile Q1 (JCR)

British Journal of Educational Technology Vol 49 No 4 2018 636–645
doi:10.1111/bjet.12627

CPRforblind: A video game to introduce cardiopulmonary resuscitation protocol to blind people

Antonio Rodríguez, Imma Boada, Santiago Thió-Henestrosa and Mateu Sbert

Antonio Rodríguez is a Ph.D. student with research focused on serious games, e-learning and adapted games for disabled people. Imma Boada is associate professor in Computer Science at the University of Girona, Ph.D. in Computer Science. Her research is focused on visualization and image processing in medicine, serious games and e-learning techniques. Santiago Thió-Henestrosa is associate professor in Statistics at the University of Girona, Ph.D. in Computer Science. His research is centered on compositional data and conducts statistical studies in medicine and video games areas. Mateu Sbert is the professor in Computer Science at the University of Girona and 1000 Plan professor at the Tianjin University, China and Ph.D. in Computer Science with research interests in serious games, computer graphics, visualization, and image processing. Address for correspondence: Imma Boada, Institution: Graphics and Imaging Laboratory, Escola Politècnica Superior, Campus de Montilivi, Edifici P4, Girona 17003, Spain. Email: imma.boada@udg.edu

Abstract

Cardiopulmonary resuscitation (CPR) is a first aid survival technique used to recover victims of cardiac arrest. To learn CPR different handheld device applications have been proposed. Most of them are based on sophisticated graphics and interaction techniques that make them inaccessible to visually impaired people. In this paper, we propose CPRforBlind, a video game designed to introduce the main steps of the CPR protocol to visually impaired people. The game is composed of different mini-games inspired by the CPR steps proposed by European Resuscitation Council. The player acts as a helper who has to save the victim by using tactile interaction to solve the challenges assigned to each mini-game. To test the game, 16 participants from which 8 are blind have been considered. After and before playing the game participants answered different questionnaires related to CPR knowledge, playability and enjoyability. The obtained results are very promising detecting a great improvement on CPR knowledge. In addition, blind players enjoyed the game and found it easy to play.

Introduction

Cardiopulmonary resuscitation (CPR) is a first aid key survival technique used to stimulate breathing and keep blood flowing to the heart. Its effective administration can significantly increase the chances of survival for victims of cardiac arrest. Kouwenhoven, Jude, and Knickerbocker (1960) published that anyone, anywhere, could perform CPR. Since then, providing CPR has become a main competency and not only for experts. Organizations such as the European Resuscitation Council (Monsieurs *et al.*, 2015) have defined guidelines to describe how to perform CPR.

The strategies proposed to teach CPR range from classical teaching with mannequins, through interactive videos to 3D simulation scenarios and serious games. Examples of virtual scenarios can be found in Ponder *et al.* (2002), Laerdal (2012), Ilumens (2011) and Wattanasoontorn, Boada, Sbert, Olivet, and Juvinya (2014), and in the context of serious games, in Semeraro *et al.* (2014), VivaGame (2013), Schmitz, Klemke, Walhout, and Specht (2015) and Boada,

Practitioners notes

What is already known about this topic

- Sound and touch interaction techniques make video games accessible to visually impaired people.
- Anyone, anywhere, could perform cardiopulmonary resuscitation (CPR) protocol.
- There are few studies focused on CPR for visually impaired people.

What this paper adds

- The first video game to introduce CPR protocol to blind people is proposed.

Implications for practice and/or policy

- Video games are a good strategy to introduce CPR concepts to visually impaired people.
- A good strategy to teach step-composed procedures is the design of video games composed of mini-games linked by a common plot.

Rodríguez-Benítez, García-González, Thió-Henestrosa, and Sbert (2016). Unfortunately, visually impaired players have many difficulties to access these applications, since most of them rely on impressive graphics and immersive visual experiences. They may also find barriers in providing input. To adapt video games to visually impaired people, strategies to replace visual stimuli are required. The most popular are audio-based techniques that use auditory icons to associate sound to information (Brewster, 1998; Friberg & Gärdenfors, 2004; Miller, Parecki, & Douglas, 2007). There are also more advanced techniques that assign a 3D effect to sound allowing it to come from any part of a scene (Sánchez, Sáenz, & Ripoll, 2009). Modern game engines such as Unreal Game Development Kit (Unreal 2017) and Unity 3D (Unity 2017) provide functionalities to create these effects. In addition, there are haptic-based strategies to enhance immersion, for instance, by vibrating when collisions are detected. For more details on game accessibly, see Yuan, Folmer, and Harris (2011) and Manduchi and Kurniawan (2017).

As far as we know, no approaches to teach CPR to visually impaired people have been proposed. There is only a study from Bertini *et al.* (2015) where the capability of blind people to perform CPR is evaluated. This study concluded that, in adult training, blindness appeared not to be a limitation for adequately performing CPR maneuvers. Focusing on visually impaired people, we propose a video game, named CPRforBlind, designed to introduce the CPR protocol proposed by the European Resuscitation Council (ERC), to this community. The game is inspired in our previous work, 30:2 (Boada *et al.*, 2016), designed to introduce CPR to children. CPRforBlind follows a linear story where the player acts as a helper of an emergency situation that requires the application of the CPR protocol. A voice introduces game challenges and to surmount them actions based on sound, vibration or touch have to be done. The game has been implemented in Unity3D for which we have developed a library to support player actions.

Method

Proposed game

CPRforBlind is composed of 13 mini-games related to main steps of the CPR sequence represented in Figure 1 (see Appendix A for more details). To interact, players use actions illustrated in Figure 2. A brief description of each mini-game is given below. In these games player acts as a helper. At the beginning of each mini-game, a voice message recorded by the developer team describes the

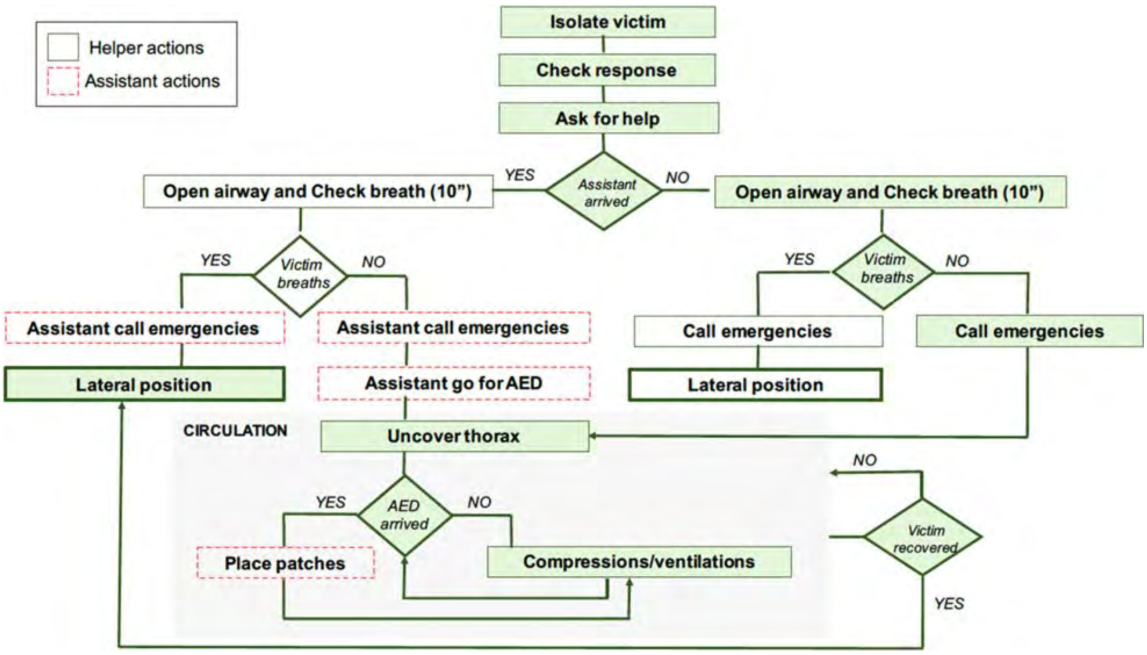


Figure 1: According to ERC 2015 guidelines (Monsieurs et al.*, 2015), the CPR step-by-step sequence for the helper and the assistant considering different situations. Dark blocks correspond to basic sequence with no breathing victim, no assistant, and no AED. [Colour figure can be viewed at wileyonlinelibrary.com]*

situation, the challenge and the actions that have to be carried out to achieve the goal. At the end, a description of the game status is also given.

1. Locate victim: A vibration pattern is assigned to the victim and the player has to find the screen position where it sounds. The player has to drag the finger on the screen, locate the victim, and tap on the victim's position (see Figure 3(a)).
2. Isolate Victim: Different bystanders are around the victim and they have to be moved to create a security perimeter where only the victim and the helper are present. Bystanders are represented with two different vibration patterns. One requires a horizontal shake and the other a vertical one to move out from the screen. The player has to identify vibration patterns and react according to the pattern by shaking the device in the correct direction (see Figure 3(b)).
3. Check Response: To determine if the victim responds or not, the helper has to shake victim's shoulder. Two vibration patterns, one requires player to drag the finger in the upper vertical direction and the other in the lower vertical one, have been defined. The player has to wait for a vibration, identify the vibration pattern, and react according to it by touching and dragging the finger across the screen in the correct direction. These actions simulate the movement required to shake the victim shoulder (see Figure 3(c)).
4. Ask for Help: If the victim does not respond, the helper has to ask for help. This action can be done by moving the hand from left to right. To simulate this movement, different

Figure 2: Player actions to interact with the game. [Colour figure can viewed at wileyonlinelibrary.com]

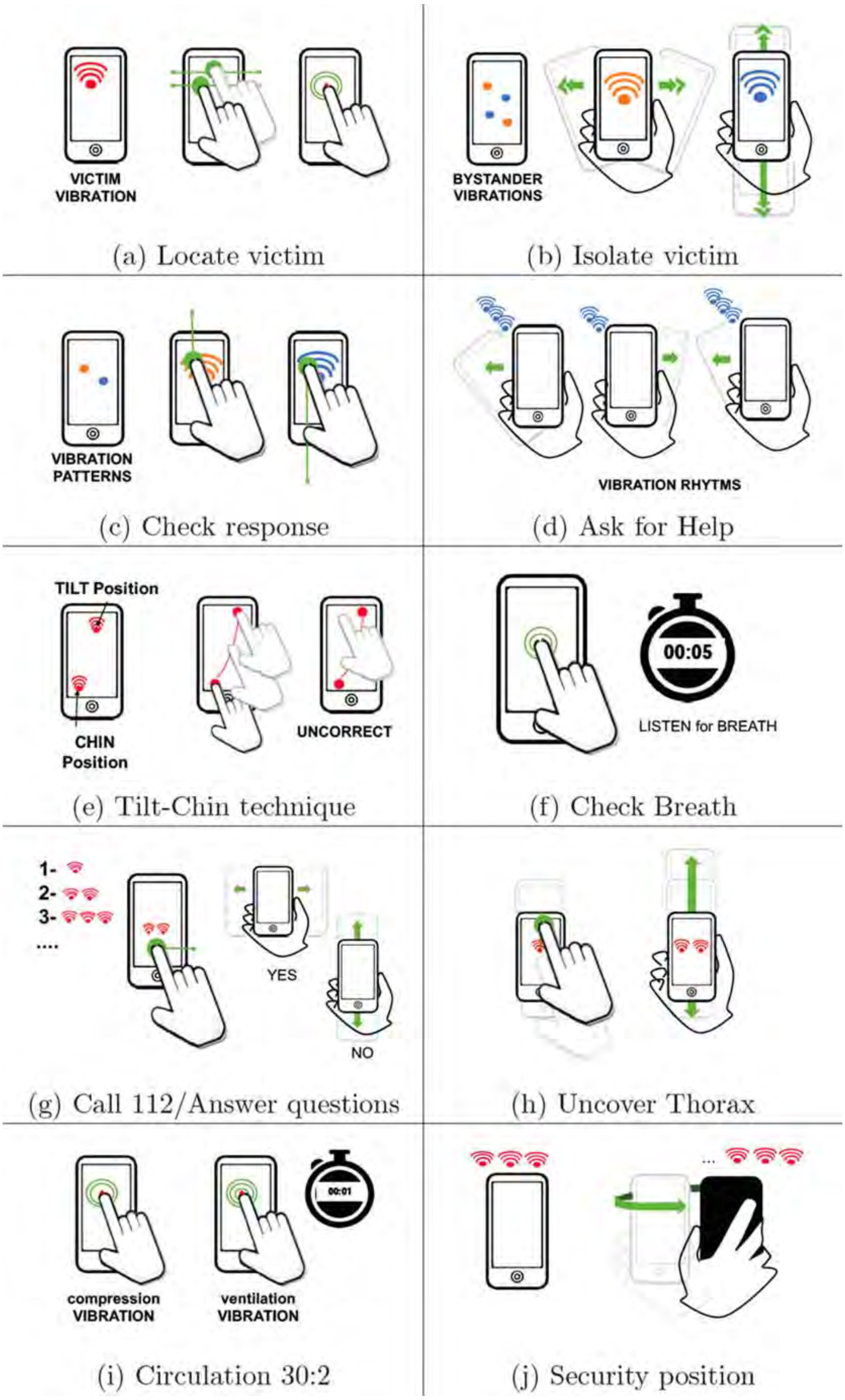


Figure 3: Mini-games of helper mode. [Colour figure can be viewed at wileyonlinelibrary.com]

vibration rhythms with a pause between them have been defined. For the first vibration, the player has to move the device to the left and for the next to the right, then to the left and in this way sequentially until the last vibration sequence (see Figure 3(d)).

5. Open Air-way: The helper has to open the airway using the head tilt and chin lift technique to check if victim is breathing. One screen position for the tilt, another for the

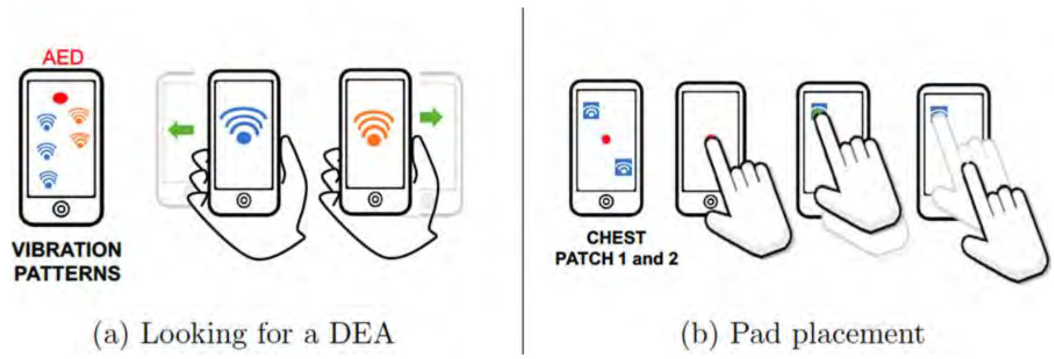


Figure 4: Mini-games related to automatic external defibrillator (AED) use. The player acts as an assistant. [Colour figure can be viewed at wileyonlinelibrary.com]

chin, and a path to go from one to the other have been defined. The player has to detect the chin position and go to the tilt by dragging finger across the screen following the correct path. The intensity vibration indicates if the followed direction is right or wrong (see Figure 3(e)).

6. Check breathing: The helper has to look, listen and feel to check if the victim is breathing or not. A vibration pattern indicates breathing. The player has to press on the screen between 5 and 10 seconds and listen for breathing. If vibration sounds the victim breaths, otherwise does not breath (see Figure 3(f)).
7. Call emergencies and answer questions: The helper has to call emergency and ask for a defibrillator. Numbers from 0 to 9 are placed on the screen. Each number has assigned as many vibrations as the number represents. The player has to drag the finger from one corner to the other to detect numbers and simulate the emergency call. Then, an operator will ask yes/no questions related with the emergency. To answer yes/no the device has to be moved in the correct direction (see Figure 3(g)).
8. Uncover Thorax: To start the CPR maneuver, the helper has to uncover victim's thorax. Two vibration patterns have been defined. One requires a shake in the vertical direction, and the other a drag in the vertical direction. A sequence of vibrations sounds and the player has to perform corresponding movements (see Figure 3(h)).
9. Compressions and Ventilations: The helper has to perform 30 compressions plus 2 ventilations. A vibration sequence represents compressions ventilations rhythm. The player has to tap on the screen following this rhythm. Compressions require a single tap on the screen and ventilations a one second tap (see Figure 3(i)).
10. Recovery position: If the victim has recovered, the helper has to put the victim in lateral position. To simulate this movement, the player has to turn down the device by following a vibration rhythm (see Figure 3(j)).
11. Ordering Protocol Steps: The protocol steps are announced in a noncorrect order and the player has to correctly order them. To select or discard a step, the player has to touch the screen or move the device to the left, respectively. The challenge is to remember the names of the steps that have been already selected and which is the next one.

