UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Ingeniería y Sistemas de Telecomunicación

Framework for the Creation of Serious Games to Support the Early Detection of ADHD in School Settings

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Ana Marta Gabaldón Pérez
Máster Universitario en Tratamiento Estadístico Computacional de la Información

Madrid, 2024

UNIVERSIDAD POLITÉCNICA DE MADRID
Escuela Técnica Superior de Ingeniería y Sistemas de Telecomunicación

Doctoral Degree in Systems and Services Engineering for the Information Society

Framework for the Creation of Serious Games to Support the Early Detection of ADHD in School Settings

DOCTORAL THESIS

Submitted for the degree of Doctor by:

Ana Marta Gabaldón Pérez
Máster Universitario en Tratamiento Estadístico Computacional de la Información

Under the supervision of:
Dr. Iván Pau de la Cruz
Dr. María Luisa Martín Ruiz

Madrid, 2024

Title: Framework for the Creation of Serious Games to Support the Early Detection of ADHD in School Settings

Author: Ana Marta Gabaldón Pérez

Doctoral Programme: Systems and Services Engineering for the Information Society.

Thesis Supervision:

Dr. Iván Pau de la Cruz, Titular de Universidad, Universidad Politécnica de Madrid (Supervisor)

Dr. María Luisa Martín Ruiz, Titular de Universidad, Universidad Politécnica de Madrid

External Reviewers:

Thesis Defense Committee:

Thesis Defense Date:

“Sólo hay que quererlo lo suficiente y durante el tiempo suficiente”.

Eduardo, Prado, Teresa y Calderón, gracias por emprender y recorrer hasta el final este camino, siempre a mi lado.

Acknowledgement

Firstly, I would like to express my gratitude to María Luisa Martín Ruiz for that day in February 2020, when she opened the doors of her office to me, thereby providing the opportunity to realise my dream job.

The combined efforts of Marisa and Iván Pau de la Cruz have enabled me to set and achieve goals that, truthfully, I was never certain I could reach. Thank you for your patience, availability, and support, but also for the challenging questions and moments of uncertainty, which have made me grow and discover myself in ways I never imagined possible.

To María Dolón, Fernando Díez, and Marta Muriel, without you, this would have been simply impossible.

To my cousin, Javier Monero Pérez, who once again was there to remind me of the true meaning of the word 'family'.

To Fernando Seoane, thank you for hosting me during my stay and introducing me to new research avenues related to my doctoral thesis.

To Fernando Sánchez, for believing in the potential of the research team and facilitating access to the ENFEN test battery.

To Nuria Máximo Bocanegra, as well as the management and/or teaching staff, and all the parents and children of the ANCOHA association and the CP Montes de Toledo for their collaboration in validating the solution proposed in this document.

To my undergraduate thesis students, thank you for your hard work, patience, and effort in understanding and implementing both the existing needs in the field of application and my, at times, incomprehensible instructions.

Last but not least, I would like to thank Ana Belén García and César Sanz for their kindness, patience, and availability in guiding me through the final steps to complete this work.

Abstract

Attention Deficit Hyperactivity Disorder (ADHD) is currently recognised as one of the most prevalent neurodevelopmental disorders in children worldwide. With a multifactorial aetiological hypothesis, the presence of this disorder directly impacts the performance of an individual's Executive Functions (EFs), thereby compromising their ability to plan, organise, and regulate their behaviour. At present, the diagnostic process for this disorder is based on a clinical evaluation ideally conducted during childhood, aiming to detect the persistence of symptoms related to inattention, hyperactivity, and impulsivity. Generally, this diagnosis is carried out in a clinical setting and is largely based on the collection of opinions from various parties associated with the child under suspicion. Consequently, the current diagnostic process for ADHD lacks the inclusion of specific biomarkers, is subject to the subjectivity inherent in symptom evaluation, and requires the presence of the suspected child in environments that may be stressful for them. The coexistence of all these factors during the diagnostic process could lead to inaccurate diagnoses.

Currently, Information and Communication Technologies (ICTs) are integrated into numerous aspects of daily life: the workplace, the educational environment, the healthcare sector, and even the home. More specifically, within the realm of clinical practice, eHealth represents a subset of ICT-based tools aimed at enhancing the processes of monitoring, treating, and diagnosing various health conditions in individuals. Within this subset of tools are Serious Games (SGs). These solutions have demonstrated validity in bringing various health services closer to patients, collecting relevant information regarding the condition of interest, and minimising the monotony perceived by individuals during treatment and/or rehabilitation processes. Contrary to these positive assertions, there is currently limited research on the use of these solutions -SGs- to support professionals in cases of suspected ADHD.

This doctoral thesis aims to contribute to the advancement of procedures and tools for the diagnosis of childhood ADHD through the incorporation of ICTs. By developing a framework for creating SGs, this research intends to introduce objective screening tools for ADHD into the natural environment of children, thereby avoiding the stress and sense of evaluation they might experience in a clinical setting. To properly address this objective, results are provided at conceptual, technological, and experimental levels. Specially, a conceptualization of the framework is offered, which is then used as a guide for the creation of four serious videogames that are subsequently tested by the target audience.

The discussion of the obtained results suggests the potential of applying ICT-based screening tools in the natural environment of children, yielding clinical results comparable to those obtained with traditional diagnostic tests. Future lines of work include the need to incorporate the solution provided in this thesis into ongoing developments within research projects involving the author, optimising its characterisation in line with emerging standards.

Resumen

El Trastorno por Déficit de Atención e Hiperactividad (TDAH) se presenta actualmente como uno de los déficits del neurodesarrollo infantil con mayor prevalencia a nivel mundial. Con una hipótesis etiológica multifactorial, la presencia de dicho déficit afecta directamente al rendimiento de las funciones ejecutivas del individuo, comprometiendo así su capacidad para planificar, organizar y regular su comportamiento. Actualmente, el proceso diagnóstico de dicho trastorno se basa en una evaluación clínica realizada, deseablemente, en la etapa infantil y que trata de detectar la persistencia de síntomas relacionados con la inatención, la hiperactividad y la impulsividad. De forma general, dicho diagnóstico se lleva a cabo en un entorno clínico y se encuentra, mayoritariamente, basado en la recopilación de opiniones referidas por diferentes actores relacionados con el niño bajo sospecha. Así, el proceso diagnóstico actual del TDAH carece de la incorporación de biomarcadores específicos, se encuentra sujeto a la subjetividad en la evaluación de los síntomas y demanda la presencia del niño bajo sospecha en entornos estresantes para éste. La coexistencia de todos los factores anteriores durante dicho proceso diagnóstico podría conducir a diagnósticos inexactos.

Actualmente, las Tecnologías de la Información y la Comunicación (TICs) se encuentran incorporadas en múltiples espacios de la vida cotidiana de las personas: su entorno laboral, el entorno educativo, el ámbito sanitario e, incluso, su propio hogar. Más concretamente, centrado en el entorno de la práctica clínica, el *eHealth* representa un subconjunto de herramientas basadas en las TICs el cual trata de mejorar los procesos de monitorización, tratamiento y diagnóstico de diversas condiciones de salud en los individuos. Concretando aún más, dentro de este subconjunto de herramientas se encuentran los Juegos Serios (JS). Dichas soluciones poseen probada validez a la hora de acercar diversos servicios de salud a los pacientes, recolectando información relevante en relación a la condición de interés y minimizando la monotonía percibida por el individuo en procesos de tratamiento y/o rehabilitación. Contrariamente a las afirmaciones anteriores, actualmente existe escasa investigación en relación al uso de dichas soluciones -JS- para proporcionar apoyo a los profesionales en caso de sospecha de TDAH.

La presente tesis doctoral trata de colaborar en el avance de los procedimientos y herramientas para el diagnóstico de TDAH infantil mediante la incorporación de las TICs. A través de la generación de un marco de creación de juegos serios, esta investigación pretende acercar herramientas objetivas de cribado para TDAH a los entornos naturales del niño, evitando así el estrés y la sensación de evaluación que éstos pudieran percibir en el entorno clínico. Para abordar correctamente este objetivo, se proporcionan resultados a nivel conceptual, tecnológico y experimental. Más

concretamente, se ofrece una conceptualización del marco, el cual es utilizado como guía para la generación de cuatro videojuegos serios que, posteriormente, se ponen a prueba mediante su uso por parte del público objetivo.

La discusión de los resultados obtenidos sugiere el potencial de la aplicación de herramientas de cribado basadas en las TICs en los entornos naturales del niño, arrojando resultados clínicos similares a los obtenidos con pruebas de diagnóstico tradicionales. Las líneas de trabajo futuras contemplan la necesidad de incorporar la solución proporcionada en esta tesis a desarrollos en curso, dentro de proyectos de investigación en los que participa la autora, optimizando su caracterización con los estándares emergentes.

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

AAP	American Academy of Paediatrics
ADHD	Attention Deficit Hyperactivity Disorder
AEPap	Asociación Española de Pediatría de Atención Primaria
APA	American Psychiatry Association
App	Application
CAPD	Central Auditory Processing Disorder
CATTS	Children's ADHD Telemental Health Treatment Study
CBCL	Child Behaviour CheckList
CD	Conduct Disorder
CNC	Consorcio de Neuropsicología Clínica
CPT	Conners Continuous Performance Test
CRS-R	Conners' Rating Scale-Revised
DFG	Directly-Follows Graphs
Dp	Dopamine
DSM-V	Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition
EFs	Executive Functions
eHealth	Electronic Health
EHR	Electronic Health Record Systems
ENFEN	Evaluación Neuropsicológica de las Funciones Ejecutivas en Niños
HIS	Hospital Information Systems
ICTs	Information and Communication Technologies
ICU	Intensive Care Unit
IGT	Iowa Gambling Task

IS	Information Society
ITU	International Telecommunication Union
ITV	Interactive Television
JSON	JavaSript Object Notation
mHealth	Mobile Health
ML	Machine Learning
MRI	Magnetic Resonance Imaging
NE	Norepinephrine
PAHO	Pan American Health Organization
PM	Process Mining
PM4H	Process Mining for Health
RCTs	Randomized Controlled Trials
SGs	Serious Games
SLI	Specific Language Impairment
SUS	System Usability Scales
TCV	Total Cerebral Volume
TMT	Trail Making Test
UI	User Interface
UPM	Universidad Politécnica de Madrid
UX	User Experience
WHO	World Health Organisation

1 Introduction

This section aims to briefly place the reader within the context of the doctoral thesis. Throughout its writing, the most characteristic aspects of the thesis scope are highlighted, along with the identified needs and possible solutions. Subsequently, the problem to be addressed in this research work is presented. Finally, the organisation of the thesis document is detailed to facilitate its reading and analysis.

1.1 Contextualisation and thesis problem

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most common neurodevelopmental disorders in childhood. Its persistence has steadily increased over recent years [1], **and the presence of this disorder has direct impact on an individual's Executive Functions (EFs) performance**, affecting their attention span, emotional regulation, and more. Consequently, their behaviour and functioning in all areas of daily life may be disrupted by this deficit. Despite the well-documented impairment of normative EFs functioning, the current diagnosis process for ADHD primarily relies on a behavioural assessment of the individual under suspicion. By using diagnostic manuals and rating scales, healthcare professionals must evaluate the child's behaviour across several aspects of their life. With the information gathered, along with their experience, prior knowledge, and personal judgement, they assign a diagnosis in each case. This means the current decision-making process is subject to a degree of subjectivity. However, as a complement to this type of evaluation, there are currently various neuropsychological test that assess EFs performance. The use of these test as auxiliary tools has been recommended by the Consorcio de Neuropsicología Clínica (CNC), as they provide healthcare professionals with an objective source of information upon which to base their decision [2].

Nonetheless, in the quest to increase the objectivity of the decision-making process, one might ask: does the use of such test constitute an inherently objective source of information? Or, conversely, could there be other factors that potentially compromise the objectivity of the results obtained? **Neuropsychological test of prove validity must be administered under direct supervision of a healthcare professional.** This expert must guide the child through the process, observe their behaviour during the test, and record various relevant indicators for the subsequent diagnosis.

Consequently, **if the patient wishes to undergo diagnostic testing, they will be required to travel to a healthcare facility, facing the inevitable logistical challenges associated with such a visit**.

Setting aside the inconveniences associated with this requirement, there are clinical factors that have been shown to affect an individual's performance and, consequently, the results obtained from test and the diagnostic conclusions reached. **The administration of test -necessarily in a clinical setting and under the supervision of a healthcare professional- can induce a sense of evaluation in the child** [3]**, which can directly affect their performance during task execution and thus biasing the objectivity of the collected information.**

Information and Communication Technologies (ICTs), and more specifically the area of Electronic Health (eHealth), currently demonstrate a high potential in their application within the health sector, including clinical practice. Encompassing a wide range of applications within this context, these technologies have enabled, among many other benefits, improvements in scientific efficiency, rapid and secure access to patient health data, the education and promotion of healthy lifestyle habits, and the possibility of remote consultations, **thereby reducing the need for travel by both patients and healthcare providers**.

Additionally, the use of ICTs enables the incorporation of sophisticated data analysis techniques, which not only enhance the understanding of the collected information and provide greater depth of knowledge but also facilitate the ongoing improvement of technological solutions to better meet the actual needs of patients and healthcare professionals. For example, **Process Mining (PM) consist of a set of algorithms that allow for the understanding of different processes by analysing the event logs generated during their execution** [4]. Nowadays, these techniques are widely used in the healthcare context with the aim of improving the reach, quality, and effectiveness of interventions through the optimisation of existing healthcare processes.

Figure 1.1. illustrates the previously outlined context, making visible the issues identified in the healthcare sector and reflecting the potential solutions using ICTs.

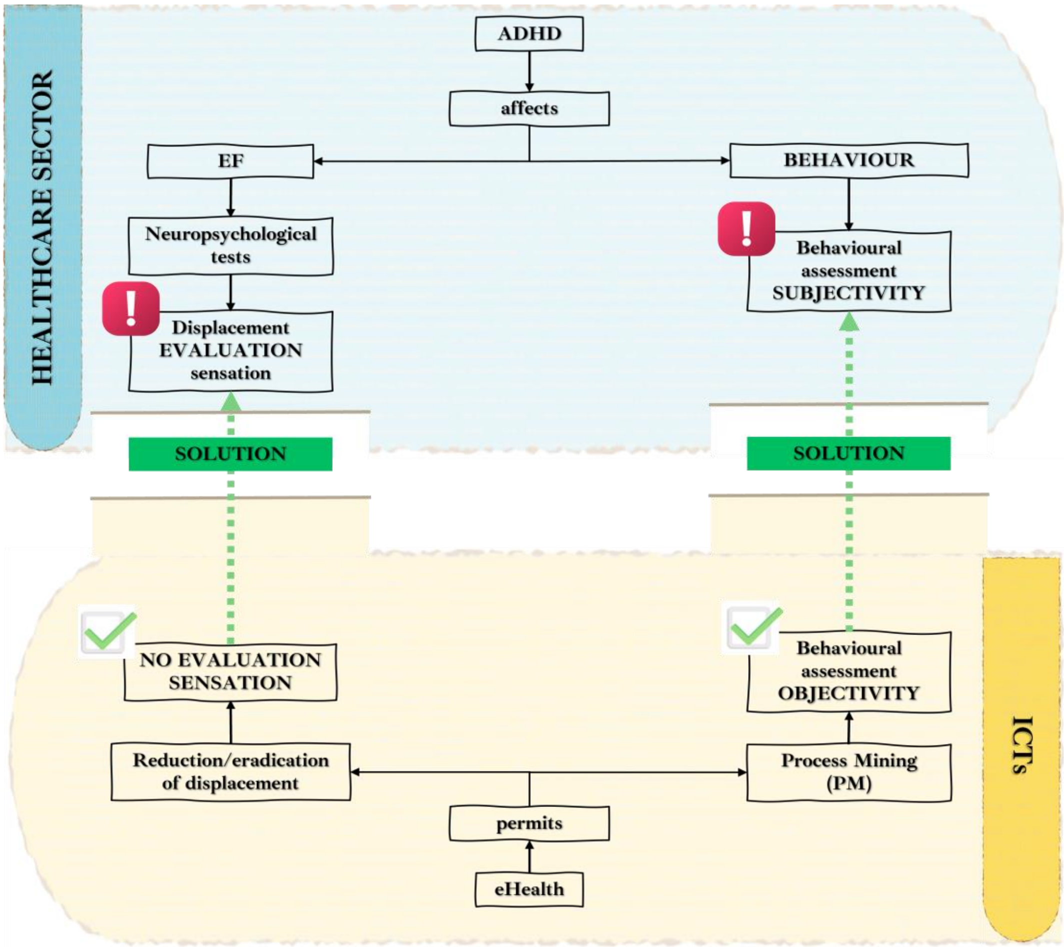


Figure 1.1. *Problem statement and identified solutions.*

Yet, given the novelty of implementing such technological solutions in the healthcare sector and the wide range of context in which they can be utilised -such as treatment, diagnosis, or prevention; for specific health conditions; whether physical or psychological- there are potential areas of application for these technologies that have yet to be validated. This is particularly true in the diagnostic domain of ADHD.