To take into account, the case of automatic external defibrillator (AED), we have defined two mini-games where the player acts as an assistant (see Figure 1)

1. Locate AED: To look for AED player has to skip obstacles, represented with two vibrations patterns, by dragging the finger to one side or the other depending on the vibration. The game finishes when all obstacles are skipped (see Figure 4(a)).
2. Place AED pads: To place AED pads on the victim's chest three vibration patterns representing chest, patch one, and patch two have been defined. The player has to drag over

the screen to locate the chest and then, locate left upper position, to place the first patch, and right under position, to place the second one (see Figure 4(b)).

Participants
To test the game, we considered a group of 16 participants from which 8 were blind and 8 were sighted. We want to know the impressions of sighted participants when playing a game with no visual stimuli.

Moreover, a game where both sighted and visual impaired can play should be a good environment to improve social skills. Participants were recruited through personal contacts. The study was conducted in a laboratory at the University of Girona. There was the same number of females and males on both groups, with an average age of 35 years old and a standard deviation of 14.78 for the blind group, and an average age of 37.75 years old and a standard deviation of 13.23 for the sighted group. Only two sighted participants have previous knowledge on CPR (see Supporting Information Table S1)

Designed study
Each participant carried out a study with three parts. All the used questionnaires are presented in the appendix. First, we described the experiment to the participant and we asked them to answer a questionnaire with personal information (see Supporting Information Table S2) and another related to CPR knowledge (see Supporting Information Table S3). Second, participants played the game. Third, participants answered again the CPR questionnaire, and three new questionnaires about game experience (see Supporting Information Table S4) , mini-games enjoyability and mini-games difficulty. The two last questionnaires were answered with the 5-level Likert scale where 1 means Strongly disagree and 5 Strongly agree.

For the test, a Google Nexus 6 (6” screen) and a Sony Xperia Z5 Compact (4.6” screen) were used. The only requirement for device selection is that the player has to be able to hold it with one hand to interact with the other. The minimum recommended screen size is 3.5”.

Statistical analysis
A descriptive statistical analysis was performed to describe the answers of all questionnaires. To analyze if there are significant differences on the answering of the CPR questionnaire before and after playing the game, the Wilcoxon-signed-rank test is performed as the data are paired. To detect significant differences about game experience between group of blind and sighted participants the U de Mann–Whitney test (also known as Wilcoxon rank sum test) is performed as the 5-level Likert scale provides rank data.

Results

Improvement on CPR knowledge
To measure the improvement on CPR knowledge, we scored each question of CPR questionnaire with one point when it was correctly answered, giving a final score from 0 to 10. Table 1 shows

Table 1: Results from the RCP test (see Supporting Information Table S3) before and after playing the game

Blind	*Time*	*Mean*	*Sd*	*Q1*	*Md*	*Q3*	*Wilcoxon-signed rank*
No	Before	2.938	2.46	l	2	4.13	0.008
	After	9.325	0.75	8.94	9.43	10	
Yes	Before	2.125	0.64	2	2	2.25	0.013
	After	9.731	0.50	9.75	10	10	

the obtained results before and after playing the game. Note that for both groups, the difference on CPR knowledge before and after playing is considerable. Before playing, sighted and blind participants, have a median of 2. After playing, this median has increased to 9.43 and 10, respectively. Moreover, despite the low size of the sample, there is significant difference on the knowledge of CPR before and after playing the game on both groups (*p*-value .008 and .013), respectively.

Game experience

A better game experience of blind people against sighted people has been detected (see Supporting Information Table S5). Despite of this, probably due to the low sample size, we have only found significant differences in question Q4 (Game difficult), and Q5 (Game funny) with *p*-values .009 and .03, respectively. These results do not surprise us since we conceived the game for blind people and we do not consider visual aids. We think that adding more graphical effects, the experience of sighted people could be improved.

Enjoyability of mini-games

As in the previous experiment, better results are obtained for the blind participants group (see Supporting Information Table S6) In this group, every first quartile (Q1) of each mini-game is 4 or greater, and all third quartiles (Q3) are 5. On the sighted participants group, Q1 and median are all lower, and Q3 is lower on half of the mini-games. In spite of the low sample size, we have found significant differences on six of the mini-games (*p*-values below .05).

Difficulty of mini-games

Blind participants group found the mini-games less difficult than sighted participants group (see Supporting Information Table S7). Q1 of blind participants group ranges from 1 to 3, while sighted participants group ranges from 3 to 5. Focusing on Q3, this ranges from 2.25 to 4.25, and from 4 to 5, for blind and sighted participants groups, respectively. Again, despite having a low sample size, we have found significant differences on seven of the mini-games (*p*-values below .05).

Discussion and conclusions

Video games have great potential not only to entertain but also as an instrument to improve skills. Focusing on visually impaired people, different games have been proposed to improve orientation and mobility skills (Sánchez & Espinoza, 2011; Sánchez, Espinoza, & Garrido, 2012). It has been proved that skills acquired in virtual worlds are transferable to the real one (Merabet, Connors, Halko, & Sánchez, 2012; Sánchez, Sáenz, & Garrido, 2010). Moreover, the benefits of gaming for improving cognitive, motivational, emotional or social skills have been also studied (Vorderer & Bryant, 2006; Zheng & Gardner 2017).

This paper presented, to our knowledge, the first video game to introduce the CPR protocol to visually impaired people. The proposed game introduces the main steps of the protocol as a set of mini-games where the player has to act as a helper or as an assistant. Mini-games have been designed to reproduce the main actions of the ERC 2015 protocol as a challenge. All the player actions are based on sound, vibration and tactile input and output. We carried out a test with blind and sighted participants to evaluate the game with respect to improvement on CPR knowledge, game enjoyability and difficulty.

From our results, we observed a clear improvement on CPR knowledge after playing the game. From personal interviews with blind participants, they highlighted that the last mini-game, where all the steps of the protocol have to be ordered, is the one that requires major concentration. In addition, it is at this point where they were aware that they know more about the protocol than before playing, which satisfies them. With respect to sighted participants, they also improved their CPR knowledge although they would prefered to play with more visual aids. They considered playing only with audio and vibration stimuli quite difficult although they enjoyed the experience.

With respect to game difficulty some participants, sighted and visually impaired, asked us to repeat instructions several times. To overcome this limitation, we consider that a new version of the game with extra aids is required. Our proposal is to add a practice mode where the player could practice the required actions in order to feel more confident with the mini-game before achieving the final goal. In addition, we are considering adding some visual aids to improve sighted players experience in order to support both type of players.

Although, the obtained results are very promising, we are aware that a main limitation has been the low number of participants in the tests. Therefore, a more exhaustive experiment with a larger population should be done in the future. Moreover, new experiments have to be designed in a CPR teaching scenario with mannequins to evaluate how CPRforBlind improves the learning experience. In particular, we want to compare the proposed approach with other learning procedures for the protocol. We consider that video games are a good strategy to introduce CPR to visually impaired people. In addition, from our experience and considering the obtained results, we consider that the proposed approach can be applied to other scenarios with procedures composed of sequential steps. The idea is to define one mini-game for each step trying to keep coherence between them with a common plot.

Acknowledgements

This work was supported by the Catalan Government (Grant No. 2017-SGR-1101) and by the Spanish Government (Grant No. TIN2016–75866-C3-3-R).

Statements on open data, ethics and conflict of interest

Additional data are available on request to the authors. The experiment was described to all participants and informed consent was obtained from all them. Subjects participated voluntary in the study. They were free to withdraw from the study at any time with no undesirable consequences. The study does not require ethics approval since it did not involve patients or patient data. The authors declare that, to the best of their knowledge, participants were no harmed or disadvantaged through involvement. Participants are anonymous and all identifying information has been removed. The authors declare that there are no conflicts of interest.

References

Bertini, A., Ristori, R., Squicciarini, M., Mazzei, S., Letto, D., & Kette, F. (2015). Can blindness be a limitation to perform CPR? Preliminary Report. *Resuscitation*, *96*, 67.

Boada, I., Rodriguez-Benitez, A., Garcia-Gonzalez, J. M., Thi'O-Henestrosa, S., & Sbert, M. (2016). 30:2: a game to promote cardiopulmonary resuscitation protocol. *International Journal of Computer Games Technology*, doi: 10.1155/2016/82521461

Brewster, S. A. (1998). Using nonspeech sounds to provide navigation cues. *ACM Transactions on Computer–Human Interaction*, *5*, doi:10.1145/292834.292839

Friberg, J., & Gärdenfors, D. (2004). Audio games: new perspectives on game audio. Proceedings of the 2004 ACM SIGCHI International Conference on Advances in Computer Entertainment Technology (ACE '04), Singapore, pp. 148–154. ISBN: 1–58113-882-2.

Ilumens (2011). Staying alive 3D. Retrieved November 27, 2017, from http://www.stayingalive.fr/index?uk.html

Kouwenhoven, W., Jude, J., & Knickerbocker, G. (1960). Closed-chest cardiac massage. *JAMA*, *173*, 1064–1067. doi: 10.1001/jama.1960.03020280004002.

Laerdal. MicroSim Prehospital Laerdalcom (2012). Retrieved November 11, 2017, from http://www.laerdal.com/gb/docid/12984879/
Manduchi, R., & Kurniawan, S. (2017). *Assistive technology for blindness and low vision*. Florida: CRC Press (Rehabilitation Science in Practice Series). ISBN: 9781138073135.
Merabet, L. B., Connors, E. C., Halko, M. A., & Sánchez, J. (2012). Teaching the blind to find their way by playing videogames. *PLoS-One*, *7*, e44958.
Miller, D., Parecki, A., & Douglas, S. A. (2007). Finger dance: a sound game for blind people. Proceedings of the 9th International ACM SIGACCESS Conference on Computers and Accessibility (Assets '07), Tempe, Arizona.
Monsieurs, K. G., Nolan, J. P., Bossaert, L. L., Greif, R., Maconochie, I. K., Nikolaou, N. I., *et al*. (2015). European Resuscitation Council guidelines for resuscitation 2015: Section 1. *Executive Summary. Resuscitation*, *95*, 1–80. 2015. doi:10.1016/j.resuscitation.2015.07.038
Ponder, M., Herbelin, B., Molet, T., Scherteneib, S., Ulicny, B., Papagiannakis, G., *et al*. (2002). Interactive scenario immersion: health emergency decision training in JUST project. International Workshop on Virtual Reality Rehabilitation.
Sánchez, J., Sáenz, M., & Ripoll, M. (2009). Usability of a multimodal videogame to improve navigation skills for blind children. Proceedings of the 11th International ACM SIGACCESS Conference on Computers and Accessibility (Assets '09), ISBN: 978-1-60558-558-1. Pittsburgh, Pennsylvania, USA: ACM. doi: 10.1145/1639642.1639651
Sánchez, J., Espinoza, M., & Garrido, J. (2012). Video gaming for way finding skills in children who are blind. Proc. 9th International Conference on Disability, Virtual Reality and Associated Technologies, pp.131–140. Laval, France: The University of Reading.
Sánchez, J., & Espinoza, M. (2011). Audio haptic video gaming for navigation skills in learners who are blind. Paper presented at the 13th International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'11), pp. 199–208. New York, NY: ACM Press.
Sánchez, J., Sáenz, M., & Garrido, J. M. (2010). Usability of a multimodal video game to improve navigation skills for blind children. *ACM Trans on Accessible Computing*, *3*, 1–29.
Schmitz, B., Klemke, R., Walhout, J., & Specht, M. (2015). Attuning a mobile simulation game for school children using a design-based research approach. *Computers and Education*, *81*, 35–48. ISSN: 0360–1315. doi: 10.1016/j.compedu.2014.09.001,
Semeraro, F., Frisoli, A., Ristagno, C., Loconsole, C., Marchetti, L., Scapigliati, A., *et al*. (2014). Relive: a serious game to learn how to save lives. *Resuscitation*, *85*, e109–e110.
Unity (2017). Game engine. Retrieved from November 19, 2017, from https://unity3d.com/
Unreal (2017). Game engine technology. Retrieved from November 18, 2017, from https://www.unrealengine.com/
VivaGame (2013). Staying alive 3D. Accessed November 16, 2017, from https://play.google.com/store/apps/studioevil.vivagame
Vorderer, P., & Bryant, J. (2006), Playing video games-motives, responses and consequences. Mahwab, NJ: LEA; ISBN: 978–0805853223
Wattanasoontorn, V., Boada, I., Sbert, M., Olivet, J., & Juvinya, D. (2014). LISSA: a serious game to teach CPR and use of AED. *Resuscitation*, *85*, 72.
Yuan, B., Folmer, E., & Harris, F. C. (2011). Game accessibility: a survey. *Universal Access in the Information Society*, *10*, 81–100. doi: 10.1007/s10209-010-0189-5
Zheng, R., & Gardner, M. (2017). *Handbook of research on serious games for educational applications*. Hershey, PA: IGI Global. ISBN: 10: 152250513X

Appendix

CPR protocol

According to ERC, the CPR protocol (or adult basic life support sequence) is composed of eight main steps that have to be applied sequentially. These steps and their corresponding actions are (1) Safety. Make sure that the helper, the victim of cardiac arrest, and any bystanders are safe; (2) Response. Check the victim for a response; (3) Airway. Open airway using the head tilt and chin lift technique; (4) Breathing. Look, listen and feel for normal breathing; (5) Alert. Call emergency services and send someone to get automatic external defibrillator; (6) Circulation. Start chest compressions combined with rescue breaths; (7) Defibrillator. If there is an assistant in the scene and also an AED, the assistant has to follow AED instructions while helper continues with compressions and rescue breaths. Repeat (6) and (7) until health professionals arrive or the victim recovers. In this last case, (8) Recovery position. Place the victim in the recovery position. For a more detailed description, please see Monsieurs *et al*. (2015).

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Chapter 6

Design and evaluation of a serious game to educate on choking

In the context of the second goal of the thesis focused on how serious games can be used as a tool to teach first-aid protocols, a game to promote choking protocol among non-expert people is presented. The chapter describes the game which is composed of a set of mini-games representing the main steps of the protocol. The evaluation that has been carried out is also presented.

This contribution has been submitted to *JMIR Serious Games* under the title *Design and evaluation of a serious game to educate on choking* with the following authors *Antonio Rodríguez-Benítez, Imma Boada, Santiago Thio-Henestrosa, and Josep Soler*

Design and evaluation of a serious game to educate on choking.

Abstract

Background and Objective: Choking is one of the causes of unintentional injury death. Prevention and knowledge of the first-aid procedure that has to be applied in case of choking can increase the chances of survival for choking victims. Serious games can be a good channel to educate on this topic. Our objective is to present and evaluate the effectives of a serious game designed to prevent choking and promote the first-aid procedure to be applied.

Methods: A game that reproduces the main steps of the first-aid choking protocol as a set of mini-games is presented. In the proposed game, the player acquires the role of a helper who has to save the victim of a choking emergency by applying the main steps of the protocol. Time and score restrictions are imposed to pass each mini-game. To test the game, a pilot study with 48 high school students has been carried out. Different tests to assess subjects preferences and their knowledge on the topic have been performed before and after playing the proposed game. The obtained results have been analyzed using U Mann-Whitney test, when a grade variable was involved, and Fisher exact test, when we have two categorical variables.

Results: The analysis performed showed that players enjoyed the game. No statistical differences were detected when considering the gender of the player, their preferences for games or their previous experience on choking emergencies. Comparing their knowledge before and after playing the game we detected that all indicators of the knowledge about how to act in case of a choking emergency have improved.

Conclusion: The proposed game is a good strategy to promote and teach first-aid procedures on choking emergencies to non experts on the topic.

Keywords: Serious games; choking; first-aid procedures; first-aid education.

1. Introduction

A foreign object lodged in the throat or windpipe may cause choking and unless the air passage is cleared the choking person can lose consciousness within three to five minutes. In the worst cases, the lack of oxigen to the brain could cause brain damage or death. In these situations, it is recommended to administer as quickly as possible first-aid which consists of abdominal thrusts combined with back blows [1]. Unfortunately, not all the people know this procedure and strategies to promote it are necessary [2].

With the aim to educate about choking risks, prevention and treatment, different approaches have been proposed. On the one hand, organizations, such as the Resuscitation Council [3], the Red Cross [1], or the American Heart Association [4], have defined guidelines that describe how choking interventions should be undertaken both safely and effectively. These organizations also offer courses, videos, and other materials to teach the choking rescue procedure. In addition, many countries have initiated campaigns to educate citizens about prevention, risks, and treatment of choking. Special attention has been given to children since they are the most susceptible to choking [5]. The effectiveness of these initiatives have also been studied and, in most of the cases, the general conclusion is that prevention strategies are effective and contribute to decrease choking incidence [6, 7, 8]. On the other hand, there are initiatives focused on the development of first-aid training devices. Zoll Medical corporation proposed a handheld device that uses several accelerometers to monitor abdominal thrusts [9]. More recently, Watson and Zhou [10] presented BreathEZ, a smartwatch application that provides both choking first-aid instruction and real-time tactile and visual feedback on the quality of the abdominal thrust compressions.

In this paper, we propose to tackle the problem using serious game strategies. Serious games are digital games used for purposes other than mere entertainment and are applied in different areas such as military, government, educational, or healthcare [11]. They can recreate scenarios to experiment with situations that otherwise would be impossible in the real world due to required safety, cost, and time [12]. In addition, serious games enhance the development of skills, such as analytical and spatial, strategic, or psychomotor [13]. Although, there is a large number of serious game applications related to health and healthcare, as far as we know, no serious game only focused on first-aid choking education exists.

2. Background

Serious games for health and healthcare include application areas such as simulation and training, health promotion and education, or rehabilitation. For surveys on the topic see [14, 15, 16]. In this section, we review some of these games.

In the context of *simulation and training*, there are games that provide health professionals with simulation environments and virtual patients to practice and acquire relevant skills with no risks for the patient [17]. For instance, MyCraft provides virtual consultation training with a focus on tuberculosis [18]. There are also games to practice surgeries, blood management, image-guided procedures, assessment, prevention, and treatment [19, 20, 21, 22, 23]. Focusing on *health promotion and education*, there are games to deal aspects such as hygiene, daily activity, mobility or healthy eating. Some examples are: Yummy Tricks, a game intended to teach healthy eating habits[24, 25, 26] or the game by Ito et al. developed to evaluate the dissemination of public awareness on preschool childrens oral health [27, 28]. Centered on *rehabilitation*, proposed games present new strategies to make rehabilitation exercises more fun compared to traditional methods. These cover two main areas: (i) cognitive rahabilitation games, designed for patients to achieve a highest level of functioning proposing individualized goals according to their strengths and weaknesses. Some examples are games to recover from brain injury or cognitive impairments [29]; and (ii) physical-motor rehabilitation games, designed to help patients to recover from some motor deficiency [30]. For a survey on serious games for rehabilitation see [31].

Focusing on *first-aid*, the Virtual Heroes company [18] proposed serious games for healthcare professionals such as 3DiTeams, a first person, multi-player training application where the player is placed in a high fidelity virtual hospital, Combat Medic, an online 3D collaborative virtual world to deal with hemorrhage, airway management and tension pneumothorax, or HumanSim: Blast where after a train station explosion, the player must identify and label zones on an area map, tag potential hazards, assess patient vitals, perform life-saving procedures, and triage patients. In a similar way, BreakAway Company proposed Code Orange [32], a serious game where the players work in concert with the first-aid staff of a hospital to save people injured by a weapon-of-mass-destruction event. Other games for emergency staff training are Nuclear Event Triage Challenge [33], Peninsula City [34], Burn Center [35], and CliniSpace [36]. In the field of cardiopulmonary resuscitation, Jerin et al. proposed AED Challenge, a web-based serious game for teaching and training automated external defibrillation and first-aid maneuvers to lay people and emergency medical services professionals [37]. Other proposals are: JUST [38], an immersive virtual reality situation training system for non-professional health emergency operators; MicroSim Prehospital [39] designed for pre-hospital training on emergency medical services, and Staying alive [40], an on-line 3D simulator which provides a learning experience of saving a virtual patient from cardiac arrest in four minutes; LISSA [41, 42] presents an emergency situation where cardiopulmonary resuscitation actions have to be applied to save the victim; 30:2 [43] is a game to educate on CPR to non experts; Relive [44], a first person 3D adventure where the player faces different rescue situations; Viva!Game [45], a Web-based serious game designed to create awareness on cardiac arrest and cardiopulmonary resuscitation, and HeartRun [46], a mobile simulation game to train resuscitation and targeted at giving school children an understanding of this protocol. In the context of choking, Carvalho et al. [47] proposed an Android application video game where different first-aid actions are presented to familiarize users with these scenarios being choking one of them. In most of the cases, games focused on first-aid procedures have been designed for players with a health background being the game a media to practice on a given topic [48]. In general, few attention has been paid to non-experts although first-aid protocols would be a basic knowledge for everyone.

3. Material and Methods

3.1. The choking prevention game

The aim of the proposed game is to introduce the main steps of the first-aid choking prevention protocol to non-experts on the topic. To design the game we have considered the main steps of the protocol illustrated in Figure 1. For each step we have defined a mini-game resulting in a game composed of 6 mini-games, a first one focused on dangerous elements that can produce choking and the rest centered on the steps of the procedure to be applied in case of a choking emergency.

In all the mini-games, the player acts as a helper who can play each mini-game independently to reach the maximum level, or sequentially completing all the sequence of mini-games with the same level of difficulty to see the whole protocol each time. In all the games, correct actions add points and incorrect ones subtract, being the mini-game over when time is finished or the maximum score is reached. For the seek of simplicity, game scenarios follow a same screen design with time and score information on the top of the screen as well as help messages used to highlight relevant information of the step protocol. To guide the player between mini games at the beginning of each mini-game we present the instructions of the step protocol as highlighted keywords, with the goal that the player could retain them easily. In addition, at the end of the mini game, another message communicates if the step has been achieved or not. Below, a more detailed description of each mini-game is given below. and a complete demo of the game is provided at http://gilabparc.udg.edu/jocs/choking/trailer.mov.

3.1.1. Mini-game 1. Choking prevention

In the first mini-game, we focus on children which are more likely to choke than adults. The aim of this mini-game is to promote three tips for preventing choking: (i) avoid small and dangerous objects; (ii) keep food pieces small; and (iii) do not move while eating. To reproduce these situations, an icon representing a child appears in the middle of the screen and different elements fall around it. The player has to interact with these elements and carry out different actions according to elements (see Figure 2). In particular, if it appears a danger element, the player has to drag it out of the screen. If it appears a piece of meat, the player has to click on it five times to simulate small pieces cutting. If the child icon moves from the center, the player has to drag it to the center again. This last action represents do not move while eating. In Figure 3(a), 3(b) and 3(c), the different scenarios corresponding to these situations are illustrated.

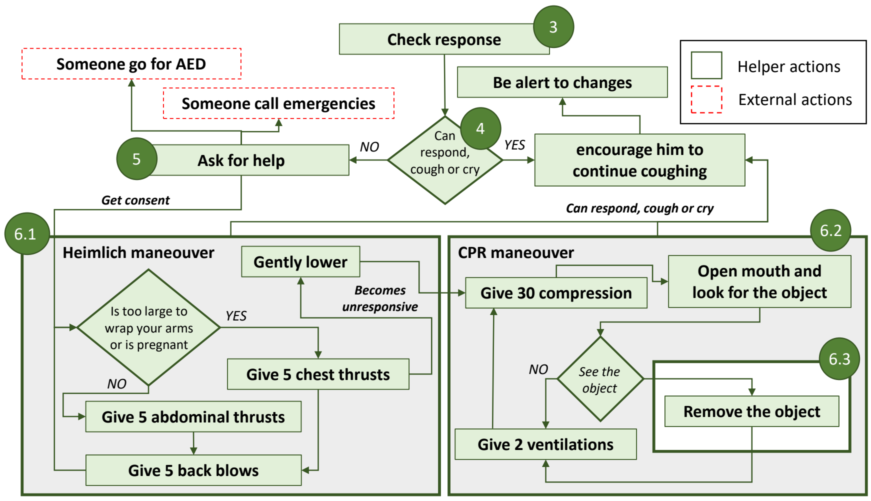


Figure 1: Main steps of the first-aid procedure that has to be applied in a choking emergency. The numbers in the boxes indicate the relationship of proposed mini-games with the procedure steps.

Figure 2: Some of the items of the choking prevention mini-game where player actions vary according to the type of item.

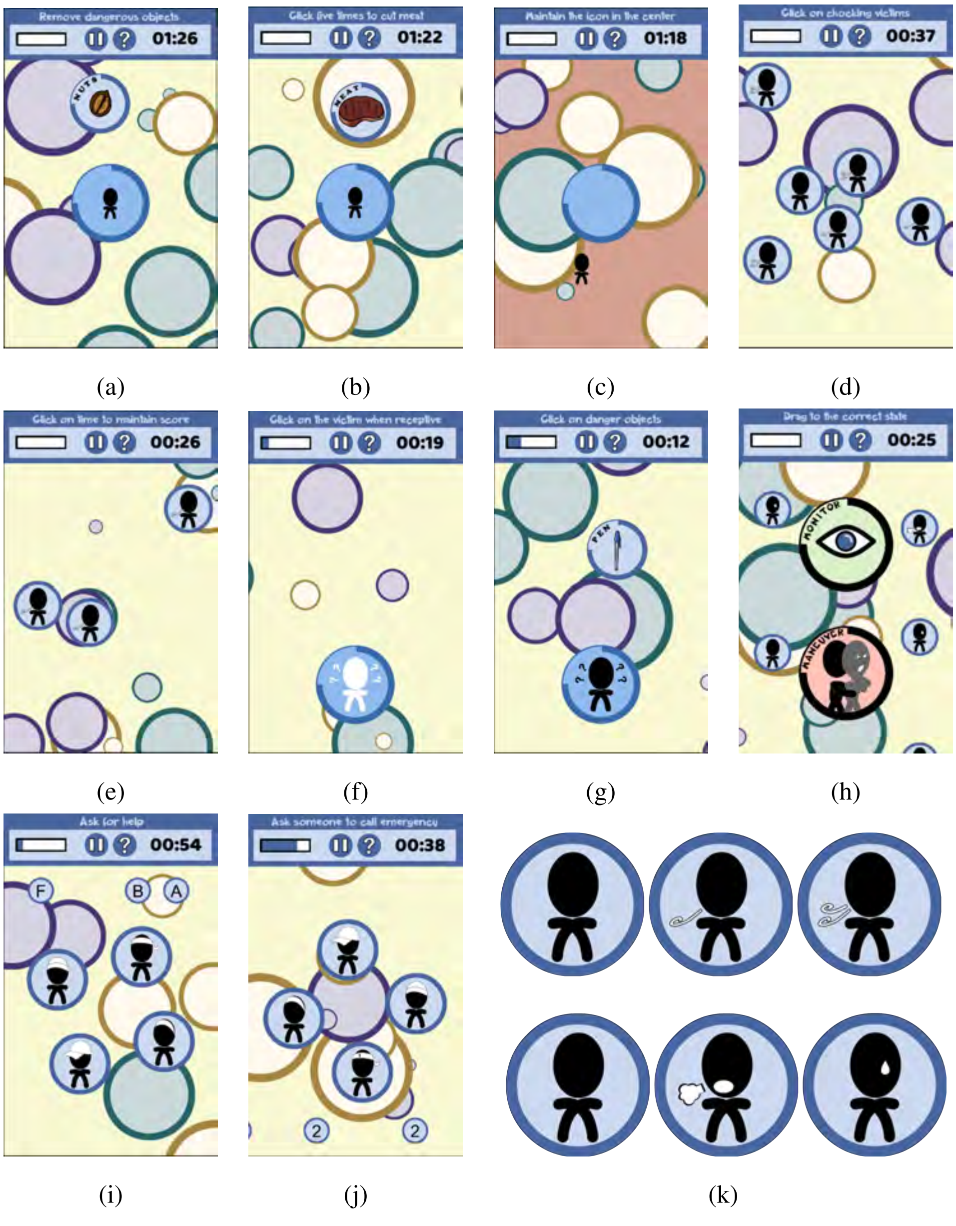


Figure 3: Choking prevention mini-game: (a) avoid small and dangerous objects; (b) keep food pieces small; and (c) do not move while eating; Identify choking victims mini-game ((d) and (e)); Ask for response mini-game ((f) and (g)); Identify choking symptoms mini-game (h); Aks for help mini-game ((i) and (j)). The icons representing breath status (no breath-breath with difficulties-normal breath) and choking symptoms (no breath-cough-cry) (k).

3.1.2. Mini-game 2. Identify choking victims

The aim of this mini-game is to identify choking victims and remove them from the screen. On the screen appear person icons with two, one, or no air lines (see Figure 3(k)) to represent breath status as normal, with difficulties, and airway totally blocked, i.e. choking victims, respectively. When the icon is on the screen its breath status can become worse (see Figure 3(d) and 3(e)). The player has to click on choking victims and if these are not selected they will disappear and the player score will decrease.

3.1.3. Mini-game 3. Check response

A choking victim will not be able to talk but will probably communicate through signs and actions, such as grabbing his or her throat. The rescuer has to know when the victim is able to communicate or not. To reproduce this situation, in this mini-game, a victim represented as a person icon appears on the screen. The icon changes its color from black to white to indicate that victim is receptive to be asked or not, respectively. In addition, danger elements going to the victim appear on the screen. The player has to drag these objects out from the screen and click on the victim when this is receptive to be asked. If a danger object arrives to the victim, this become not receptive and the player score will decrease. Score also decreases when a no receptive victim is asked. In Figure 3(f) and 3(g) screenshots of this mini-game are presented.

3.1.4. Mini-game 4. Identify choking symptoms

A choking victim typically has a panicked, confused or surprised facial expression and usually place hands on their throat. If the airway is not totally blocked, victims will be able to cough or make squeaking noises trying to breathe. If airway is totally blocked the victims will not be able to speak, cry or cough and their skin will range from red to pale due to lack of oxigen. In this mini-game, person icons appear on the screen and some of them represent choking symptoms. The player has to identify icons and separate choking victims from the others. Points are lost in case of incorrect or no classification of victims. A screenshot of this mini-game is presented in Figure 3(h) and the icons representing the different symptoms in Figure 3(k).

Figure 4: Icons representing different hands position used in the ....

3.1.5. Mini-game 5. Ask for help

After identification and confirmation that victim is choking the player has to ask for help and call to emergency number. In this mini-game, person icons will appear on the screen as well as letters on the top and numbers on the bottom. The player has to select one of the icons and write *help* by attaching selected letters from the top. Icons and letters are continuously moving. The same procedure has to be done to call emergencies selecting one of the icons, not necessarily the same, and attaching the correct emergency numbers. The player ends the game when *help* and the correct emergency number are written. In Figure 3(i) and 3(j) the game screens are shown.

3.1.6. Mini-game 6. Choking manouver

This mini-game represents the most important part of the choking rescue protocol. To reproduce it we have divided the mini-game in three parts that recreate black blows and abdominal thrust, cardiopulmonary resuscitation, and object removal, respectively. To pass the mini-game the player has to pass the three parts. The description of each part is presented below.

- *Back blows and abdominal thrust.* For adult and child victims, to force the object out of the airway the helper has to give a combination of five back blows between the shoulder blades followed by five abdominal thrusts inward and upward thrusts just above the navel. To reproduce this situation two silhouettes, representing the victim and the helper, and icons representing different hands positions will appear on the screen. First, the player has to put the victim on the correct position by clicking on the head and dragging to the right side (see Fig-

Figure 5: Choking manouver screens corresponding to the different parts of the mini-game: Images (a), (b), (c), (d), and (e) correspond to Back blows and abdominal thrust; Images (b), (f), (g), (h), and (j) to cardiopulmonary resuscitation; and image (i) to remove the object.

ure 5(a)) and select the correct hand position represented in one of the different icons that will appear (see Figures 4 and 5(b)). Then, the player has to give five clicks on the correct position of the victim (see Figure 5(c)) to simulate the five back blows. Player has to place victim in the initial position by clicking on the head and dragging to the left side (see Figure 5(d)). The player has to perform five abdominal thrust by selecting the correct hands position (see Figure 5(b)) and then clicking five times in the correct position (see Figure 5(e)). This process is repeated until the victim ejects the object or passes out. If the victim ejects the object, a new victim will appear. If the victim passes out, the second part of the mini-game, the cardiopulmonary resuscitation will start.

- *Cardiopulmonary resuscitation.* When the victim is unresponsive because back blows and abdominal thrust have been unsuccesfull, the player has to perform the cardiopulmonary resuscitation protocol (CPR) which combines 30 chest compressions with 2 rescue breaths. First of all, the player has to gently lower the victim by touching the body while this is falling (see Figure 5(f)). At this point of the mini-game, the victim and the helper stay in position of the CPR protocol. To start the player has to select the icon representing the correct hands position to perform chest compressions (see Figures 4 and 5(b)). Then, the player has to click 30 times on the victims chest following the correct rhythm (see Figure 5(g)). After each set of chest compressions and before rescue breaths, player has to click on victims mouth and look for the object. If the player sees an object, the third part of the mini-game starts (see Figure 5(h)). If the object is not visible, the player has to perform two rescue breaths by touching victim's mouth following the correct rhythm (see Figure 5(k)). Again a new sequence of compressions has to be performed and repeat the process until help arrives.

- *Remove the object.* If the helper sees the object on the mouth of the victim, this has to be removed. To reproduce this situation, the object appears into the mouth of the victim with a sphere behind it. The sphere changes its colour and the player can only move the object when it is green (see Figure 5(j) and (i)). If the player moves the object when the sphere has another colour the object will fall. The object has to be removed with the given time.