Thus, the problem to be addressed in this work is framed as **"the need to develop a framework for generating ICT-based solutions to enhance the accessibility and objectivity of the ADHD diagnostic process for school aged children".**

1.2 Structure of the thesis document

In this section, the contents covered in each of the sections that make up the thesis document are listed.

- ***Chapter 1. Introduction.***

This section introduces the reader to the domain of the thesis, aiming to quickly place them within the general problem and the context addressed.

- ***Chapter 2. Background.***

The main purpose of this section is to describe the most relevant aspects framing the thesis. It presents the social and healthcare context in detail, as well as the identified needs and current action tools. Key concepts related to eHealth are then synthesised, along with the various advantages and challenges associated with managing these technologies in the healthcare field. Finally, the characteristic of the analytical techniques to be used are detailed, highlighting their potential and the challenges related to their implementation in the clinical setting.

- ***Chapter 3. Hypothesis and Objectives.***

Building on the statements presented in the previous two chapters, this section provides a detailed discussion of the research premises, the hypotheses to be tested, their scope, and the objectives to be achieved, with particular emphasis on the procedures and actions directly related to achieving these objectives.

- ***Chapter 4. Methodology and Materials***

This chapter provides a systematic description of how the research was conducted, allowing the reader to assess the validity and reliability of the results presented in the following section. It describes the resources and tools used, as well as the methodological approach adopted, including specific aspects of the development and application of data analysis techniques.

- ***Chapter 5. Results.***

Through the presentation and analysis of the main findings derived from the research, this chapter provides empirical evidence of the methods applied in the study. It details the developed framework and its validation through experiments conducted in real-world application settings.

- ***Chapter 6. Discussion and Conclusions.***

This section provides an interpretation, analysis, and contextualisation of the results obtained during the research. It reflects on the meaning and potential consequences of adopting or rejecting the hypothesis posed in earlier sections. Generally, this section summarises the main findings, consolidating and synthesising the conducted research.

- ***Chapter 7. Bibliography.***

Finally, this chapter list the bibliographic references used in relation to the context of interest -social, healthcare, and technological-, eHealth services, and data analysis techniques, along with their applications, advantages, and implementation challenges.

2 Background

"And what would have become of the lives of Leonardo da Vinci, Beethoven, Mozart, Dustin Hoffman, Harrison Ford, John Irving, Steven Spielberg, or Alejandro Rojas without ADHD" [5].

Within their respective disciplines, these and others influential figures have experienced significant growth despite having ADHD. Each one exemplifies that, through the proper harnessing of individual abilities, this deficit need not be a limitation for those who have it. According to Barkley, ADHD *"may simply represent a human trait rather than a pathological condition"* [6]. The management of behaviours, supervision of conduct, and assessment of the abilities of children with ADHD can realign the future expectations. Yet, this task of guidance requires a series of actions that must be rigorously selected and tailored for each case to achieve an optimal outcome.

This chapter provides a synthesis of the most relevant aspects related to ADHD that will be addressed in this research, as well as an overview of the techniques and tools employed to achieve the outlined objectives.

2.1 Define what ADHD is

Throughout history, the restless, disruptive, forgetful, and procrastinating behaviour of certain individuals -both children and adults- has attracted the attention of educators, doctors, psychologist, and psychiatrist, who have sought to understand these behavioural patterns and their underlying causes.

In 1902, George Frederick Still provided what is considered the first clinical definition of ADHD, attributing the observed behavioural problems to a defect in moral control, resulting from an organic issue [7]. Since this initial conceptualisation of ADHD, various experts have studied its signs and symptoms, linking its onset to lesions in the central lobe of the brain, which could cause broad deficits in Executive Functions (EFs). By 1960, Europe and the United States were engaged in a controversy regarding the severity of this deficit, with the former considering ADHD to be a rare phenomenon associated with brain damage. More recent studies have integrated neuropsychological difficulties and clinical symptoms into a framework of brain dysfunctions, with cognitive theories suggesting that ADHD is associated with deficits in EFs [8].

Currently, ADHD is described as a *"neurobiological disorder with onset in childhood and severe functional implications across various environments, characterised by the presence of inappropriate levels of inattention, hyperactivity, and impulsivity"* [9][10].

So, based on the previous paragraph, what does it mean for a person to be diagnosed with ADHD today? To answer this question accurately, it is necessary to understand the significance of the aforementioned statement.

2.1.1. "Neurobiological disorder..."

The Central Nervous System of the human being consist of the brain, diencephalon, cerebellum, and brainstem. Among these, the brain is considered the most complex organ in the human body. Located in the anterior and superior part of the cranial cavity, this organ controls the body's vital functions, and everything related to senses, thoughts, movements, behaviours, and reasoning. In other words, it is responsible for managing the proper functioning of the body and its adaptation to the surrounding environment, with the ultimate aim of ensuring the individual's survival.

Due to the complexity of the brain structure, various research profiles have subdivided this organ according to the regulation of different actions into various brain areas, facilitating its study (Figure 2.1.). Divided into two large hemispheres (figure A in Figure 2.1.), the brain is characterised by its convoluted cerebral cortex, which is further subdivided into four visible lobes and a fifth situated in the depths of the outer cortex (figures B and C in Figure 2.1.). These regions are associated with specific functional attributes and may be developed in individuals with particular talents or deficits [11].

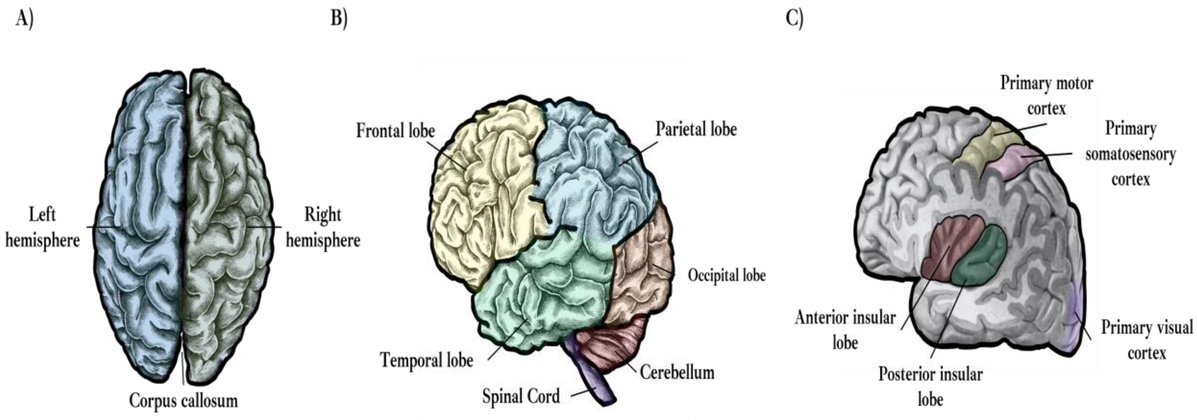


Figure 2.1. *Anatomy of the human brain. A) cerebral hemispheres; B) lateral view: cerebral lobes, cerebellum, and brainstem; C) lateral view: insula.*

Thanks to Magnetic Resonance Imaging (MRI) techniques, there is now evidence of anatomical differences between brains with normative development and those with ADHD [12], some of which are outlined below.

Regarding volumetrics, ADHD brains exhibit a reduction of up to 4% in Total Cerebral Volume (TCV), affecting the major lobes [9]-[11]. In particular, the prefrontal cortex (a specific part of the frontal lobe, located in its most anterior region) can experience a volume reduction of up to 48%, being significantly smaller in individuals with the mentioned deficit [13], [16], [17]. In terms of symmetry, in a normally developed brain, the right cerebral hemisphere, specifically the right prefrontal cortex, is significantly larger than the left [14]-[16]. Consistent with this, the volumes of the lateral ventricle and cerebrospinal fluid are greater on the left side. In an ADHD brain, the asymmetry between the right and left prefrontal cortex is reduced due to a significant decrease in brain volume and, consequently, in prefrontal regions. At last, concerning grey matter and white matter, located in the cerebral cortex and deeper brain tissues respectively, ADHD brains show a reduction in both in the left and right prefrontal cortices [16], [21], [22]. Contrarywise, in 2003, Sowelll found an increase of between 15-30% in grey matter density in the left occipital lobe [23].

Among the various effects that can results from the aforementioned anomalies in proper brain function is an imbalance in the normal functioning of neurotransmitters in the prefrontal cortex. In an ADHD brain, the levels of presynaptic reuptake of Dopamine (Dp) and Norepinephrine (NE) are altered, disrupting the function of the frontostriatal, mesolimbic, or frontocerebellar circuits. This situation leads to abnormal functioning of the brain's self-regulation mechanisms and executive functions, resulting in the symptoms experienced in daily life and the common clinical manifestations of ADHD [24].

2.1.2. "..., with onset in childhood..."