3.2. Designed study and statistical analysis

To test the game a sample population composed of 48 subjects from a summer campus of our university created to promote the research groups was considered. Our laboratory, the Graphics and Imaging Laboratory, participated in this campus in a two hours session that took place in a computers room. The aim of the session was to introduce students to video games and serious games. After a first introduction of our research, we asked them to answer the questionnaire presented in Table 1. Then, the students had 30 minutes to play the proposed game as an example of a serious game. Each student has a computer to play and no introduction to the game was given, we just asked them to play it. During the session, we observed them to detect game difficulties. At the end, we asked them to answer the new questionnaire presented in Table 2.

To detect significant statistical differences we used U Mann-Whitney test, when a grade variable was involved, and Fisher exact test, when we have two categorical variables.

4. Results

The obtained results are presented in three subsections. The first one describes our sample population, the second one the results obtained from game performance evaluation, and the third one compares the results obtained before and after playing the game.

4.1. Testing population

Our testing population was composed of 16 males (33.3%), and 32 females (66.7%). They have an age mean of 15.42 years (Standard deviation = 0.74 years). From this population, 29 subjects liked videogames (60.4%) while19 do not like (39.6%), and 12 have been in a choking emergency (25%), while 36 have never been in this emergency situation (75%).

1. Select gender	Male/female
2. Age	Number
3. Do you like video games?	Yes/No
4. Do you know what is a choking?	Yes/No
5. Grade from 1 to 5 your knowledge of choking protocol	1..5
6. Have you ever been in a choking emergency?	Yes/No
7. In case of choking, to remove the throat object you have to	
(only one correct option)	
- Perform abdominal thrust until object expulsion	
- Perform back blows until object expulsion	
- Repeat five back blows and five abdominal thrust until object expulsion	
- Repeat ten back blows and ten abdominal thrust until object expulsion	
8. In case of choking, the resuscitation protocol (CPR) to be applied?	
(only one correct option)	
- In all the cases, it is a part of the choking protocol	
- In case of unconscious victims	
- Never, the object causing choking does not allow to apply CPR	
9. Write the emergency number	Number

Table 1: Test1 questions carried out before playing the game

(*) Questions 4, 5, 7, 8 and 9 of Test 1
Grade from 1(completely desagree) to 5 (completely agree)
a. The game entertaints
b. I like the game
c. The complexity of the game is correct
d. The help indications provided by the game are enough
e. The game describes how to proceed in a choking emergency
f. After playing the game I know how to proceed in a choking emergency

Table 2: Test2 questions carried out after playing the game. This test repeats questions 4, 5, 7, 8 and 9 from Test1

Grade from 1(completely desagree) to 5 (completely agree)	Q1	Median	Q3
a. The game entertaints	3	3,5	4
b. I like the game	2	3,02	4
c. The complexity of the game is correct	3	3,46	4
d. The help indications provided by the game are enough	2	3,8	4
e. The game describes how to proceed in a choking emergency	2,75	3,58	5
f. After playing the game I know how to proceed in a choking emergency	2	3,13	4

Table 3: Descriptive statistics of the answers to the questions related to the game

4.2. Evaluation of game performance

Firstly, we present the results obtained from the answers related to game such as complexity and degree of entertainment (see Test2 questions from *a* to *f*). Then, we describe the results considering player gender, videogame preferences, and choking emergency experience.

In Table 3 descriptive statistics of the answers to the questions related to the game are shown. Although, answers are not extremely positive we can observe that they tend to be more positive than negatives. Note that all medians are above 3, being the highest values items: e.*The game describes how to proceed in a choking emergency*, a.*The game entertains*, and c. *The complexity of the game is correct.* From these results, we consider that the primary aim of the game, teaching the procedure to be applied in case of choking, has been reached. In addition, we have seen that players enjoyed the game, it has been considered not boring and not difficult.

In Table 4, descriptive statistics of the answers to the questions related to the game considering player gender are shown. No statistically significant differences were found except on item c. *The complexity of the game is correct* where agree more men than women. The results considering subjects that like or not videogames are presented in Table 5 and, in Table 6, considering subjects that have been in a choking emergency or not. In any of the cases no statistically significant differences were found. Therefore, we can consider that the game fits to the different player profiles.

Question	Gender	Q1	Median	Q3	p-value
a. The game entertaints	woman (32)	3	4	4	0,212
	man (16)	2	3	4	
b. I like the game	woman (32)	2	3	4	1
	man (16)	2	3	4	
c. The complexity of the game is correct	woman (32)	3	3	4	0,0257
	man (16)	3,75	4	4,25	
d. The help indications provided	woman (32)	2	3	4	0,8479
by the game are enough	man (16)	2	3	4	
e. The game describes how to	woman (32)	2,75	4	4,25	0,6921
proceed in a choking emergency	man (16)	3	4	5	
f. After playing the game I know	woman (32)	2	3	4	0,6854
how to proceed in a choking emergency	man (16)	3	3	4	

Table 4: Descriptive statistics of the answers to the questions related to the game by gender.

Question	Do you like videogames?	Q1	Median	Q3	p-value
a. The game entertaints	Not like(19)	3	3	4	0,8956
	Like (29)	3	4	4	
b. I like the game	Not like(19)	2	3	3	0,1745
	Like (29)	2	3	4	
c. The complexity of the game is correct	Not like(19)	3	3	4	0,1885
	Like (29)	3	4	4	
d. The help indications provided	Not like(19)	2	3	4	0,6401
by the game are enough	Like (29)	2	3	4	
e. The game describes how to	Not like(19)	3	4	4,5	0,6391
proceed in a choking emergency	Like (29)	3	3	5	
f. After playing the game I know	Not like(19)	2	3	4	0,3623
how to proceed in a choking emergency	Like (29)	3	3	4	

Table 5: Descriptive statistics of the answers to the questions related to the game by the fact of the subjects like or not videogames.

Question	**Have you ever been in a choking scenario?**	**Q1**	**Median**	**Q3**	**p-value**
a. The game entertaints	No (36)	3	4	4	0,6836
	Yes (12)	2,75	3,5	4	
b. I like the game	No (36)	2	3	3	0,8733
	Yes (12)	2,75	3	4	
c. The complexity of the game is correct	No (36)	3	4	4	0,5712
	Yes (12)	3	3	4	
d. The help indications provided	No (36)	2	3	4	0,8155
by the game are enough	Yes (12)	2	3	4	
e. The game describes how to	No (36)	3	4	5	0,4982
proceed in a choking emergency	Yes (12)	2,75	3,5	4,25	
f. After playing the game I know	No (36)	2	3	4	0,7224
how to proceed in a choking emergency	Yes (12)	2,75	3	4	

Table 6: Descriptive statistics of the answers to the questions related to the game by the fact that the subject have ever been in a choking emergency.

4.3. Protocol knowledge before and after playing

Secondly, focusing on the main steps of the choking protocol (see Test1 questions from 4 to 9) we compared the answers obtained before and after playing the game. In Table 7, the self impression of the knowledge of the choking protocol before and after playing the game (p-value = 0.00001) is shown. In addition, in Table 8 and Table 9, the results of how the subjects have to act in case of choking to remove the throat object (p-value = 0.0003), and when has the resuscitation protocol to be applied (p-value = 0.00002), are shown. On these two analysis, we have compared the correct answer in front of the incorrect. We can observe that all indicators of the knowledge about how to act in case of a choking emergency have improved after playing the game.

5. Discussion

Serious games have become a useful training technology for health profession and also for patients to teach them procedures regarding their health habits. In this context,

		Q1	Median	Q3	p-value
Grade your knowledge of choking protocol	Before playing	2	3	4	0,00001
	After playing	3	4	5	

Table 7: Self impression of the knowledge of the choking protocol before and after playing the game.(Grade from 1 to 5)

		After the game			
		Correct	Incorrect	**Total**	p-value
Before the game	Correct	28	0	**28**	0,0003
	Incorrect	12	8	**20**	
	Total	**40**	**8**		

Table 8: Action in case of choking to remove the throat object before and after playing the game.

		After the game			
		Correct	Incorrect	**Total**	p-value
Before the game	Correct	27	1	**28**	0,00002
	Incorrect	8	12	**20**	
	Total	**35**	**13**		

Table 9: In case of choking, when has the resuscitation protocol to be applied before and after playing the game.

the main applications areas include, amongst others, surgery, odontology, cardiology, nursing, diabetes, pshycology, and first-aid [16]. Focusing on the latter, first-aid, triage, and mass emergency are the most popular fields with games developed for training residents, medical doctors or students. Few attention has been paid to general players with no health background. Moreover, although different games have been proposed to educate on first-aid procedures such as the resuscitation cardiopulmonary protocol, as far as we know, no game focused on the first-aid choking procedure has been proposed. To overcome these limitations, in this paper, we have proposed a game for general population to introduce the main steps of this procedure.

In the proposed game, the player acquires the role of a helper who has to save the victim of a choking emergency by applying the main steps of the first-aid choking protocol which have been represented as mini-games. To guide the player in the mini-games, help messages with the instructions of the step protocol appear on the top of the screen. Time and score restrictions are imposed to pass each mini-game. To test the game a sample population composed by 48 students has been considered. In the tests we have evaluated player impressions about game complexity, enjoyability, etc. and also the knowledge of the procedure to be applied in case of choking before and after playing the game. From the results, we have observed that players have enjoyed the game with no differences depending on the player gender, the preference for games or the previous presence in a choking emergency. Regarding the acquired knowledge on the procedure we have observed that it has been improved. Therefore, the aim of the serious game has been reached, it educates on choking.

Although, the obtained results are satisfactory, we consider that different improvements need to be done. In our study, we focused our interest on high school students, which is a limiting factor since all of them are in the same range of ages. To overcome this limitation, our idea is to extend the study to a more general population. Moreover, we have not considered particular player's capabilities, needs and interests. Our idea is to adapt the game according to player age group. We also want to consider players with visual impairments [49].

6. Conclusions

Serious games are increasingly gaining space in health to complement and promote training of experts in the field. However, few attention has been paid to the use of serious games as a tool to promote health contents to non expert population. With the aim to educate on first-aid choking procedure, a serious game has been proposed. The game introduces the main steps of the procedure as a set of mini-games. It has been tested in a pilot study and very promising results have been obtained. Participants enjoyed the game and, more important, they improved their knowledge on the topic. We can conclude that serious games are a good strategy to promote first-aid knowledge to non experts.

Conflict of interest

There are no conflicts of interests.

Acknowledgements

This work was supported by the Catalan Government (Grant No. 2017-SGR-1101) and by the Spanish Government (Grant No. TIN2016-75866-C3-3-R).

[1] https://www.redcross.org.uk/first-aid/

[2] B.G. Nichols, A. Visotcky, M. Aberger, N.M. Braun, R. Shah, S. Tarima, D.J. Brown. Pediatric exposure to choking hazards is associated with parental knowledge of choking hazards, International Journal of Pediatric Otorhinolaryngology,76, (2), (2012), pp.169-173

[3] https://www.resus.org.uk/apps/lifesaver/

[4] https://www.heart.org/

[5] A.Thamboo, T. Nguyen, and J.P.Ludemann. Choking Prevention: Shortcomings of Traditional Public Education Campaigns, Prompting the Development of Web-Based Interactive Teaching Tools for Preteens, Teenagers, and Adults.

Journal of Otolaryngology – Head Neck Surgery, 38(6), (2009). pp.646651. https://doi.org/10.2310/7070.2009.080277

[6] C. K. Bentivegna, K. T. Borrupa,, M.E. Clough, S.R. Schoemc, Basic choking education to improve parental knowledge, International Journal of Pediatric Otorhinolaryngology 113 (2018) pp.234239 https://doi.org/10.1016/j.ijporl.2018.08.002

[7] A.D. Karatzanis, A. Vardouniotis, J. Moschandreas, E.P. Prokopakis, E. Michailidou, C. Papadakis, D.E. Kyrmizakis, J. Bizakis, G.A. Velegrakis, The risk of foreign body aspiration in children can be reduced with proper education of the general population, Int. J. Pediatr. Otorhinolaryngol. 71 (2007) pp. 311315, https://doi.org/10. 1016/j.ijporl.2006.10.020.

[8] N. Sadan, A. Raz, B. Wolach, Impact of community educational programmes on foreign body aspiration in Israel, Eur. J. Pediatr. 154 (1995) pp.859862.

[9] M. H.Totman, Method of measuring abdominal thrusts for clinical use and training, US Patent 8,827,721 (2014).

[10] A. Watson, G Zhou BreathEZ: Using smartwatches to improve choking first-aid Smart Health (2018), https://doi.org/10.1016/j.smhl.2018.07.026i

[11] D.Michael, and S. Chen, Serious games: Games that educate, train, and inform. Boston, MA.: Thomson Course Technology. (2006)

[12] K. Squire, and H. Jenkins, H. Harnessing the power of games in education. Insight, 3(1), (2003) pp.5-33

[13] A. Mitchell, and C. Savill-Smith The use of computer and video games for learning: A review of the literature. Learning and Skills Development Agency. [www.LSDA.org.uk] (2004)

[14] V. Wattanasoontorn, I.Boada, R. Garca, and Mateu Sbert, Serious Games for Health, Entertainment Computing, 4 (4), (2013) pp.231-247

[15] F.Laamarti, M. Eid, and A.El Saddik, An Overview of Serious Games International Journal of Computer Games Technology, Article ID 358152, (2014,) pp.1-15, http://dx.doi.org/10.1155/2014/358152

[16] F. Ricciardi and L.T. De Paolis A Comprehensive Review of Serious Games in Health Professions. International Journal of Computer Games Technology, Article ID 787968, (2014), pp.1-11 http://dx.doi.org/10.1155/2014/787968

[17] M.Graafland, J.M. Schraagen, M.P. Schijven, Systematic review of serious games for medical education and surgical skills training. British journal of surgery. (2012), Oct 1;99(10):1322-30.

[18] https://www.virtualheroes.com/portfolio/Medical/

[19] J. Qin, Y. Chui, W. Pang, K. Choi, and P. Heng, Learning blood management in orthopedic surgery through gameplay, IEEE Computer Graphics and Applications, vol. 30, no. 2, (2010) pp. 4557,

[20] H. Sabri, B. Cowan, B. Kapralos, F. Moussa, S. Cristancho, and A. Dubrowski, Off-pump coronary artery bypass surgery procedure training meets serious games, Proceedings of the 9th IEEE International Symposium on Haptic Audio-Visual Environments and Games (HAVE 10), pp. 15, Phoenix, Ariz, USA, October 2010.

[21] W.-Y. Chan, J. Qin, Y.-P. Chui, and P.-A. Heng, A serious game for learning ultrasound-guided needle placement skills, IEEE Transactions on Information Technology in Biomedicine, 16 (6) (2012) pp.10321042.

[22] Virtual Heroes, Va critical thinking, http://virtualheroes.com/ projects/va-critical-thinking.

[23] B. Richards, University of Glamorgan, Treforest, UK. Virtual ECG, http://ecg.glam.ac.uk/.

[24] M. Papastergiou. Exploring the potential of computer and video games for health and physical education: A literature review. Computers and Education.30;53(3):(2009),pp.603-22.

[25] A. Makhlysheva, E. Arsand, G. Hartvigsen, Review of serious games for people with diabetes. Handbook of Research on Holistic Perspectives in Gamification for Clinical Practice. (2015) Sep 1:412.

[26] B.A. Primack, M.V. Carroll, M. McNamara, M.L. Klem, B. King , M.Rich, C.W. Chan, S. Nayak. Role of video games in improving health-related outcomes: a systematic review. American journal of preventive medicine. 42(6) (2012) pp.630-8.

[27] C. Ito, A. V. Marinho Filho, M. Ito, M. M. Azevedo, and M. A. de Almeida, Preliminary evaluation of a serious game for the dissemination and public awareness on preschool childrens oral health, Studies in Health Technology and Informatics, 192, (2013) pp.1034.

[28] G.Ingls-Camats, M.Presno-Rivas, M. Antonijoan, O. Garcia-Panella, T. Forres, Yummy Tricks: A Serious Game for Learning Healthy Eating Habits. Series Studies in Health Technology and Informatics Ebook Volume 172: Advancing Cancer Education and Healthy Living in Our Communities 185-190, doi: 10.3233/978-1-61499-088-8-185

[29] M.van der Kuil, J. Visser-Meily, A. Evers, A., and I van der Ham.A Usability Study of a Serious Game in Cognitive Rehabilitation: A Compensatory Navigation Training in Acquired Brain Injury Patients. Frontiers in psychology, 9, (2018). 846. doi:10.3389/fpsyg.2018.00846

[30] N.Preston, A. Weightman, J.Gallagher, M.Levesley, M. Mon-Williams, M.,Clarke, (2015). A pilot single-blind multicentre randomized controlled trial to evaluate the potential benefits of computer-assisted arm rehabilitation gaming technology on the arm function of children with spastic cerebral palsy. Clinical Rehabilitation 30, 10041015. doi: 10.1177/0269215515604699

[31] P.A Rego, P.M. Moreira, I.P. Reis. Serious Games for Rehabilitation: A survey and a classification towards a taxonomy. 5th Iberian Conference on Information Systems and Technologies (CISTI), (2010)

[32] BreakAway, Code Orange, http://www.breakawaygames.com/ serious-games/solutions/homeland.

[33] B. P. Bergeron, Learning and retention in adaptive serious games, Studies in Health Technology and Informatics, 132, (2008) pp. 2630.

[34] W. L. Heinrichs, P. Youngblood, P. M. Harter, and P. Dev, Simulation for team training and assessment: case studies of online training with virtual worlds, World Journal of Surgery, 32(2),(2008) pp.161170.

[35] S. N. Kurenov, W. W. Cance, B. Noel, and D. W. Mozingo, Game-based mass casualty burn training, Studies in Health Technology and Informatics, 42, Article ID 142144 (2009) pp.142144.

[36] P. Dev, W. L. Heinrichs, and P. Youngblood, CliniSpace: a multiperson 3D online immersive training environment accessible through a browser, Studies in Health Technology and Informatics, 163, (2011), pp.173179.

[37] J. M. Jerin, B. A. Ansell, M. P. Larsen, and R. O. Cummins, Automated external defibrillators: skill maintenance using computer- assisted learning, Academic Emergency Medicine, 5(7), (1998) pp. 709717.

[38] M. Ponder, B.Herbelin, T.Molet, S.Scherteneib, B.Ulicny, G.Papagiannakis, N.Magnenat-Thalmann, D.Thalmann, Interactive scenario immersion: Health emergency decision training in just project. International Workshop on Virtual Reality Rehabilitation, (2002) pp.87-101

[39] Laerdal Medical (2012), MicroSim Prehospital, http: //www.laerdal.com/gb/docid/12984879/ MicroSimPrehospital.

[40] Ilumens(2011).StayingAlive3D.http://www.stayingalive.fr/index?uk.html

[41] V. Wattanasoontorn, I. Boada and M. Sbert. LISSA: A Serious Game to learn Cardiopulmonary Resuscitation. Resuscitation 85(S1) (2014) S72 doi:0.1016/j.resuscitation.2014.03.182

[42] I.Boada, A. Rodriguez-Benitez, J.Garcia-Gonzalez, J.Olivet, V. Carreras, M.Sbert, Using a serious game to complement CPRinstruction in a nurse faculty, 122 Computer Methods and Programs in Biomedicine (2015) pp.282-291 doi: 10.1016/j.cmpb.2015.08.006

[43] I.Boada, A.Rodriguez-Benitez, J.M.Garcia-Gonzalez, S. Thi-Henestrosa, and M.Sbert M., 30:2: A Game Designed to Promote the Cardiopulmonary Resuscitation Protocol Hindawi Publishing Corporation. International Journal of Computer Games Technology (2016) Article ID 8251461, 1-14,http://dx.doi.org/10.1155/2016/8251461

[44] F. Sameraro , A.Frisoli, G. Ristagno, C.Loconsole, L. Marchetti, A.Scapigliati,T.Pellis, N.Grieco, E.L.Cerchiari, Relive: A serious game to learn how to save lives, Resuscitation, 85(7) (2014), e109-10. doi:10.1016/j.resuscitation.2014.03.306

[45] Viva!Game http://www.viva2013.it/viva-game

[46] B.Schmitz, R.Klemke, J. Walhout, M.Specht. Attuning a mobile simulation game for school children using a design- based research approach. Computers and Education 81 (2015), 35-48, doi:10.1016/j.compedu.2014.09.001

[47] J. P. Carvalho, N. Horta and J. A. B. Tome, Fuzzy Boolean Nets Based Paediatrics first-aid Diagnosis, NAFIPS 2007 - 2007 Annual Meeting of the North American Fuzzy Information Processing Society, San Diego, CA, (2007), pp. 644-649. doi: 10.1109/NAFIPS.2007.383916

[48] Z.S.de Urturi, A.M. Zorrilla, B.G. Zapirain, Serious game based on first-aid education for individuals with autism spectrum disorder (asd) using android mobile devices. In: Proceedings of 16th International Conference on Computer Games (CGAMES), (2011). pp. 223227. http://dx.doi.org/10.1109/CGAMES.2011.6000343.

[49] A. Rodríguez, I. Boada, S.Thi-Henestrosa, and M.Sbert CPRforBlind, a videogame to introduce CardioPulmonary Resuscitation protocol to blind peo-

ple British Journal of Educational Technology, 49(4), 636-645, July 2018, doi: 10.1111/bjet.12627

Chapter 7

Results and discussion

The main contributions of the thesis have been presented as a set of articles, each one presented in a different chapter. In this one, we will give a global view of the work that has been carried out by presenting and discussing the results.

The main objectives of the thesis can be reduced to two general ones. The first one is focused on how to adapt video games to players with visual impairments. The second one is focused on the application of serious games as a tool to promote first-aid protocols. In next sections, we will evaluate our contributions considering these objectives independently.

7.1 Serious games and visual impaired players

Despite research presenting the benefits of playing videogames for people with disabilities, the number of videogames that support users with visual impairments is still very low. The main limitation is due to the fact that graphics representations are one of the key elements of videogames and generally designers do not consider other alternatives that could also satisfy impaired players. To overcome this limitation, audio-based, text-based, and haptic-based techniques have been proposed. These techniques aim to transform the game experience to other stimuli that can be perceived by these players. Generally, these strategies follow a disability-specific design that do not consider other players preferences, leading to games for disabled users and games for non-disabled. To tackle this problem, we consider that inclusion has to be considered from the first step of the design process. Designers do not have to renounce to graphics resources but they have to consider the non-graphics ones from the beginning of the process. In this way, games with a wide audience will be obtained. Unfortunately, this is hard to achieve since specific resources are required which are not always provided by the game engines. With the idea to promote and make inclusion easier we have presented two proposals.

7.1.1 Game interaction devices

The first proposal has been centered on user interaction. We have evaluated the different solutions that have been provided to integrate visual impaired players. Generally, these solutions are expensive, not user-friendly and difficult to manage. To overcome these limitations, and inspired by the white cane, we have proposed a new interaction device to allow visual disable players to play videogames. Our aim was to complement current games with a low-cost device that allow disabled players

	Camera	Sensors	Audio	Haptic	Indoor	Outdoor	Portable	Low Cost
[Cardillo 2018]	N	Y	Y	Y	Y	Y	Y	Y
[Mancini 2018]	Y	N	N	Y	N	Y	Y	N
[Kammoun 2012]	Y	N	Y	N	Y	Y	N	N
[Yang 2018]	Y	N	Y	N	Y	Y	Y	Y
[Kang 2015]	Y	N	Y	N	Y	Y	N	N
[Yang 2016]	Y	N	Y	N	Y	Y	Y	Y
[Söveny 2014]	Y	N	Y	N	Y	Y	Y	Y
[Cheraghi 2017]	Y	N	Y	N	Y	N	Y	Y
[Ţepelea 2017]	Y	N	Y	N	Y	Y	N	N
[Kwiatkowski 2017]	N	Y	Y	Y	N	Y	N	N
[Rizvi 2017]	N	Y	Y	N	Y	Y	N	N
[Prattico 2013]	N	Y	Y	N	N	Y	Y	Y
[Vera 2017]	Y	Y	Y	N	Y	Y	N	Y
[Tsirmpas 2015]	N	Y	N	Y	Y	N	Y	Y
[Kaushalya 2016]	N	Y	Y	N	N	Y	N	Y
[Bhatlawande 2014]	N	Y	Y	N	Y	Y	Y	Y
[O'Brien 2014]	N	Y	Y	N	Y	Y	Y	Y
[Zhou 2016]	N	Y	Y	N	N	Y	N	Y
[Sohl-Dickstein 2015]	N	Y	Y	N	N	Y	N	N
[Sadi 2014]	N	Y	Y	N	Y	Y	Y	Y
[Bharambe 2013]	N	Y	N	Y	N	Y	N	N
[Aladren 2014]	N	Y	N	Y	Y	N	Y	Y
[Alghamdi 2014]	N	Y	Y	N	Y	Y	Y	N
[Nakajima 2013]	N	Y	Y	N	Y	N	Y	Y
[Bai 2017]	Y	Y	Y	N	Y	N	Y	Y
[Mekhalfi 2016]	Y	Y	Y	N	Y	N	Y	Y
Proposed Device	Y	Y	Y	Y	Y	Y	Y	Y

Table 7.1: Comparison of different devices with the proposed one taking into account the use of cameras, sensors, audio, if indoor or outdoor, its portability and the low cost. Parameters are evaluated as yes or no, represented with Y and N respectively.

to play any game. In the context of the thesis, we have created a first prototype of the device reducing the movements that can be supported and the sounds that can be integrated. The device has been tested in games where space exploration is the main player action. The obtained results encourage us to prepare a new version of the device that supports more movements and more actions to extend the type of games where it can be used. We consider that the proposed device can be seen as a first step towards a new type of low-cost devices that are easy to manage. In addition, since the proposed framework allows the integration of the device to any motor engine, our proposal can be seen as tool for designers to consider inclusion from the beginning of the process.

In Table 7.1 the proposed device has been compared with different devices proposed to help visually impaired people in real situations. To evaluate the devices a set of *yes/no* parameters have been considered. These are: use a camera; use a sensor; use audio; is a haptic; it is indoor; it is outdoor; has easy portability (referred to size) and is not expensive ($\leq$ 300$) [Islam 2019]. From collected data we can see that 42% of 26 devices use the camera, 69% use sensors and 11% use both. Regarding audio and haptic, 85% of devices use audio, 23% use haptic, and only 8% use both. With respect to location, 73% and 77% of the devices are prepared to be used indoor and outdoor, respectively, and 50% can be used in both places. Regarding portability, 62% of devices are portables. Finally, with focusing on the cost 27% are too expensive. In the last row, where our device is evaluated we can see that all parameters are set to yes. Our device uses the game engine camera to simulate the real cameras of other devices. It uses the sensors of the device and also the ones of the game engine to detect the objects of the virtual scene. The audio comes from the device head speaker and also from the computer. Haptic is the basis of our device. It interacts with virtual scenarios that can simulate any type of scene indoor or outdoor, therefore it is suitable for both situations. Considering portability as the size of the device we can consider that it can be classified as a portable device, moreover if we consider that the current version is a prototype that can be improved to reduce size and weight. Finally, cost is one of the main features of our device since one of our restrictions was to design low cost device. From this evaluation, we consider that the proposed device is a suitable approximation of current devices to reproduce real situations in virtual scenarios.

In Table 7.2 different game interaction devices have been compared taking into account parameters required to be used by visually impaired players. The first parameter, which has been graded as yes or no, is design *specificity*, which refers to the specificity of the design considering whether it has been specifically designed for visually impaired users or not. The other parameters which have been graded from 0 (minimum) to 5 (maximum) are: *Inmersion* degree, which refers to the degree of immersion that can experiment a visually impaired player when using it. This value has been set considering the number of device actuators and their possibilities; *Usability*, which refers to the difficulty of the device to be used. To determine this value, the number of the device sensors and their possibilities have been taken into account; *Mobility*, which refers to the movements that can be experimented by the

	Specificity	Inmersion	Usability	Mobility	Adaptability	Cost
Mouse and Keyboard	N	0	1	0	3	5
Gamepad controller	N	1	2	1	5	5
Steering wheel	N	2	2	2	1	2
Space simulator joystick	N	2	2	2	1	2
Smartphone	N	3	3	1	3	2
Wiimote	N	2	3	3	3	5
Joy-Con	N	3	4	3	3	4
Proposed device	Y	5	5	5	3	4

Table 7.2: Comparison of different game interaction devices focusing on specificity, inmersion, usability, mobility, adaptability and cost. All parameters are graded from 0 to 5 except specificity which is evaluated as (Y)es/(N)o.

blind player in the context of a virtual scenario. To set this value, the capability of the device to simulate a real one for the blind has been considered; *Adaptability*, which refers to the capability to fit requirements of different game genres. To determine this value, the needs of other types of control for other game genres have been taken into account; and *Cost*, which refers to the economical cost of the device. To determine this value, 50$ has been considered how a good price. From the table we can see that the more classic input interaction devices such the keyboard and the mouse give little immersion and are difficult to use for people with visual disabilities due to lack of the haptic component. More specific devices such as flywheels and joystick flight simulators, with a higher haptic component, make it possible to slightly improve the adaptation to people with visual impairments although they fit to few game genres besides having a high cost. The smartphones, thanks to the haptic component and the amount of sensors that they have, can be very useful to create content for people with visual disabilities. However, since they are not linked to any physical support it is difficult to use them to navigate through 3D scenarios. Other three-dimensional positioning devices such as Wiimote and Joy-Con are devices that, thanks to their sensors, and especially in the case of Joy-Con, the different levels of vibration they have are fairly balanced to achieve, with a good design of the video game, a decent experience for people with visual impairments. Finally, focusing on our proposal we can see how our device satisfies all considered factors with a controlled cost. Therefore, we consider that it is a good solution to be considered as an interaction game device.

	Text Based	Audio Based	Haptic Based	Game1	Game2
Implementation	Low	Low	High	Medium	Low
Scope	Low	Medium	Low	Medium	High
Extra support	Medium	Low	High	Medium	Low
Immersion	Low	Low	Hight	High	Medium

Table 7.3: Comparison of videogames for visually impaired players considering the dificulty of implementation, the scope, the extra support required, and the immersion degree. Game1 and Game2 correspond to the navigation game presented in Chapter 2 and the CPR game presented in Chapter 5, respectively. Parameters are graded as low, medium or high.

7.1.2 Teaching first-aid procedures

The second proposal has been centered on how to promote first-aid procedures to blind players using serious games. From our research, no previous work on the topic was found. Since part of the thesis was focused on serious games as a channel to promote first-aid protocols to non-experts, we exploited our experience on the topic to adapt one of the games to blind players. In particular, the cardiopulmonary resuscitation protocol was translated to a set of mini-games where only sound and vibrations were required to pass them. The proposed game was tested by blind and non-blind players to detect knowledge acquisition and also enjoyability. From this experience, we observed that knowledge on the topic was improved but although blind players enjoyed the game, non-blind do not enjoy. This fact reinforces the idea that inclusion has to be considered from the beginning if the idea is the development of a general game with no public restrictions. We make the mistake of considering only blind players for the development, in this case the non-blind do not feel comfortable. Therefore, the key is to consider the greater number of player profiles.

In table 7.3 the main strategies that have been proposed to develop videogames for visually impaired players are evaluated considering four factors: implementation difficulty, application scope, need of extra support to play, and immersion degree. Each factor is graded as low, medium or high setting the values as follows. We consider *implementation difficulty* low if no extra knowledge is required to implement the videogame, medium if well-documented libraries are required, and high if it is hard to implement. Regarding the *application scope*, the number of genres covered by this strategy determines its grade. In this way, the value is low when the game fits to at least 3 game genres; medium to 7, and high to almost all genres. With respect to the *need of extra support to play*, we considered the economic cost of this support. This factor is low when no support is required, high when a very expensive support is necessary (greater than 150$), and medium in the other cases. The last factor is the *immersion degree* that can achieve the player. This value is low if no actuators are used to give immersion, it is medium if some actuators are used to give immersion, and it is high if it uses actuators and also imitates a real device. Using this grading we can observe from the table that text-based games are easy to implemente but they have a low degree of immersion due to the lack of haptic or auditory component. In addition, they need a extra software to play them [FreedomScientific 1989] and only cover one game genre, the text adventures [IngeniiInteractive 1996, Stegner 2019]. Focusing on audio-games, they are also easy to implement. They cover more game genres such as action, racing, musical, and adventures, among others [DCH 2002] and they do not need an extra support being better than the text-based games. The degree of immersion is similar to text-based games. Finally, haptic-based games which are the more complex to implement. They do not cover a large variety of game genres and require extra support. However, they provide a high degree of immersion. In this comparison, we have also considered the games proposed in the context of the thesis, labelled as Game1 and Game2. The first has been developed to test the device presented in Chapter 2 and the second is the game to teach CPR to visually impaired players. Game 1 can be considered as a haptic-based game but with the advantage of requiring a low cost device. Moreover, the libraries provided with the device make the implementation of similar games easier. Regarding Game2, this can be considered as a combination of audio and haptic-based games with the advantage of not requiring an extra device other than the one used to play.

7.2 Serious games and first-aid procedures

First-aid refers to the emergency or immediate care that can be provided when a person is injured or ill until full medical treatment is available. Two of the most popular first-aid protocols are the cardiopulmonary resuscitation and the choking ones. Due to the importance of these procedures, many initiatives have been proposed to disseminate them. However, they are still unknown for a large number of people, and new strategies to promote them are needed. In this thesis, we have proposed serious games as a tool to teach the protocols focusing on the non-expert population. We detected a lack of this type of games for non-experts on the topic and for this reason we considered them as our target players.