Brain development is a lengthy process that begins in the third week of gestation and continues until the adolescence. This process, influenced by genetics as well as the individual's surrounding environmental conditions and experiences, is characterised as *"a complex series of dynamic and adaptive processes that operate throughout the course of development to promote the emergence and differentiation of new neuronal structures and functions"* [25]. It is important to emphasise that, since neurodevelopment is a continuous phenomenon, there are no distinct states. However, due to the varying prominence of different skills acquisition, different states of brain maturation have been identified.

In the case of prenatal neurodevelopment -during intrauterine life- the predominant phenomenon is the acquisition of the brain structure as it will exist in the adult brain. Through the generation of new cells, their grouping to form the organs of the nervous system, and its anatomical growth, by the ninth month of pregnancy, the foetus's brain reaches an estimated weight of about 350 grams, and the cranial capacity has an average circumference of between 33 and 36 cm [26].

At the time of birth, the number of neurons present in the brain is approximately the same as in an adult, around one hundred billion cells, even though the brain's volume has only developed to about 25% of its full size. Moreover, neither the neural connections (fifty trillion synapses) nor the support cells that insulate them are fully formed at birth.

During the first three years of life, the number of synapses in the baby's brain can reach one quadrillion, with a total of one hundred and fifty trillion in an adult brain. However, between the ages of three and ten, many of these connections will disappear, with only those most frequently used by the individual through various experiences remaining active (Figure 2.2.) [27]. During this growth period, the acquisition of motor autonomy is the focus. By the age of three, a typically developed child is expected to be able to walk independently, show a preference for one hand, have control over speech (though not necessarily language), and manage sphincter control. This is also the stage when cerebral palsy can be diagnosed with certainty, and delays in language and social interaction begin to be detected.

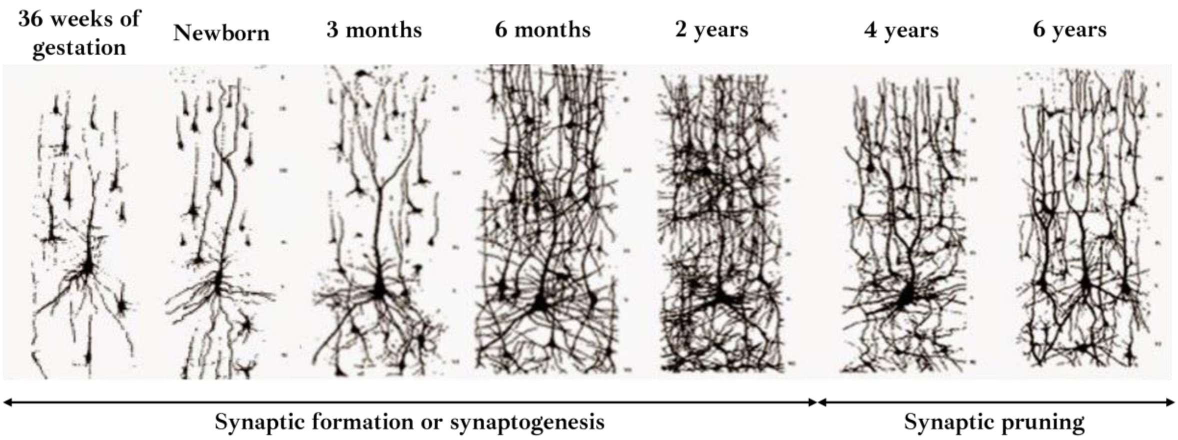


Figure 2.2. *Synaptogenesis and synaptic pruning.*

(Taken from https://www.psicoactiva.com/blog/la-poda-neuronal-nos-sirve/)

From three to ten years of age, the neurodevelopment of language and knowledge of the environment takes place. In this period, the consolidation of the circuits formed in the previous stage predominates, becoming increasingly consistent. By the age of five, 90% of the volume of an adult brain is reached, with gender differences, the cerebrum and cerebellum being larger in the case of boys. By the age of six, the frontal lobe of the brain is fully developed, although it will not finish maturing until the mid-twenties.

The frontal lobe is responsible for executive work -cognitive processes- in the brain. Its purpose is to enable the programming, development, execution, and monitoring of a goal-directed action plan. A typically developed child should be able to solve simple problems, intellectually, emotionally, and socially. Though, there is a certain percentage of children whose learning and behavioural problems are attributable to minimal infantile brain dysfunction, presenting regular intellectual development, but with alterations in some of the cognitive or behavioural processes [28]. It is from this age, six years old, when a diagnosis of ADHD can be made [5], [29].

Lastly, from the age of ten until about twenty, there is the stage of neurodevelopment of identity, in which psychological changes take place, in personal autonomy and in social relations. This is the period in which the personality of each individual is created and in which individual critical thinking is forged.

2.1.3. "..., and severe functional implications across various environments"

Under normal conditions, neurotransmitters are released in the brain in a matter of milliseconds, allowing the individual to adapt to a constantly changing reality. In the ADHD brain, *"this only occurs when the goal set is sufficiently motivating for the individual or when the achievement of results is immediate"* [5]. This fact is directly related to the problems detected in emotional regulation and lack of performance in the school or work environment. In turn, the existing dysfunction in the regulation of cognitive processes may lead to the appearance of other learning and/or psychiatric problems.

According to the presence of the main symptoms[1], this deficit presents three typologies [30]:

- *Predominantly hyperactive-impulsive presentation.* Characterised by slow information processing, low levels of alertness, and mild memory and orientation problems. With a prevalence of 30% among ADHD cases, these children often struggle to remain seated or to control their behaviour.

- *Predominantly inattentive presentation.* With a prevalence of 10% among all ADHD cases, predominantly in females, it is the most difficult type to diagnose due to the subtlety of its symptoms. Children with this type of deficit are characterised by inattentiveness to detail and constant distraction, which can lead to a gradual decline in self-esteem over time.
- *Combined presentation.* Present in 60% of cases, individuals with this type of ADHD exhibit significant difficulties with both hyperactivity-impulsivity and inattention. This form of ADHD is most closely associated with comorbidities, including other mental disorders such as anxiety, depression, and substance use.

In general, the presence of this deficit is associated with an increased likelihood of experiencing accidents, academic failure or job loss, social difficulties, higher rates of psychiatric comorbidity, a risk of premature death up to three times greater than that of individuals without ADHD, and, in the case of adolescents, up to twice the risk of substance use [5].

Summary of the section *Define what ADHD is*

ADHD is a disorder whose aetiological hypothesis is based on the disruption of the presynaptic reuptake process of neurotransmitters due to abnormalities in various brain structures. Among the different areas that may be affected is the frontal lobe, which is associated with the management of the executive functions.

The diagnosis of ADHD can be reliably made from the age of six, when the frontal lobe is sufficiently developed, thereby reducing the risk of confusing it with age-appropriate behaviours or a delay in the individual's brain maturation. Early diagnosis of this disorder during childhood currently allows for the reduction of symptoms, facilitates adaptation to the surrounding environment, and helps direct individual abilities towards achieving a fulfilling and happy life.

2.2. Diagnosing ADHD

One of the main objectives underlying the task of defining ADHD, determining its origin and discovering its main manifestations is to be able to diagnose it.

Correct and early detection and treatment of ADHD can help to reduce the consequences it may have on the individual, thereby reducing its long-term impact and improving the prognosis [31] (assumed premise **Prem.1**). Since, according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-V), symptoms must be present before the age of twelve, and given the biological basis explained previously, the diagnosis process of the aforementioned deficit is currently mostly carried out in school-aged children, although it is possible to carry it out in adolescents and adults [30], [32].

Due to the above, this section focuses on detailing the current diagnostic process aimed at school-aged children (between six and twelve years). The different protocols of action are mentioned, as wells as the different test used for the detection of the disorder and the possible diagnostic difficulties.

2.2.1. General protocol for suspected ADHD

As of today, no universally agreed-upon protocol exists, either internationally or within a single region, detailing the steps to take when ADHD is suspected. Specifically, in Spain, each autonomous community has developed its own informational framework, procedures, intervention guidelines, and evaluation tools over the years to address the challenges posed by this disorder in their respective territories [33].

Nevertheless, despite the apparent lack of consensus, some authors have identified common elements across these guidelines: the stakeholders involved in the process, the steps to be followed until a diagnosis is made, and the tools used for this purpose generally align in most documents. In 2017, Cardo et al. proposed *"the simplest diagnostic pathway"* [34], which outlines and sequences the various steps to be taken when there is a suspicion of childhood ADHD (Figure 2.3.).