After analyzing the protocols, in both cases composed by a set of well-defined steps, we decided to design games composed by a set of mini-games where each mini-game corresponds to a step of the protocol. All mini-games where linked by a common history that defines the emergency situation and the player has to act as a helper to solve the situation. The approach was different to state of the art first-aid games since these are focused on a single step of the protocol and in some cases, they are only a support to mark the rhythm of one of the parts of the protocol. In this last case, although proposed applications are related with the protocol they cannot be considered as serious games. Therefore, novelty can be considered as one of the features of our proposals.

In Table 7.4 some strategies that have been proposed to teach CPR are presented. They have been grouped in different categories according to the type of application.

Application type	
Video Training	Save-a-life simulator [Medtronic 2012] CPR-and-Choking [StoneMeadow 2011] ScuolaSalvaVita [Paglino 2019]
Handheld device	CPR-Game [LLC 2011a], LifeSaver [Percy 2012] iCPR [Alessandri 2009, Semeraro 2011] M-AID [Zanner 2007], CPR-simulator [Medtronic 2012] iResus [Low 2010], PocketCPR [Plata 2018, Plata 2019]
PC platform	Mini-VREM [Semeraro 2010, Semeraro 2012] AED-Challenge [LLC. 2011b]
Virtual and Augmented Reality	VR-CPR [Almousa 2019], CPReality [Balian 2019] AR-based self-training CPR [Kadosawa 2019]
Serious games	JUST [Ponder 2002], MicroSim [Medical 2012] Staying-alive [Ilumens 2011] LISSA [Wattanasoontorn 2013] Relive [Semeraro 2014], Viva!Game [Settimanaviva 2013] HeartRun [Schmitz 2015], FASim [Benkhedda 2019]

Table 7.4: Some of the proposed applications to introduce CPR or some of the steps of the protocol.

First group corresponds to video-based training applications such as Save a life simulator [Medtronic 2012], CPR-and-Choking [StoneMeadow 2011] and ScuolaSalvaVita [Paglino 2019]. The seconds group considers handheald device applications such a CPR-Game [LLC 2011a], LifeSaver [Percy 2012], iCPR [Alessandri 2009, Semeraro 2011], M-AID [Zanner 2007], CPR-simulator [Medtronic 2012], iResus [Low 2010] and PocketCPR [Plata 2018, Plata 2019]. The third category represents personal computer platforms with applications such as Mini-Virtual Reality Enhanced Mannequin (Mini-VREM) [Semeraro 2010, Semeraro 2012] which is a CPR feedback device with motion detection technology including Kinect, sensor and software specifically designed to analyze chest compression performance and provide real time feedback in a simulation training setting; andAEDChallenge [30], an application that provides online automated external defibrillation and CPR skill practice and testing with realistic scenarios. The fourth category represents more recent applications that use virtual or augmented reality to teach CPR. Some applications of this group are: VR-CPR [Almousa 2019], CPReality [Balian 2019] and AR-based self-training CPR [Kadosawa 2019]. The last category corresponds to serious games with applications such as JUST [Ponder 2002], MicroSim [Medical 2012], Staying-alive [Ilumens 2011], LISSA [Wattanasoontorn 2013], Relive [Semeraro 2014], Viva!Game [Settimanaviva 2013], HeartRun [Schmitz 2015] and FASim [Benkhedda 2019]. The different applications that have been proposed in the context of the thesis fall in this last category.

In the case of CPR for blind and choking games, no comparison can be done since no references to similar games on the topic have been found. Focusing on choking,

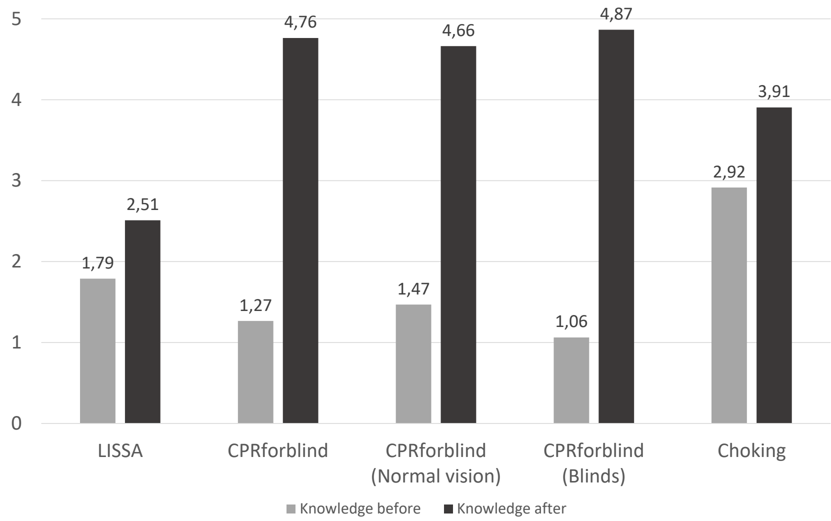


Figure 7.1: Knowledge of the first-aid protocol before and after playing the game considering the different proposed games.

there is only one product related to the topic, CPR-and-Choking [StoneMeadow 2011] which uses videos to teach how to react on a choking situation. Therefore, the proposals of the thesis can be seen as new solutions to a problem that was not previously considered.

Another factor to be considered in this discussion is users' impressions after playing the game and more important the acquired knowledge on the procedures. In all the tests that have been carried out the results demonstrated that players improved their knowledge on the topic. In Figure 7.1 we have summarized the results of the different tests carried out for the different proposed games considering the knowledge on the topic before and after playing the game. For comparison purposes collected data has been normalized to the 0 to 5 range. We can observe that in all the cases the knowledge has increased considerably. Therefore, serious games can be considered a good approach to teach on this topic. Note that the worst results are obtained in the case of LISSA. This is due to the fact that LISSA was tested by students with knowledge on the topic and hence the improvement has been lower since what they have learnt are specific details of the protocol such as the number of seconds they have to observe the patients.

Regarding user's satisfaction with respect to the game we have also summarized the results of the different tests carried out for the different proposed games. Again, for comparison purposes collected data has been normalized to the 0 to 5 range. The obtained results are shown in Figure 7.2. Note that in all the cases the degree of satisfaction is between 3 and 4. A result that reinforces the idea of using serious games as a channel to promote first-aid knowledge.

Finally, as a work to complement our research we also used part of our developments to investigate the impact of victim gender on the player performance. There

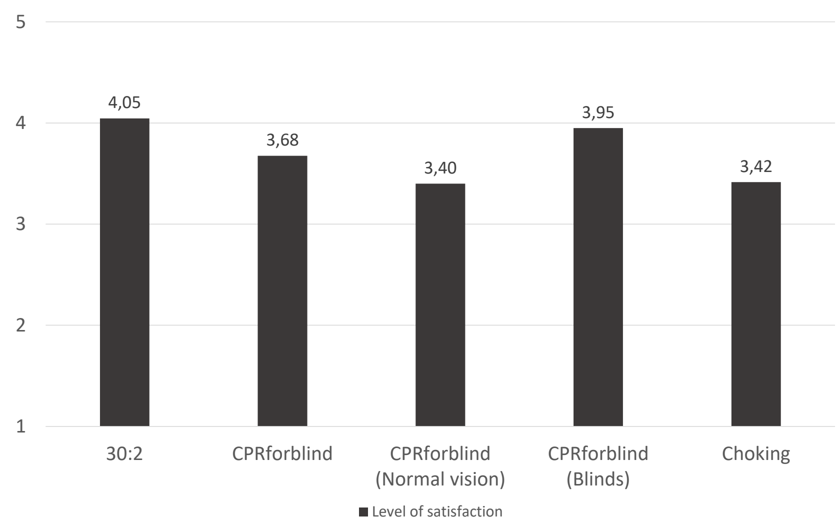


Figure 7.2: Satisfaction after playing videogames

were little research on the topic.

Chapter 8

Conclusions

Serious games are digital games used for purposes other than mere entertainment and are applied in many different areas, amongst them healthcare [Michael 2006]. They can recreate scenarios to experiment with situations that otherwise would be impossible in the real world due to required safety, cost, and time [Squire 2003]. In addition, serious games enhance the development of skills, such as analytical and spatial, strategic, or psychomotor [Mitchell 2004]. With the aim to exploit serious games advantages as much as possible, in this thesis we have focused our interest on two main focus of research. The first focus of research, has been centered on how to make serious games (and video games in general) more accessible to players with visual impairments. To reach this objective we have proposed a device that simulates a white cane allowing to interact with virtual scenarios. In addition, we have proposed a serious game based on sound and tactile interaction to teach the cardiopulmonary resuscitation (CPR) protocol to players with visual impairment. The second focus of research, has been centered on how to extend serious games to first-aid survival procedures considering players with and without experience on the topic. To reach this objective we have centered our interest on CPR protocol and the protocol to be applied in case of choking victims. For the first protocol, we have evaluated how the gender of victims in virtual scenarios can impact on player performance. Moreover, we have proposed two serious games to promote the CPR and the choking protocol, respectively. All proposals have been implemented and tested in real scenarios with very satisfactory results. Below, a detailed description of the main contributions of this thesis as well as the publications related to each contribution are given.

8.1 Contributions

The contributions of the thesis, presented in the order that have been published, are the following ones:

- *A new device designed for visually impaired people to interact with virtual scenes of video games.*

  Generally, video games rely on impressive graphics and immersive visual experiences which make interaction difficult in the case of visual impaired players. To overcome this limitation, we have proposed a device to interact with virtual scenes. The device has been designed considering as main features usability, economic cost, and adaptability. Regarding usability, we have considered the white cane paradigm since this is the most used device by the blind community. The proposed device supports left to right movements, collision detection and actions to manipulate scene objects such as drag and drop. To enhance realism, the device integrates a sound library. To reduce the economic cost, we have used Arduino as the basis of our development. The device can be adapted to different game engines. Promising results have been obtained in the performed tests. This contribution has led to the following publication:

> An Arduino-based device for visually impaired people to play videogames, Antonio Rodríguez, Imma Boada, and Mateu Sbert, Multimedia Tools and Applications, 77(15) , pp:19591 – 19613 (2018), ISSN: 1380-7501 DOI 10.1007/s11042-017-5415-1 JCR- Computer Science and software engineering; position: 40/107; IF:2.101; Quartile Q2.

- A study of how character gender of a victim, in a simulation scenario created to practice the cardiopulmonary resuscitation protocol, influences the performance of student nurses.

  Serious games have become a useful training technology for health profession where experts can practice in controlled environments and students can practice to gain experience and develop problem solving skills. Focusing on simulation scenarios, we have analyzed how the character gender influences the performance of users practising CPR. We have created different simulation situations and we have evaluated how students of a nurse faculty interact with them. The obtained results have shown that the gender of the victim character does not affect student performance when applying the CPR protocol. From these results, we have seen that virtual scenarios are not only useful for skill practicing but also as a way to reduce differences across genders.

  This contribution has led to the following publication:

> How the gender of a victim character in a virtual scenario created to learn CPR protocol affects student nurses performance, Imma Boada, Antonio Rodriguez, Santiago Thió-Henestrosa, Josep Olivet, and Josep Soler, Computer Methods and Programs in Biomedicine, August (162), Pp:233-241 (2018), doi: 10.1016/j.cmpb.2018.05.019. JCR-Computer Science interdisciplinary applications, position:25/106; IF:3,424; Quartile Q1

- *A video game to disseminate and promote cardiopulmonary resuscitation protocol to non-experts*

  Cardiopulmonary resuscitation (CPR) is a first-aid key survival technique used to stimulate breathing and keep blood flowing to the heart. Its effective administration can significantly increase the survival chances of cardiac arrest victims. We have proposed 30:2, a videogame designed to introduce the main steps of the CPR protocol to non-experts. Driven by the European Resuscitation Council guidelines, we have designed a game composed of eight mini games corresponding to the main steps of the protocol. The player acts as a helper and has to solve different challenges related with the protocol steps. Different tests have been carried out to test the game regarding the aesthetics of scenarios, the playability, and the enjoyability of each mini game. All games were well punctuated concluding that the proposed game can be a suitable tool to disseminate and promote CPR knowledge.

This contribution has led to the following publication:

> 30:2 a Game Designed to Promote the Cardiopulmonary Resuscitation Protocol, Imma Boada,Antonio Rodriguez-Benitez, Juan Manuel Garcia-Gonzalez, Santiago Thió-Henestrosa, and Mateu Sbert, International Journal of Computer Games Technology, 2016 ISSN: 1687-7047. Scopus-Computer Graphics and Computer-Aided Design , position: 24/64-IF:1,54.

- *A video game to disseminate and promote cardiopulmonary resuscitation procedure to non-experts with visual impairment*

  The 30:2 video game proposed in the context of the thesis has been extended to introduce the main steps of the CPR protocol to visually impaired people. The proposed game denoted CPRforBlind is composed of different mini-games inspired by the CPR steps proposed by European Resuscitation Council. To save the victim, the player has to solve the challenges assigned to each mini-game by using tactile interaction. To test the game, 16 participants from which 8 were blind have been considered. After and before playing the game participants answered different questionnaires related to CPR knowledge, playability and enjoyability. The obtained results were very promising detecting a great improvement on CPR knowledge. In addition, blind players enjoyed the game and found it easy to play. This contribution has led to the following publication:

  > CPRforBlind, A videogame to introduce CardioPulmonary Resuscitation protocol to blind people, Antonio Rodríguez, Imma Boada, Santiago Thió-Henestrosa, Mateu Sbert, British Journal of Educational Technology, 2018, ISSN: 1467-8535, JCR- Education and Educational research, 31/243; IF:2,588; Quartile Q1 (JCR)

- *A video game to teach to non-experts the procedure to be applied in case of choking.*

Choking is one of the causes of unintentional injury death. Prevention and knowledge of the first aid procedure that has to be applied in case of choking can avoid some of these deaths. Serious games can be a good channel to educate on this topic. We have designed a serious game to prevent choking and promote the first-aid procedure to be applied. In the proposed game, the player acquires the role of a helper who has to save the victim of a choking emergency by applying the main steps of the first-aid choking protocol which have been represented as mini-games. To guide the player in the mini-games, help messages with the instructions of the step protocol appear on the top of the screen. Time and score restrictions are imposed to pass each mini-game. To test the game a sample population composed by 48 students has been considered. In the tests we have evaluated player impressions about game complexity, enjoyability, etc. and also the choking knowledge before and after playing the game. From the results, we have observed that players have enjoyed the game and have improved their knowledge on the procedure.

This contribution has been submitted to *JMIR Serious Games* under the title *Design and evaluation of a serious game to educate on choking* with the following authors *Antonio Rodríguez-Benítez, Imma Boada, Santiago Thio-Henestrosa, and Josep Soler*

8.2 Lessons Learned

To prepare this last chapter of the thesis we have revisit the fixed objectives and the different proposals that have been done to reach them. In addition, with the aim to utilize the experience gained from the thesis work and with the idea to benefit future projects, we have examined and evaluated the thesis to find underlying lessons.

- A first lesson learned is focused on the methodology applied to design the different games that have been proposed to teach first-aid protocols. It has been seen that focusing on protocols composed of different steps, a good strategy to design a serious games is to propose a mini-game for each step and integrate all them in a common story. In this way, the whole objective of learning the protocol is decomposed in a set of subobjectives. The user focuses on a new subobjective once the previous one has been reached. This design methodology will be suitable for any procedure that can be decomposed in different steps.

- A second lesson learned is centered on the strategy used to test the proposed serious games. It has been seen that as important as the serious objective is the playability of the game (more related with game enjoyability). In our tests we have always defined questions to assess playability focused on scenarios and game mechanics and also pre- and post- questionnaires related to the knowledge to be transmitted. This strategy allows to measure key points of serious games in a single testing scenario.

- A third lesson learned is related to the design of videogames for visually impaired players. It has been seen that a successful strategy is to consider interaction devices that use techniques that are familiar to this community. As an example, consider the interaction device inspired by the white cane. When designing interaction techniques for visually impaired players it is important to consider their real world user experiences.

- A fourth lesson learned is also focused on games for visually impaired players. Consider only this profile when designing a game is not a good strategy. It would be better to consider from the beginning the possibility of combining sighed and non-sighted players in the same environment. This strategy allows to enhance game playability and also improve the collaboration between both collectives.

- A fifth and last lesson learned is centered on gender issues. Although in the thesis it has been studied in a very well defined situation (the avatar gender in an emergency scenario), it has been seen that virtual scenarios are a good strategy to tackle gender issues.

8.3 Future Work

The work presented in this thesis can be extended and further investigated in different directions. Regarding players with visual impairments, we want to exploit the results obtained in our two main contributions in different directions.

- Centered on the devices, our aim is to develop an improved version that supports more movements and that can be used not only with PC's. In addition, we want to extend the application of the device to other game modalities and not only to games based on navigation skills.

- Centered on the proposed game to teach CPR to visually impaired players, we want to exploit the haptic possibilities of mobiles devices. The current version of the game only considered the vibration of the device. We want to add extra actuators to achieve more complex vibration patterns that improve the player experience [Nintendo 2019b]. The proposed strategies could be extended to other games. Our idea is to develop a library with all these contributions to share it with other game designers. The main aim is to make the development of games for visually impaired people more ease.

Focusing on the serious games proposed to teach first-aid protocols, which are based on the conversion of main steps of these protocols to mini-games, we aim to extend the idea in different ways.

- We want to prepare a publication where the methodology used to design, implement and test the serious games is integrated in a common framework. We want to apply this framework to other scenarios where procedures composed of sequential steps are required. These scenarios can be found in other first-aid protocols [Redcross 2019b], in the context of occupational risk prevention [Ferreira 2018, Velasquez 2018], or any other situation where actions that have to be applied can be defined step by step [Colombo 2016].

- Since all new developments will be done considering players of different profiles with visual impairments and not, we want to investigate the interaction between sighted and visual impaired players in a same scenario. Our interest is on how to exploit the skills of both players to improve the game experience and increase provided benefits [Yevhenii 2017, Grabski 2016, Morelli 2014].

In addition, we want to investage other type of disabilities and how provided solutions can be adapted to them. We have special interest on non-photorealistic effects [Magdics 2013] and how they can be applied to provide support to other type of visual disabilities.

Finally, focusing on first-aid protocols our aim is to integrate all the proposed games in a common platform and extend the versions of the game to more realistic 3D scenarios. Our idea is to analyze players performance according to graphical representations and determine which are the best scenarios according to players profiles. We also want to apply augmented reality and virtual reality technologies.

Bibliography

[4AGames 2019] 4AGames. *Metro Exodus*. https://www.metrothegame.com/, 2019. Accessed: 2019. (Cited on pages ix and 1.)

[Adams 1976] Rick Adams. *Colossal Cave Adventure*. https://rickadams.org/adventure/, 1976. Accessed: 2019. (Cited on page 3.)

[Adams 1978] Scott Adams. *Adventureland*. http://www.msadams.com/adventures.htm, 1978. Accessed: 2019. (Cited on page 3.)

[AHAE 2012] American Heart Association Emergency AHAE. *Cardiovascular Care online education*. http://www.onlineaha.org, 2012. Accessed: 2019-10-02. (Cited on pages ix, 2, 4, 5 and 7.)

[Aladren 2014] Aitor Aladren, Gonzalo López-Nicolás, Luis Puig and Josechu J Guerrero. *Navigation assistance for the visually impaired using RGB-D sensor with range expansion*. IEEE Systems Journal, vol. 10, no. 3, pages 922–932, 2014. (Cited on page 110.)

[Alessandri 2009] A. Alessandri. *iCPR - iPhone App for CPR training*. http://www.icpr.it/, 2009. Accessed: 2019. (Cited on page 115.)

[Alghamdi 2014] Saleh Alghamdi, Ron van Schyndel and Ibrahim Khalil. *Accurate positioning using long range active RFID technology to assist visually impaired people*. Journal of Network and Computer Applications, vol. 41, pages 135–147, 2014. (Cited on page 110.)

[Almousa 2019] Omamah Almousa, Joana Prates, Noor Yeslam, Dougal Mac Gregor, Junsong Zhang, Viet Phan, Marc Nielsen, Richard Smith and Karim Qayumi. *Virtual Reality Simulation Technology for Cardiopulmonary Resuscitation Training: An Innovative Hybrid System With Haptic Feedback*. Simulation & Gaming, vol. 50, no. 1, pages 6–22, 2019. (Cited on page 115.)

[Atkinson 2006] Matthew T Atkinson, Sabahattin Gucukoglu, Colin HC Machin and Adrian E Lawrence. *Making the mainstream accessible: redefining the game*. In Proceedings of the 2006 ACM SIGGRAPH symposium on Videogames, pages 21–28. ACM, 2006. (Cited on page 2.)

[Bai 2017] Jinqiang Bai, Shiguo Lian, Zhaoxiang Liu, Kai Wang and Dijun Liu. *Smart guiding glasses for visually impaired people in indoor environment*. IEEE Transactions on Consumer Electronics, vol. 63, no. 3, pages 258–266, 2017. (Cited on page 110.)

[Balian 2019] Steve Balian, Shaun K. McGovern, Benjamin S. Abella, Audrey L. Blewer and Marion Leary. *Feasibility of an augmented reality cardiopulmonary resuscitation training system for health care providers*. Heliyon, vol. 5, no. 8, page e02205, 2019. (Cited on page 115.)

[Benkhedda 2019] Samira Benkhedda and Fatima Bendella. *FASim: A 3D Serious Game for the First Aid Emergency*. Simulation & Gaming, 2019. (Cited on page 115.)

[Bentivegna 2018] Kathryn C Bentivegna, Kevin T Borrup, Meghan E Clough and Scott R Schoem. *Basic choking education to improve parental knowledge*. International journal of pediatric otorhinolaryngology, vol. 113, pages 234–239, 2018. (Cited on page 5.)

[Bertini 2015] Alessio Bertini, Riccardo Ristori, Marco Squicciarini, Stefano Mazzei, Domencio Ietto and Fulvio Kette. *Can blindness be a limitation to perform CPR? Preliminary report*. Resuscitation, vol. 96, page 67, 2015. (Cited on page 5.)

[Bharambe 2013] Sachin Bharambe, Rohan Thakker, Harsharanga Patil and KM Bhurchandi. *Substitute eyes for blind with navigator using android*. In 2013 Texas Instruments India Educators' Conference, pages 38–43. IEEE, 2013. (Cited on page 110.)

[Bhatlawande 2014] Shripad Bhatlawande, Manjunatha Mahadevappa, Jayanta Mukherjee, Mukul Biswas, Debabrata Das and Somedeb Gupta. *Design, development, and clinical evaluation of the electronic mobility cane for vision rehabilitation*. IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 22, no. 6, pages 1148–1159, 2014. (Cited on page 110.)

[Brewster 1998] Stephen A Brewster. *Using nonspeech sounds to provide navigation cues*. ACM Transactions on Computer-Human Interaction (TOCHI), vol. 5, no. 3, pages 224–259, 1998. (Cited on page 2.)

[Cardillo 2018] Emanuele Cardillo, Valentina Di Mattia, Giovanni Manfredi, Paola Russo, Alfredo De Leo, Alina Caddemi and Graziano Cerri. *An electromagnetic sensor prototype to assist visually impaired and blind people in autonomous walking*. IEEE Sensors Journal, vol. 18, no. 6, pages 2568–2576, 2018. (Cited on page 110.)

[Carvalho 2007] Joao Paulo Carvalho, Nuno Horta and Jose AB Tome. *Fuzzy Boolean Nets Based Paediatrics First Aid Diagnosis*. In NAFIPS 2007-2007 Annual Meeting of the North American Fuzzy Information Processing Society, pages 644–649. IEEE, 2007. (Cited on page 5.)

[Chan 2012] Wing-Yin Chan, Jing Qin, Yim-Pan Chui and Pheng-Ann Heng. *A serious game for learning ultrasound-guided needle placement skills*. IEEE

Transactions on Information Technology in Biomedicine, vol. 16, no. 6, pages 1032–1042, 2012. (Cited on page 1.)

[Cheraghi 2017] Seyed Ali Cheraghi, Vinod Namboodiri and Laura Walker. *Guide-Beacon: Beacon-based indoor wayfinding for the blind, visually impaired, and disoriented*. In 2017 IEEE International Conference on Pervasive Computing and Communications (PerCom), pages 121–130. IEEE, 2017. (Cited on page 110.)

[Colombo 2016] Graziano Colombo, Marco Clerici, Maria Elisa Garavaglia, Daniela Giustarini, Ranieri Rossi, Aldo Milzani and Isabella Dalle-Donne. *A step-by-step protocol for assaying protein carbonylation in biological samples*. Journal of Chromatography B, vol. 1019, pages 178–190, 2016. (Cited on page 124.)

[Cooke 2019] Annemarie Cooke. *A History of Accessibility at IBM*. https://www.afb.org/aw/5/2/14760, 2019. Accessed: 2019. (Cited on page 3.)

[DCH 2002] Disclaimer and Creative Heroes DCH. *Audio Games community*. https://audiogames.net/, 2002. Accessed: 2019-09-25. (Cited on pages 2 and 114.)

[de Urturi 2011] Zelai Sáenz de Urturi, Amaia Méndez Zorrilla and Begoña García Zapirain. *Serious Game based on first aid education for individuals with Autism Spectrum Disorder (ASD) using android mobile devices*. In 2011 16th International Conference on Computer Games (CGAMES), pages 223–227. IEEE, 2011. (Cited on page 6.)

[Dwyer 2004a] P. Dwyer and P. VanLund. *The Last Crusade*. http://www.cs.unc.edu/Research/assist/et/projects/RPG/TheLastCrusade.htm, 2004. Accessed: 2019. (Cited on page 2.)

[Dwyer 2004b] P. Dwyer and P. VanLund. *RPG Game Engine and Map Maker*. http://www.cs.unc.edu/research/assist/et/projects/rpg/index.html, 2004. Accessed: 2019. (Cited on page 2.)

[ERC 2019] ERC. *European Resuscitation Council*. https://www.erc.edu/, 2019. Accessed: 2019-10-02. (Cited on pages ix, 2, 4, 5 and 6.)

[Ferreira 2018] A Ferreira, A Lança, C Mendes, M Sousa and S Paixão. *Occupational risks in hospital mortuary*. In Occupational Safety and Hygiene VI: Book chapters from the 6th International Symposium on Occupation Safety and Hygiene (SHO 2018), March 26-27, 2018, Guimarães, Portugal, page 245. CRC Press, 2018. (Cited on page 124.)

[FreedomScientific 1989] FreedomScientific. *JAWS*. https://www.freedomscientific.com/products/software/jaws/, 1989. Accessed: 2019. (Cited on pages 3 and 114.)

[Friberg 2004] Johnny Friberg and Dan Gärdenfors. *Audio games: new perspectives on game audio.* In Proceedings of the 2004 ACM SIGCHI International Conference on Advances in computer entertainment technology, pages 148–154. ACM, 2004. (Cited on page 2.)

[GMA 2000] GMA. *Trek2000.* http://www.gmagames.com/trek2000.html, 2000. Accessed: 2019. (Cited on page 3.)

[GMA 2001] GMA. *Shades of Doom.* http://www.gmagames.com/sod.html, 2001. Accessed: 2019. (Cited on page 2.)

[GMA 2013] GMA. *GMA Lander.* http://www.gmagames.com/freegames.shtml, 2013. Accessed: 2019. (Cited on page 3.)

[Grabski 2016] A. Grabski, T. Toni, T. Zigrand, R. Weller and G. Zachmann. *Kinaptic - Techniques and insights for creating competitive accessible 3D games for sighted and visually impaired users.* In 2016 IEEE Haptics Symposium (HAPTICS), pages 325–331, April 2016. (Cited on page 124.)

[Heuten 2007] Wilko Heuten, Niels Henze, Susanne Boll and Palle Klante. *Auditorypong–playing pong in the dark.* Audio Mostly, pages 134–147, 2007. (Cited on page 3.)

[Ilumens 2011] Ilumens. *Staying Alive 3D.* http://www.stayingalive.fr/, 2011. Accessed: 2018. (Cited on pages 5 and 115.)

[Infocom 1980] Infocom. *Zork I.* http://www.infocom-if.org/games/zork1/zork1.html, 1980. Accessed: 2019. (Cited on page 3.)

[Infocom 1984] Infocom. *The Hitchhiker's Guide to the Galaxy.* http://www.infocom-if.org/games/hhgttg/hhgttg.html, 1984. Accessed: 2019. (Cited on page 3.)

[IngeniiInteractive 1996] IngeniiInteractive. *Materia Magica.* https://www.materiamagica.com/, 1996. Accessed: 2019. (Cited on page 114.)

[Islam 2019] Md Milon Islam, Muhammad Sheikh Sadi, Kamal Z Zamli and Md Manjur Ahmed. *Developing walking assistants for visually impaired people: A review.* IEEE Sensors Journal, vol. 19, no. 8, pages 2814–2828, 2019. (Cited on page 111.)

[Johnston 2000] Chris Johnston. *Rumble Pak Titles On the Rise.* https://www.gamespot.com/articles/rumble-pak-titles-on-the-rise/1100-2466717/, 2000. Accessed: 2019. (Cited on page 3.)

[Kadosawa 2019] Moe Kadosawa and Mitsunori Makino. *An AR-based self-training system of chest compression as CPR.* In Qian Kemao, Kazuya Hayase, Phooi Yee Lau, Wen-Nung Lie, Yung-Lyul Lee, Sanun Srisuk and Lu Yu, editeurs, International Workshop on Advanced Image Technology (IWAIT) 2019, volume 11049, pages 232 – 236. International Society for Optics and Photonics, SPIE, 2019. (Cited on page 115.)

[Kammoun 2012] Slim Kammoun, Gaétan Parseihian, Olivier Gutierrez, Adrien Brilhault, Antonio Serpa, Mathieu Raynal, Bernard Oriola, MJ-M Macé, Malika Auvray, Michel Deniset *al. Navigation and space perception assistance for the visually impaired: The NAVIG project*. Irbm, vol. 33, no. 2, pages 182–189, 2012. (Cited on page 110.)

[Kang 2015] Mun-Cheon Kang, Sung-Ho Chae, Jee-Young Sun, Jin-Woo Yoo and Sung-Jea Ko. *A novel obstacle detection method based on deformable grid for the visually impaired*. IEEE Transactions on Consumer Electronics, vol. 61, no. 3, pages 376–383, 2015. (Cited on page 110.)

[Karatzanis 2007] AD Karatzanis, A Vardouniotis, J Moschandreas, EP Prokopakis, E Michailidou, C Papadakis, DE Kyrmizakis, J Bizakis and GA Velegrakis. *The risk of foreign body aspiration in children can be reduced with proper education of the general population*. International journal of pediatric otorhinolaryngology, vol. 71, no. 2, pages 311–315, 2007. (Cited on page 5.)

[Kaushalya 2016] VSS Kaushalya, KDDP Premarathne, HM Shadir, P Krithika and SGS Fernando. *'AKSHI': Automated help aid for visually impaired people using obstacle detection and GPS technology*. International Journal of Scientific and Research Publications (IJSRP), vol. 6, no. 11, 2016. (Cited on page 110.)

[Kim 2016] Shin Kim, Kun-pyo Lee and Tek-Jin Nam. *Sonic-Badminton: Audio-Augmented Badminton Game for Blind People*. pages 1922–1929, 05 2016. (Cited on page 3.)

[Kitchen 2008] J. Kitchen. *Mach 1 Car Racing*. http://www.kitchensinc.net/, 2008. Accessed: 2016. (Cited on page 2.)

[Kwiatkowski 2017] P Kwiatkowski, T Jaeschke, D Starke, L Piotrowsky, H Deis and N Pohl. *A concept study for a radar-based navigation device with sector scan antenna for visually impaired people*. In 2017 First IEEE MTT-S International Microwave Bio Conference (IMBIOC), pages 1–4. IEEE, 2017. (Cited on page 110.)

[Laamarti 2014] Fedwa Laamarti, Mohamad Eid and Abdulmotaleb El Saddik. *An overview of serious games*. International Journal of Computer Games Technology, vol. 2014, page 11, 2014. (Cited on page 1.)

[LLC 2011a] EM Gladiators LLC. *CPR Game*. http://www.freenew.net/iphone/cpr-game-20/466678.htm, 2011. Accessed: 2019. (Cited on page 115.)

[LLC. 2011b] Insight Instructional Media LLC. *AED Challenge*. http://aedchallenge.com/, 2011. Accessed: 2019. (Cited on page 115.)

[Low 2010] D Low, N Clark, J Soar, A Padkin, A Stoneham, G Perkins and J Nolan. *Does use of iResus© application on a smart phone improve the performance of an advanced life support provider in a simulated emergency?* Resuscitation, vol. 81, no. 2, page S10, 2010. (Cited on page 115.)

[Magdics 2013] Milán Magdics, Catherine Sauvaget, Rubén J. García and Mateu Sbert. *Post-processing NPR Effects for Video Games.* In Proceedings of the 12th ACM SIGGRAPH International Conference on Virtual-Reality Continuum and Its Applications in Industry, VRCAI '13, pages 147–156, New York, NY, USA, 2013. ACM. (Cited on page 124.)

[Mancini 2018] Adriano Mancini, Emanuele Frontoni and Primo Zingaretti. *Mechatronic system to help visually impaired users during walking and running.* IEEE transactions on intelligent transportation systems, vol. 19, no. 2, pages 649–660, 2018. (Cited on page 110.)

[Medical 2012] Laerdal Medical. *Microsim prehospital.* https://www.laerdal.com/gb/docid/12984879/MicroSim-Prehospital, 2012. Accessed: 2019. (Cited on pages 5 and 115.)