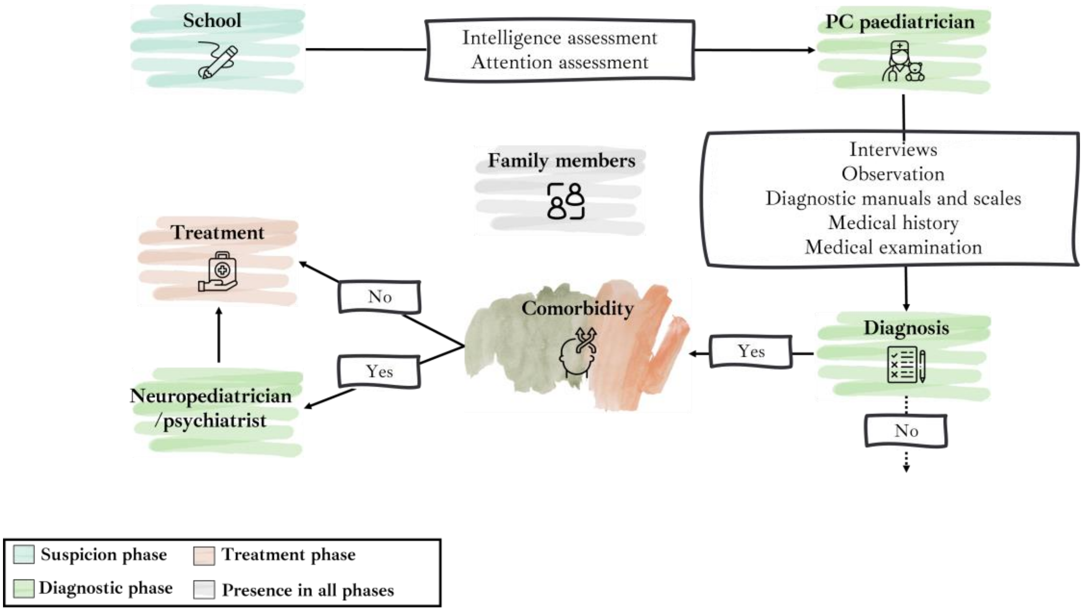


Figure 2.3. *General protocol for suspected ADHD based on the work of Cardo et al.*

Under the framework of the previous figure, it is generally the educators who are the first to detect the potential presence of the disorder (**Prem.2**). Drawing on their personal experience gained in the classroom, their knowledge of child development, and the administration of various intelligence and attention test, the teaching staff and the school's management are responsible for initiating the intervention process. The child under suspicion should then be referred to their primary care (PC) paediatrician, who will follow a diagnostic protocol involving interviews, the use of diagnostic manuals, neuropsychological test, and various medical examinations to rule out vision, hearing, and psychomotor problems. Following these tests, if the suspicion of ADHD is confirmed, the paediatrician will need to assess the possible coexistence of other disorders -comorbidity- that might be associated with or exacerbating ADHD (such as depressive disorders, Tourette syndrome, bipolar affective disorder, etc.) [35]. If the presence of these other disorders can be ruled out and ADHD is identified as an isolated condition, the paediatrician will provide the appropriate treatment for the patient. Otherwise (in 50-70% of cases), the child should be referred to a specialist in paediatric psychiatry or child neurology, who will conduct a more thorough examination of the case and determine the treatment.

Relevance of Collaboration Among Key Stakeholders

Based on Figure 2.3., the crucial importance of collaboration and communication among the primary stakeholders involved in the diagnostic process for suspected childhood ADHD becomes apparent. A close relationship between family members, educators, and healthcare professionals is essential for:

1. ***Obtaining comprehensive perspectives***. As the diagnostic evaluation primarily relies on behavioural analysis of the child across various environments, communication between stakeholders with insights into each of these contexts provides a holistic view of the child's behaviour.

2. ***Gathering a complete history***. Parents and close family members can provide information about the child's development within the family environment -emotional context-. Meanwhile, as previously mentioned, educators have the advantage of observing when the initial symptoms appear and how they have evolved -social and educational context-. Lastly, the healthcare professional has access to the child's medical history -including family history of ADHD-. Combining these three sources of information offers a comprehensive history of the child's development and their emotional, educational, social, and medical context.

3. ***Providing early support***. Observing the child in various environments and daily activities enables early detection of the disorder. Subsequently, early interventions and support can be implemented, thereby improving the child's future prospects.

4. ***Offering personalised treatment***. Collaboration among different stakeholders allows for the development of a personalised treatment plan tailored to the child's needs in each of their daily environments.

5. ***Ensuring ongoing support and treatment***. The presence of stakeholders in each of the child's environments facilitates access to treatment tools, ensuring continuous support.

Today, *"we know that a child diagnosed with ADHD benefits more when there is collaboration among families, their doctors, and teachers, who can create special plans with instructions and support"* [36] (**Prem.3**).

2.2.2. Diagnostic manuals and assessment scales

At present, the DSM-V serves as the reference tool that assists healthcare professionals in understanding, communicating, and diagnosing ADHD [30], [37]. Published by the American Psychiatric Association (APA) in 2013, this manual provides descriptions and a series of diagnostic criteria for various mental and emotional disorders, listing symptoms and diagnostic guidelines.

Regarding ADHD, the DSM-V enumerates the different common symptoms in individuals with ADHD, without distinguishing between age groups, and present a series of diagnostic criteria that vary depending on whether the individual being assessed is a child or an adult. According to this manual, *"at least six of the symptoms must be present in the individual for a period of at least six months, to a degree that is inconsistent with the developmental level and that directly affects social and academic/occupational activities"* for the disorder to be effectively diagnosed. Thus, healthcare professionals find in the DSM-V a proven and effective guide on which to base their decisions.

However, this manual presents a series of limitations regarding diagnosis that compromise its accuracy and are inconsistent with some of the knowledge acquired about ADHD in recent years. Since the publication of the DSM-IV in 1994, few changes have been introduced in its latest version to address some of its most characteristic limitations. In 2011, in anticipation of the release of the new edition, the authors of [37] detailed each of these inconsistences found in the DSM-IV with the aim of having them rectified by the APA. Table 2.1. specifies each of the recommendations proposed by these authors and indicates whether they have been considered in the DSM-V.

In the DSM-V, unlike its previous version, ADHD is removed from the category of *"Childhood and adolescent disorders,"* as it is now considered a condition that persist throughout an individual's life. Nevertheless, despite the increase in the age of onset for symptoms, from seven years in the DSM-IV to twelve in the current version, this characteristic remains a diagnostic criterion in the manual.

Regarding the number of symptoms that must be present in the individual, the latest version allows for the possibility that these symptoms may not be detected under certain conditions of motivation and different supervised activities. Yet, this does not address the fact that six or more symptoms are still required to diagnose the individual.

Moreover, the categorisation of individuals into different ADHD subtypes and the lack of thoroughness in specifying the limitations that a person with this disorder must experience to be diagnosed have not been revised.

Table 2.1. Inconsistences found in the DSM-IV and their revision in the DSM-V.

Inconsistences identified in the DSM-IV	Revised change in the DSM-V
The **age of onset for the symptoms** should not be a diagnostic criterion. If an individual presents symptoms after the age of seven, are they no longer eligible for an ADHD diagnosis?	Yes
Number of symptoms and level of impairment in the individual. Several studies have demonstrated that there is no correlation between the number of symptoms an individual presents and the degree of impairment they may experience.	No
The **existence of subtypes** within ADHD is inconsistent. The same child may present one subtype at a certain time and late develop into a different subtype.	No
Categorical model. If an individual presents some symptoms of ADHD but not six or more, they will not be diagnosed.	No

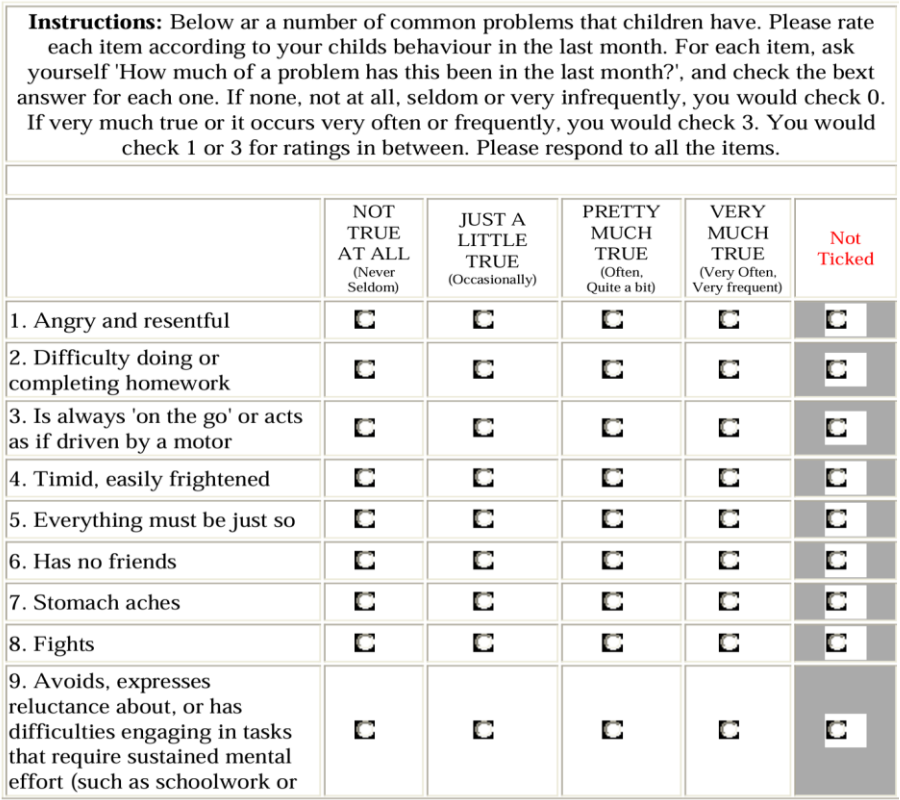
Additionally, the DSM-V *"classifies neurodevelopmental disorders as psychiatric entities without providing any neurobiological data"* [38]. This, among other reasons, has led healthcare professionals, experts in the field, and other researchers to consider that the prevalence of ADHD has increased due to overdiagnosis. That is to say, it is not that the diagnostic process has improved, but rather that incorrect diagnoses are being made.

For these and other reasons, the correct diagnosis of ADHD involves not only the use of the DSM-V but also the application of scales and questionaries [39]. Recommended for clinical use, these scales allow for the collection of more detailed information from various sources, such as family members and educators, and enable the measurement of the severity of impairments and treatment effectiveness, as well as the determination of the presence of comorbidity [40]. Once again, there is a lack of consensus regarding which and how many of these tools should be employed in clinical practice (Table 2.2.).

Table 2.2. *Some specific ADHD and broad-spectrum assessment scales applicable to children and adolescents.*

Scale	Orientation and method
Conners' scale	Evaluation of symptoms of inattention, hyperactivity, and impulsivity in children and adolescents based on the observations of family members and teachers.
Child Behaviour CheckList (CBCL)	Assessment of behaviour and various emotional disorders in children [41]. Not specific to ADHD.
ADHD Rating scale	Measures the primary traits of ADHD and possible comorbid Conduct Disorders [42]
Swanson, Nolan, and Pelham ADHD Rating Scale (SNAP-IV)	Self-administered scale aimed at family members and educators that gathers information about the child's behaviour in different settings and their academic performance [43]

Designed by C. Keith Conners in 1969, the Conners' scales (Conners ADHD Rating Scales) are among the most widely used tools for detecting ADHD in children and adolescents globally [40]. These scales are aimed at gathering information from family members, educators, and even the child themselves, consisting of a set of items or statements that assess behaviour and symptoms associated with ADHD across various areas of daily life [44]. Using Likert Scales [45], the respondent is asked to describe, according to their personal judgement, the degree to which a characteristic ADHD behaviour is present in the child under suspicion (Figure 2.4.). Typically, the administration time ranges from ten to fifteen minutes for the extended versions and from five to ten minutes for the shorter versions.



Instructions: Below ar a number of common problems that children have. Please rate each item according to your childs behaviour in the last month. For each item, ask yourself 'How much of a problem has this been in the last month?', and check the bext answer for each one. If none, not at all, seldom or very infrequently, you would check 0. If very much true or it occurs very often or frequently, you would check 3. You would check 1 or 3 for ratings in between. Please respond to all the items.

	NOT TRUE AT ALL (Never Seldom)	JUST A LITTLE TRUE (Occasionally)	PRETTY MUCH TRUE (Often, Quite a bit)	VERY MUCH TRUE (Very Often, Very frequent)	Not Ticked
1. Angry and resentful					
2. Difficulty doing or completing homework					
3. Is always 'on the go' or acts as if driven by a motor					
4. Timid, easily frightened					
5. Everything must be just so					
6. Has no friends					
7. Stomach aches					
8. Fights					
9. Avoids, expresses reluctance about, or has difficulties engaging in tasks that require sustained mental effort (such as schoolwork or					

Figure 2.4. *Conners' Rating Scale-Revised (CRS-R)*

(Taken from https://www.ncbi.nlm.nih.gov/projects/gap/cgi-bin/GetPdf.cgi?id=phd000095.1)

Despite the existing recommendation to use assessment scales as supportive tools in the diagnostic process of ADHD, *"the main disadvantage of these scales is the lack of clinical confirmation of the diagnosis, and therefore the uncertainty about whether the respondents have correctly understood the questions asked"* [46]. Consequently, the conclusions drawn from these assessments can be categorised as subjective, dependent on the understanding and personal opinion of the individual completing them.

2.2.3. Assessment of Executive Functions

Since 1982, when the American neuropsychologist Muriel Deutsch Lezak introduced the term Executive Functions (EFs) as *"all those capacities essential for carrying out effective, creative, and socially accepted behaviour,"* these functions have gained increasing prominence in the field of neuropsychology [47]. Over time, various experts have continued to review and refine this initial definition, along with the characteristics and levels of abstraction of EFs. Currently, the most general way to refer to EFs is as *"the set of skills involved in the generation, supervision, regulation, execution,* *and adjustment of appropriate behaviours to achieve complex goals, specifically those that are novel for the individual and require a creative solution"* [42]-[44].

But how are these cognitive functions related to ADHD? In humans, the prefrontal cortex, among other brain areas, is responsible for mediating executive function, involving the processing of emotional and social information as well as behaviour regulation. Thus, atypical development in this area can lead to disruptions in cognitive function. As discussed in the section *Define what ADHD is*, individuals with ADHD may exhibit changes in brain anatomy, likely resulting in subsequent alterations in the management of executive function. To date, there is substantial scientific evidence linking the presence of ADHD in an individual with impairments in EFs performance, with such impairments being recognised as one of the primary characteristics of the disorder [51], [52] (**Prem.4**).

In 1997, Russel A. Barkley, an American scientist, psychologist, and researcher, proposed a theory regarding the relationship between the presence of ADHD and executive function [52], [53]. Based on the definition of executive function as *"self-directed actions"* by the individual, Barkley theorised that there are six types of actions that may be compromised in the presence of the aforementioned deficit (Table 2.3.).

According to Barkley's theory, *"in general, individuals with ADHD are more controlled by external events than by their own mental representations, more influenced by others than by their own self-control, opting for immediate gratification over delayed rewards, and more influenced by the present than by the future that lies ahead"* [52].

Table 2.3. According to Barkley, self-directed actions that may be affected by ADHD.

Self-directed action	Linked subfunctions	Description
Self-stopping	Response inhibition	An individual's ability to stop and avoid an impulsive response to a stimulus. The author sees this ability as fundamental to the existence of the following four.
Sensing to the self	Non-verbal working memory	Mental module that allows the individual to perceive the future according to the filter of past experiences.
Self-speech	Verbal working memory	It enables the development of goal-directed strategies, problem solving and governs moral behaviour.
Emoting and motivating to the self		A person's ability to manage their thoughts, actions, and emotions. According to Barkley, self-regulation happens because of the above three actions.
Self-play	Fluency Flexibility Generativity Working memory	Barkley defines such action as *"the source of self-organisation and innovation."* A set of actions required by the individual to overcome various obstacles and achieve their goals.
Self-awareness	Attention Inhibition	Ability to pay attention to one's own behaviour and regulate it according to the context.

To evaluate the performance of these self-directed actions -executive functions (EFs) or cognitive functions- various neuropsychological test are available worldwide. Designed for their use in clinical settings, neuropsychological test are tools that assess and understand how different brain areas and systems function through the measurement of cognitive abilities. These tests aim to measure aspects such as language, attention, concentration, and EFs to determine the cognitive and affective-behavioural state of individuals.

In Spain, the Consorcio de Neouropsicología Clínica (CNC), in its efforts to disseminate knowledge and improve the quality of life for individuals with ADHD, has compiled a set of test and tasks required for evaluating cognitive functions and their components, categorised by age ranges, in relation to the diagnosis of ADHD [2].

Specifically, for school-aged children -between six and twelve years old- the CNC recommends the following[2]:

1. *Attention test.* These evaluate distinct aspects of attention, such as sustained, selective, or divided attention, using techniques based on the Trail Making Test (TMT) paradigm, Dual Task exercises, and the Conners' Continuous Performance Test (CPT).
2. *Processing Speed Test.* These assess the individual's ability to process new information and provide a rapid and optimal response to stimuli. The CNC does not specify a particular test for evaluating this cognitive function.
3. *Working Memory Tests.* These focus on verbal and spatial working memory. Recommended tests include the N Back and the Corsi Block-Tapping Test.
4. *Inhibition Tests.* These measure impulse control using the Go/NoGo and STROOP paradigms.
5. *Executive Function Tests.* These examine subfunctions such as verbal fluency, cognitive flexibility, planning, and decision-making. Tests used for this purpose include the Iowa Gambling Task (IGT), TMT, the Tower of Hanoi, and tasks for generating words within semantic and phonological categories.