[Medtronic 2012] Medtronic. *CPR Simulator.* http://www.cprsim.com/, 2012. Accessed: 2019. (Cited on page 115.)

[Mekhalfi 2016] Mohamed L Mekhalfi, Farid Melgani, Abdallah Zeggada, Francesco GB De Natale, Mohammed A-M Salem and Alaa Khamis. *Recovering the sight to blind people in indoor environments with smart technologies.* Expert Systems with Applications, vol. 46, pages 129–138, 2016. (Cited on page 110.)

[Michael 2006] David R Michael and Sandra L Chen. Serious games: Games that educate, train, and inform. Muska & Lipman/Premier-Trade, 2006. (Cited on pages 1 and 119.)

[Miller 2007] Daniel Miller, Aaron Parecki and Sarah A Douglas. *Finger dance: a sound game for blind people.* In Proceedings of the 9th international ACM SIGACCESS conference on Computers and accessibility, pages 253–254. ACM, 2007. (Cited on page 2.)

[Mitchell 2004] Alice Mitchell and Carol Savill-Smith. *The use of computer and video games for learning: A review of the literature.* 2004. (Cited on page 119.)

[Mobygames 1999] Mobygames. *Spy Snatcher.* https://www.mobygames.com/game/spy-snatcher/, 1999. Accessed: 2019. (Cited on page 3.)

[Morelli 2010a] Tony Morelli, John Foley, Luis Columna, Lauren Lieberman and Eelke Folmer. *VI-Tennis: a vibrotactile/audio exergame for players who are visually impaired.* In Proceedings of the Fifth International Conference on the Foundations of Digital Games, pages 147–154. ACM, 2010. (Cited on page 3.)

[Morelli 2010b] Tony Morelli, John Foley and Eelke Folmer. *Vi-bowling: a tactile spatial exergame for individuals with visual impairments.* In Proceedings of the 12th international ACM SIGACCESS conference on Computers and accessibility, pages 179–186. ACM, 2010. (Cited on page 3.)

[Morelli 2014] Tony Morelli and Eelke Folmer. *Real-time sensory substitution to enable players who are blind to play video games using whole body gestures.* Entertainment Computing, vol. 5, no. 1, pages 83 – 90, 2014. (Cited on page 124.)

[Nacke 2010] Lennart E Nacke. *Wiimote vs. controller: electroencephalographic measurement of affective gameplay interaction.* In Proceedings of the international academic conference on the future of game design and technology, pages 159–166. ACM, 2010. (Cited on page 3.)

[Nakajima 2013] Madoka Nakajima and Shinichiro Haruyama. *New indoor navigation system for visually impaired people using visible light communication.* EURASIP Journal on Wireless Communications and Networking, vol. 2013, no. 1, page 37, 2013. (Cited on page 110.)

[Nichols 2012] Brent G Nichols, Alexis Visotcky, Michael Aberger, Nicole M Braun, Rahul Shah, Sergey Tarima and David J Brown. *Pediatric exposure to choking hazards is associated with parental knowledge of choking hazards.* International journal of pediatric otorhinolaryngology, vol. 76, no. 2, pages 169–173, 2012. (Cited on page 7.)

[Nintendo 2019a] Nintendo. *1-2-switch.* https://www.nintendo.com/games/detail/1-2-switch/, 2019. Accessed: 2019. (Cited on page 3.)

[Nintendo 2019b] Nintendo. *Switch - JoyCon.* https://www.nintendo.com/switch/, 2019. Accessed: 2019. (Cited on pages 3 and 123.)

[O'Brien 2014] Emily E O'Brien, Aaron A Mohtar, Laura E Diment and Karen J Reynolds. *A detachable electronic device for use with a long white cane to assist with mobility.* Assistive Technology, vol. 26, no. 4, pages 219–226, 2014. (Cited on page 110.)

[Oren 2007] Michael A Oren. *Speed sonic across the span: building a platform audio game.* In CHI'07 Extended Abstracts on Human Factors in Computing Systems, pages 2231–2236. ACM, 2007. (Cited on page 2.)

[Paglino 2019] Martina Paglino, Enrico Contri, Marta Baggiani, Michela Tonani, Giulia Costantini, Maria Concetta Bonomo and Enrico Baldi. *A video-based* *training to effectively teach CPR with long-term retention: the ScuolaSalvaVita.it ("SchoolSavesLives.it") project*. Internal and Emergency Medicine, vol. 14, no. 2, pages 275–279, Mar 2019. (Cited on page 115.)

[Percy 2012] Martin Percy. *LifeSaver*. https://life-saver.org.uk/, 2012. Accessed: 2019. (Cited on page 115.)

[Plata 2018] Christopher Plata, Miriam Stolz, Tobias Warnecke, Susanne Steinhauser, Jochen Hinkelbein, Wolfgang A Wetsch, Bernd W Böttiger and Oliver Spelten. *Using a smartphone application (PocketCPR) to determine CPR quality in a bystander CPR scenario*. Resuscitation, vol. 130, page e24, 2018. (Cited on page 115.)

[Plata 2019] Christopher Plata, Miriam Stolz, Tobias Warnecke, Susanne Steinhauser, Jochen Hinkelbein, Wolfgang A Wetsch, Bernd W Böttiger and Oliver Spelten. *Using a smartphone application (PocketCPR) to determine CPR quality in a bystander CPR scenario—A manikin trial*. Resuscitation, vol. 137, pages 87–93, 2019. (Cited on page 115.)

[Ponder 2002] Michal Ponder, Bruno Herbelin, Tom Molet, S Scherteneib, Branislav Ulicny, George Papagiannakis, Nadia Magnenat-Thalmann and Daniel Thalmann. *Interactive scenario immersion: Health emergency decision training in JUST project*. In VRMHR2002 Conference Proceedings, 2002. (Cited on pages 5 and 115.)

[Prattico 2013] Flavio Prattico, Carmelo Cera and Filippo Petroni. *A new hybrid infrared-ultrasonic electronic travel aids for blind people*. Sensors and Actuators A: Physical, vol. 201, pages 363–370, 2013. (Cited on page 110.)

[Qin 2010] Jing Qin, Yim-Pan Chui, Wai-Man Pang, Kup-Sze Choi and Pheng-Ann Heng. *Learning blood management in orthopedic surgery through gameplay*. IEEE computer graphics and applications, vol. 30, no. 2, pages 45–57, 2010. (Cited on page 1.)

[Redcross 2019a] Redcross. *The American National Red Cross*. https://www.redcross.org/, 2019. Accessed: 2019-10-02. (Cited on pages 2, 4, 5 and 7.)

[Redcross 2019b] Redcross. *First AID guide*. https://www.redcross.ca/crc/documents/comprehensive_guide_for_firstaidcpr_en.pdf, 2019. Accessed: 2019-11-14. (Cited on page 124.)

[Rego 2010] Paula Rego, Pedro Miguel Moreira and Luis Paulo Reis. *Serious games for rehabilitation: A survey and a classification towards a taxonomy*. In 5th Iberian conference on information systems and technologies, pages 1–6. IEEE, 2010. (Cited on page 1.)

[Ricciardi 2014] Francesco Ricciardi and Lucio Tommaso De Paolis. *A comprehensive review of serious games in health professions.* International Journal of Computer Games Technology, vol. 2014, page 9, 2014. (Cited on page 1.)

[Richards 2017] B. Richards and University of Glamorgan. *Virtual ECG.* http://ecg.glam.ac.uk/, 2011-2017. Accessed: 2019-04-15. (Cited on page 1.)

[Rizvi 2017] Syed Tahir Hussain Rizvi, M Junaid Asif and Husnain Ashfaq. *Visual impairment aid using haptic and sound feedback.* In 2017 International Conference on Communication, Computing and Digital Systems (C-CODE), pages 175–178. IEEE, 2017. (Cited on page 110.)

[Sabri 2010] Hamed Sabri, Brent Cowan, Bill Kapralos, Fuad Moussa, Sayra Cristanchoi and Adam Dubrowski. *Off-pump coronary artery bypass surgery procedure training meets serious games.* In 2010 IEEE International Symposium on Haptic Audio Visual Environments and Games, pages 1–5. IEEE, 2010. (Cited on page 1.)

[Sadan 1995] Naum Sadan, Aryeh Raz and Baruch Wolach. *Impact of community educational programmes on foreign body aspiration in Israel.* European journal of pediatrics, vol. 154, no. 10, pages 859–862, 1995. (Cited on page 5.)

[Sadi 2014] Muhammad Sheikh Sadi, Saifuddin Mahmud, Md Mostafa Kamal and Abu Ibne Bayazid. *Automated walk-in assistant for the blinds.* In 2014 International Conference on Electrical Engineering and Information & Communication Technology, pages 1–4. IEEE, 2014. (Cited on page 110.)

[Sánchez 2010] Jaime Sánchez, Mauricio Sáenz and Jose Miguel Garrido. *Usability of a multimodal video game to improve navigation skills for blind children.* ACM Transactions on Accessible Computing (TACCESS), vol. 3, no. 2, page 7, 2010. (Cited on page 2.)

[Schmitz 2015] Birgit Schmitz, Roland Klemke, Jaap Walhout and Marcus Specht. *Attuning a mobile simulation game for school children using a design-based research approach.* Computers & Education, vol. 81, pages 35–48, 2015. (Cited on pages 5 and 115.)

[SegaRetro 1976] SegaRetro. *Fonz.* https://segaretro.org/Fonz, 1976. Accessed: 2019. (Cited on page 3.)

[Semeraro 2010] F Semeraro, A Frisoli, M Bergamasco and EL Cerchiari. *Mini VREM project (mini virtual reality enhanced mannequin).* Resuscitation, vol. 81, no. 2, page S106, 2010. (Cited on page 115.)

[Semeraro 2011] Federico Semeraro, Floriana Taggi, Gaetano Tammaro, Guglielmo Imbriaco, Luca Marchetti and Erga L Cerchiari. *iCPR: a new application of high-quality cardiopulmonary resuscitation training.* Resuscitation, vol. 82, no. 4, pages 436–441, 2011. (Cited on page 115.)

[Semeraro 2012] F Semeraro. *Mini-VREM*. http://www.mini-vrem.it/, 2012. Accessed: 2018. (Cited on page 115.)

[Semeraro 2014] Federico Semeraro, Antonio Frisoli, Giuseppe Ristagno, Claudio Loconsole, Luca Marchetti, Andrea Scapigliati, Tommaso Pellis, Niccolò Grieco and Erga L Cerchiari. *Relive: a serious game to learn how to save lives*. Resuscitation, vol. 85, no. 7, pages e109–e110, 2014. (Cited on pages 5 and 115.)

[Settimanaviva 2013] Settimanaviva. *Viva!Game*. https://www.settimanaviva.it/viva-game/, 2013. Accessed: 2017. (Cited on pages 5 and 115.)

[Simmons 1989] Yehuda Simmons. *Avalon*. https://www.avalon-rpg.com/, 1989. Accessed: 2019. (Cited on page 3.)

[Sohl-Dickstein 2015] Jascha Sohl-Dickstein, Santani Teng, Benjamin M Gaub, Chris C Rodgers, Crystal Li, Michael R DeWeese and Nicol S Harper. *A device for human ultrasonic echolocation*. IEEE Transactions on Biomedical Engineering, vol. 62, no. 6, pages 1526–1534, 2015. (Cited on page 110.)

[SomethingElse 2010] SomethingElse. *Papa Sangre*. https://www.somethinelse.com/projects/gaming-for-gamers-audio-games/, 2010. Accessed: 2019. (Cited on page 3.)

[Söveny 2014] Bálint Söveny, Gábor Kovács and Zsolt T Kardkovács. *Blind guide-A virtual eye for guiding indoor and outdoor movement*. In 2014 5th IEEE Conference on Cognitive Infocommunications (CogInfoCom), pages 343–347. IEEE, 2014. (Cited on page 110.)

[Squire 2003] Kurt Squire and Henry Jenkins. *Harnessing the power of games in education*. Insight, vol. 3, no. 1, pages 5–33, 2003. (Cited on page 119.)

[Stegner 2019] Ben Stegner. *5 Text-Based Adventure Games You Can Play in Your Browser*, 2019. (Cited on page 114.)

[StoneMeadow 2011] StoneMeadow. *CPR Choking*. http://www.stonemeadowdevelopment.com/StoneMeadowDevelopment/, 2011. Accessed: 2019. (Cited on pages 115 and 116.)

[Ţepelea 2017] Laviniu Ţepelea, Ioan Gavriluţ and Alexandru Gacsádi. *Smartphone application to assist visually impaired people*. In 2017 14th International Conference on Engineering of Modern Electric Systems (EMES), pages 228–231. IEEE, 2017. (Cited on page 110.)

[Thamboo 2009] Andrew Thamboo, Tram Nguyen and Jeffrey P Ludemann. *Choking prevention: shortcomings of traditional public education campaigns, prompting the development of web-based interactive teaching tools for preteens, teenagers, and adults*. Journal of Otolaryngology–Head & Neck Surgery, vol. 38, no. 6, 2009. (Cited on page 5.)

[Totman 2014] Mark H Totman. *Method of measuring abdominal thrusts for clinical use and training*, September 9 2014. US Patent 8,827,721. (Cited on page 5.)

[Tsirmpas 2015] Charalampos Tsirmpas, Alexander Rompas, Orsalia Fokou and Dimitris Koutsouris. *An indoor navigation system for visually impaired and elderly people based on Radio Frequency Identification (RFID)*. Information Sciences, vol. 320, pages 288–305, 2015. (Cited on page 110.)

[Velasquez 2018] Carlos Alberto Litardo Velasquez, Grether Lucia Real Perez, Andres Francisco Chavez Landa, Rosa Mariuxi Litardo Velasquez and Denis Joaquin Zambrano Ortiz. *Occupational health and safety prevention plan in water treatment plant*. International journal of life sciences, vol. 2, no. 3, pages 1–12, 2018. (Cited on page 124.)

[Vera 2017] Daniel Vera, Diego Marcillo and Antonio Pereira. *Blind guide: Anytime, anywhere solution for guiding blind people*. In World Conference on Information Systems and Technologies, pages 353–363. Springer, 2017. (Cited on page 110.)

[VirtualHeroes 2019] VirtualHeroes. *Virtual Heroes critical thinking*. http://virtualheroes.com/, 2004-2019. Accessed: 2019-10-02. (Cited on page 1.)

[Watson 2018] Amanda Watson and Gang Zhou. *Breathez: Using smartwatches to improve choking first aid*. Smart Health, vol. 13, page 100058, 2018. (Cited on page 5.)

[Wattanasoontorn 2013] V Wattanasoontorn, I Boada and M Sbert Lissa. *A serious game to learn cardiopulmonary resuscitation*. In Proceedings of the 8th International Conference on Foundations of Digital Games, Games for Learning Workshop (FDG'13), 2013. (Cited on pages 1, 35 and 115.)

[Westin 2004] Thomas Westin. *Game accessibility case study: Terraformers–a real-time 3D graphic game*. In Proceedings of the 5th International Conference on Disability, Virtual Reality and Associated Technologies, ICDVRAT, 2004. (Cited on page 2.)

[Wijman 2019] Tom Wijman. *Global Games Market*. https://newzoo.com/insights/articles/the-global-games-market-will-generate-152-1-billion-in-2019-as-the-u-s-overtakes-china-as-the-biggest-market/, 2019. Accessed: 2019-10-10. (Cited on page 1.)

[Winter 1996] David Winter. *Pong*. http://www.pong-story.com, 1996. Accessed: 2019. (Cited on pages ix and 1.)

[Yang 2016] Kailun Yang, Kaiwei Wang, Weijian Hu and Jian Bai. *Expanding the detection of traversable area with RealSense for the visually impaired*. Sensors, vol. 16, no. 11, page 1954, 2016. (Cited on page 110.)

[Yang 2018] Kailun Yang, Kaiwei Wang, Luis Bergasa, Eduardo Romera, Weijian Hu, Dongming Sun, Junwei Sun, Ruiqi Cheng, Tianxue Chen and Elena López. *Unifying terrain awareness for the visually impaired through real-time semantic segmentation.* Sensors, vol. 18, no. 5, page 1506, 2018. (Cited on page 110.)

[Yevhenii 2017] Klopota Yevhenii and Klopota Olga. *Peculiarities of Interpersonal Cooperation of Youth with Different Vision Levels.* New Educational Review, vol. 48, no. 2, pages 227–238, 2017. (Cited on page 124.)

[Zanner 2007] Robert Zanner, Dirk Wilhelm, Hubertus Feussner and Gerhard Schneider. *Evaluation of M-AID®, a first aid application for mobile phones.* Resuscitation, vol. 74, no. 3, pages 487–494, 2007. (Cited on page 115.)

[Zhou 2016] David Zhou, Yonggao Yang and Hanbing Yan. *A Smart 'Virtual Eye' Mobile System for the Visually Impaired.* IEEE potentials, vol. 35, no. 6, pages 13–20, 2016. (Cited on page 110.)