[2]For more details on the neuropsychological tests recommended by the CNC for diagnosing ADHD in school-aged children, refer to Annex B.

Neuropsychological tests, due to the way they measure an individual's performance during various tasks, introduce objective sources of information into the current process for diagnosing ADHD. By recording different measurement parameters established for each test (such as correct responses, errors, time taken to complete the task, etc.) and comparing them with *expected results*, the healthcare professionals gains insights that allow for unbiased conclusions about the patient's condition.

However, despite the undeniable improvement that the inclusion of an objective information source brings to the ADHD diagnostic process and its widespread use by healthcare professionals, neuropsychological tests have the disadvantage of requiring the individual to be present in clinical settings. Since these tests are designed for use by healthcare experts, individuals suspected of having ADHD must travel to the healthcare facility where the responsible professional will guide them through the tests and evaluate their performance. Consequently, clinical settings introduce factors that can effectively impact the individual's performance and, therefore, the results obtained, and the conclusions drawn from these tests. *"In clinical diagnosis, the monotonous hospital environment, the presence of unknown individuals, and the evaluative atmosphere a child may experience in a healthcare setting directly affect their behaviour and performance in reality"* (**Prem.5**).

Summary of the section *Diagnosing ADHD*

Although there is currently no specific protocol or consensus on the type and number of tests to be conducted for suspected ADHD -whether in children, adolescents, or adults- there are numerous tools available that can provide an approximate understanding of the individual's overall condition.

Typically, the DSM-V is the reference manual upon which healthcare professionals base their conclusion. Nevertheless, various assessment scales are required to complement the information obtained from this manual. This approach aims to gather insights into the individual's daily behaviour: how they interact socially, whether they face difficulties in academic or work settings, etc.

Given the nature of ADHD, it is notable that its diagnosis is largely based on subjective observations from those close to the suspected individual and the personal experience of the healthcare expert. As an objective source of information that evaluates cognitive performance, clinicians have access to several neuropsychological test. Yet, a significant disadvantage of these tests is the necessity for the individual under suspicion to be present in a healthcare facility. This unfamiliar environment, particularly for children, directly impacts their performance, which in turn affects the results of the tests and, consequently, the conclusions drawn by the healthcare professional.

2.3. ICTs in the healthcare sector

In the era of the Information Society (IS), the widespread use of ICTs, such as the Internet, computers, mobile phones, and other digital devices, facilitates the generation, transmission, and storage of information. Consequently, the availability of and access to information have become key aspects of daily life and are essential to economic, cultural, and social activities.

Focusing on the healthcare sector, in 2012, the Electronic Health Handbook for Health Service and Systems Managers was published, aimed to incorporating ICTs into public health strategies [54]. This handbook outlines all areas of healthcare application, clarifies key concepts, specifies the benefits of such applications, and identifies necessary requirements. Given the nature of ICT, their application in the healthcare field *"enables the integration of data and best practices, the virtualisation of certain healthcare services and resources, as well as access to such services anytime, anywhere"* [55].

Following the structure and commitment of the aforementioned handbook, this section defines a series of relevant concepts for contextualising the present doctoral thesis. Through the presentation of use cases, various areas of ICTs application are demonstrated, along with promising outcomes and the limitations/requirements that need to be addressed.

2.3.1. Electronic Health (eHealth)

What is eHealth?

Despite its widespread use by academic institutions, professionals bodies, and financial organisations, the neologism eHealth remains a concept lacking a universally agreed definition [56]. In 2005, Hans et al. defined eHealth as *"a consumer-centred model of healthcare where stakeholders collaborate using ICTs to manage health, organise, deliver, and account for care, as well as administer the healthcare system"* [56]. Later, in 2010, Van De Belt et al., from a total of forty-five proposed definitions, highlighted one that maintained eHealth refers to *"interactive applications, services, and web-based tools designed for healthcare consumers, caregivers, patients, and health professionals"* [57]. In 2011, the World Health Organization (WHO) provided a much more general and public-facing definition, describing eHealth as *"the cost-effective and secure use of ICTs for health and health-related purposes"* [58]. In 2015, the European Commission proposed that eHealth refers to *"all tools and services that rely on ICTs and can improve prevention, diagnosis, treatment, monitoring, and management"* [59].

Given the evident lack of consensus on a precise definition for this term, the present work bases its knowledge, assertions, and conclusions on the European Commission's definition of eHealth. This choice is supported by the alignment of this definition with the research focus that guides the development of this thesis.

Related Concepts

As of the writing of this document, the concept of eHealth has become an umbrella term, encompassing a wide range of services, such as Telemedicine, Mobile Health (mHealth), and Electronic Health Records (EHR), among others [59], [60] (Figure 2.5.).

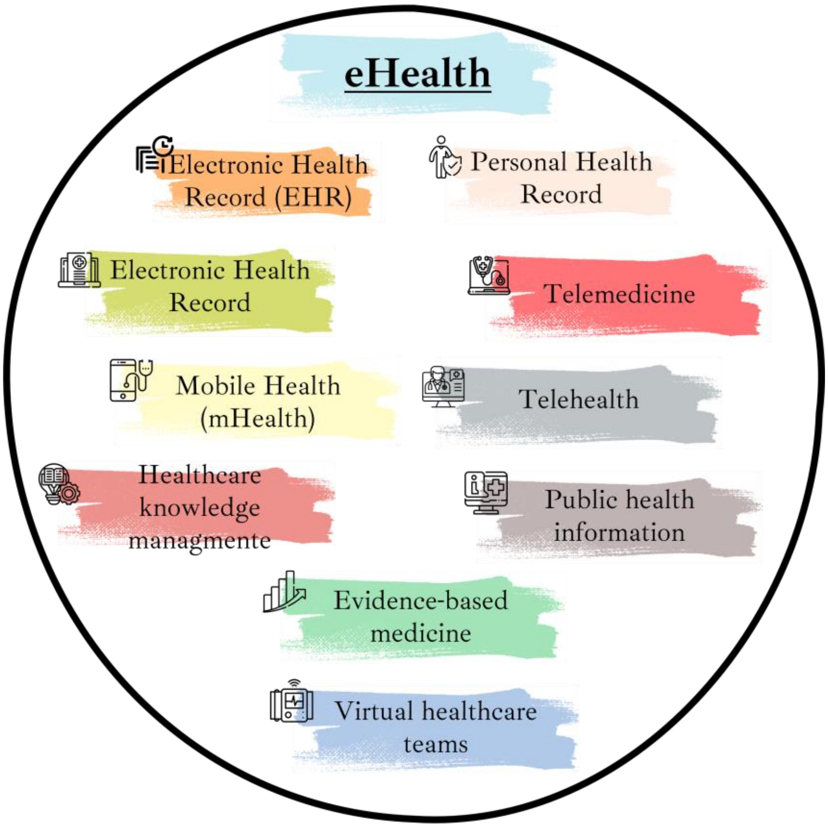


Figure 2.5. *Some eHealth services.*

Of particular interest for this research are the terms Telemedicine and mHealth.

The term Telemedicine refers exclusively to aspects of medical care. After reviewing a total of one hundred and four proposed definitions, both the European Commission and Sood et al. concluded that the term is part of eHealth, defining it as *"the remote use of ICTs to provide medical care and education services"* [59], [61]. According to Loxo et al., Telemedicine includes all types of treatments, both physical and psychological, that do not require the patient to travel, thus reducing the need for visits to specialists' clinics [60].

In contrast to Telemedicine, the concept of mHealth describes *"the use of mobile communications for health information and services"* [62]. This definition, by its very nature, eliminates the mandatory presence of the healthcare provider, highlighting the capacity of ICTs to transform the patient into a *"proactive partner and co-producer of their health and care"* [55]. Mobile devices enable users to obtain contextual information about their daily lives through the real-time monitoring of various health parameters, allowing for instant and objective feedback.

All the services outlined in Figure 2.5. can strengthen health systems in a wide variety of aspects [63]:

- They improve the availability, quality, and use of information and evidence by strengthening health information systems and public health surveillance systems.
- They enable the development of the healthcare workforce and enhance performance by overcoming distance and time barriers through telemedicine and continuous medical education.
- Tey improve access to existing global and local health information and knowledge.
- They promote positive lifestyle changes to prevent and control common diseases.

For all these reasons, eHealth has been referred to as *"the greatest revolution in healthcare since the advent of modern medicine"* [64].

Foundations for the Development of eHealth Strategies

Despite the interest shown by the WHO, the International Telecommunication Union (ITU), the Pan American Health Organization (PAHO), the African Union, and the Commonwealth in developing a unified strategy for the advancement of eHealth projects, there remains no clear guidance to inform countries and their organisations on how and why they should develop specific eHealth strategies. In response to this, in 2013, Scott et al. developed a framework for the implementation of eHealth strategies, enabling institutions, subnational regions, and countries to adopt a systematic and methodological approach to creating comprehensive eHealth strategies [65].

According to the authors, there are a total of seven basic principles underpinning the development of eHealth strategies:

1. ***Simplifying complex contexts.*** By establishing a robust, evidence-based eHealth strategy, it is possible to reduce the impact of the complexities and challenges involved in integrating eHealth

as routine healthcare tools. This process is more effective when carried out by a local team, which has a more intimate understanding of the environment and builds local capacity.

2. ***Pragmatic approach.*** The aim of the strategy is to find solutions to prevailing healthcare problems, which requires an understanding of the urgent needs in healthcare delivery.
3. ***Distributing costs.*** The ICTs network supports sectors such as government, business, education, and health. This network thus provides opportunities to distribute the costs of developing infrastructures and info-structures across these sectors.
4. ***Balance in the application of eHealth components.*** Solutions to specific health problems may require the predominance of certain eHealth services over others, with the most likely scenario involving the use of several of these services to develop sustainable solutions.
5. ***eHealth solutions must be appropriate for the context.*** Appropriate technology can be defined as *"the most benign technological solution that achieves the desired purpose within the limits of the current social, cultural, environmental, and economic conditions of the setting in which it is to be applied, and that promotes self-sufficiency among its users in that setting."* As such, appropriate technology will generally be easy to adopt and require fewer resources to operate and maintain.
6. ***Providing a long-term approach.*** A clear and widely accepted vision is required to guide the process and secure sustained support from various stakeholders.
7. ***Setting medium-term goals.*** Stating a specific goal that people can adopt helps build and maintain momentum.

Additionally, the authors of [65] propose eight steps to be followed for the achievement of sustainable and environmentally respectful eHealth strategies (Figure 2.6.).

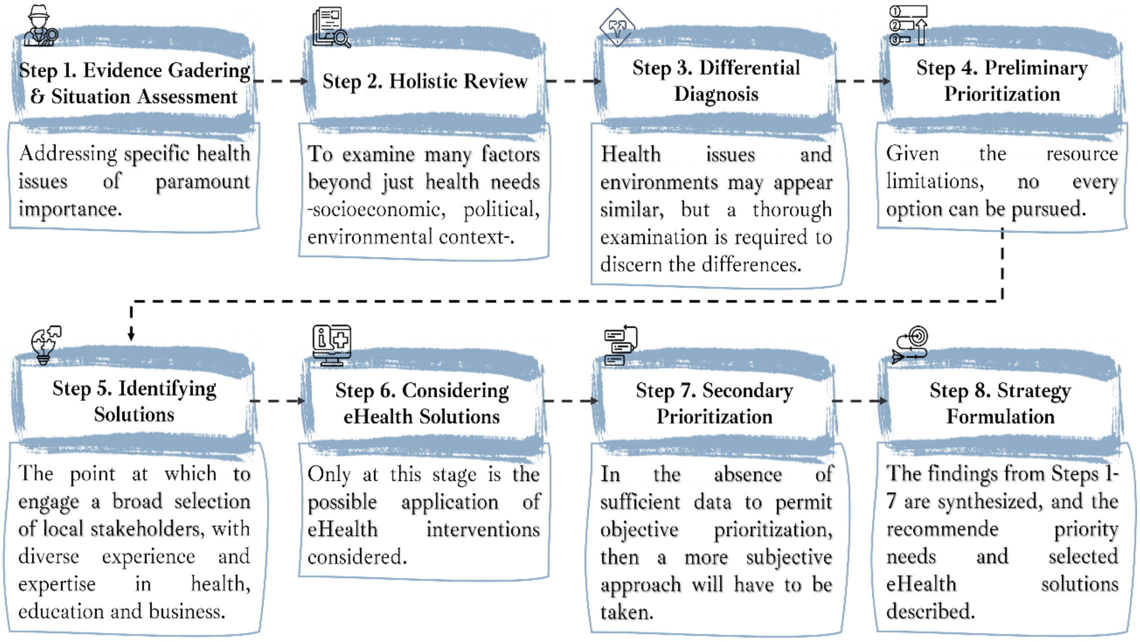


Figure 2.6. *Summary outline of the steps detailed by Scott et al. for the development of eHealth strategies (based on* [65]*).*

As a conclusion, Scott et al. state that *"to be effective, an eHealth strategy must be firmly grounded in an understanding of the boarder context within the environment, along with the challenges and opportunities that exist."*

2.3.2. Serious Games

"Children do not play to learn, but they learn also because they play" – Jean Piaget.

What are Serious Games?

The idea of using games for purposes beyond fun and entertainment was first introduced in 1970 by the researcher Clark C. Abt in his book *Serious Games* [66]. The author states that *"we refer to a serious game in the sense that these have an explicit and carefully crafted educational purpose and are not intended to be played primarily for entertainment."* If we conceive of games as *"a fundamental means for structuring language and though, acting systematically on psychosomatic balance; enabling deeply meaningful learning; reducing the sense of seriousness in the face of errors and failures; inviting active participation from the player and developing creativity, intellectual competence, emotional strength, and personal stability,"* it makes sense to design or redesign various games to provide specific learning, training, or communication of relevant information in areas such as education, healthcare, and corporate training (**Prem.6**) [67], [68]. Consequently, any game whose primary purpose goes beyond mere entertainment will be considered a Serous Game (SG), regardless of its platform or mode of execution [69].

That said, this section focuses on SGs in digital format.

SGs as Part of eHealth

As previously discussed, SGs are applicable to various fields that promote education, training, and skill development for users. They can be found in diverse areas such as military training or health education.

In the healthcare sector, the use of SGs has been widely researched, aiming to enhance patient engagement and motivation during diagnosis, treatment, and recovery processes, as well as that of professionals throughout their various stages of training [70].

SGs specifically designed with health or well-being objectives, which educate and promote healthy behaviours, can be considered one of the services encompassed by the term eHealth (Figure 2.7.). Being available applications for devices such as laptops, tablets, and even mobile phones, these games enable remote healthcare in processes such as the detection and treatment of health conditions, while also allowing users to monitor and manage their health on a daily basis. As such, they can be viewed as a blend between Telehealth and mHealth services.

Figure 2.7. *SGs as part of eHealth.*

Remote access and digital distribution of content enable users to access services offered by various companies through networks such as the Internet. Thanks to this, users can enjoy these services whenever and wherever they desire. In other words, SGs can be ubiquitous.

Moreover, through the sensors available in digital devices and the explicit programming of desired functionalities for each specific game, SGs facilitate the collection of patient-generated data, as well as the monitoring and immediate feedback to the player.

Additionally, as mentioned previously and as will be explored in more detail in the next section, SGs are present in a wide range of area within the healthcare environment [71]. This not only allows patients and healthcare providers to benefit from the advantages these resources provide but also fosters interdisciplinary collaboration. The development of these health-oriented solutions, which also involve significant engineering and data analysis components, requires the presence of a multidisciplinary team. This team should include service providers, healthcare experts in the relevant discipline, patients, and their families.

Lastly, the potential for continuous content updates, as well as possible adaptation to the individual user's profile, increases the motivation and adherence of the player -or patient- to whichever healthcare activity the game is promoting.

2.3.3. Applications, potential, and challenges in technology management

Once the most relevant concepts for contextualising the present thesis have been clarified, this section presents, through the discussion of use cases, the application of eHealth services -Telemedicine, mHealth, and SGs- in various healthcare areas, with particular emphasis on psychiatric disorders and, more specifically, on the diagnosis and treatment of childhood ADHD. Likewise, for each of the aforementioned services, promising outcomes are highlighted, as well as the limitations or challenges that need to be addressed.

Telemedicine

Application Cases and Potential

In the case of Telemedicine, J. Carnicero y A. Fernández identify a total of fourteen areas of application -both clinical and non-clinical- for this service, ranging from patient triage to medical education and the promotion of public health [54]. Various authors have also harnessed the potential of these technologies, applying them in areas such as Intensive Care Units (ICU), cancer treatment and recovery, and surgical care [68]-[70].

Regarding the use of Telemedicine in the context of childhood ADHD, Spencer et al. conducted a systematic review in 2020 of various studies in this field to clarify the use of this eHealth service [75]. After applying filters to exclude studies not relevant to their research, the authors identified a total of eleven articles of interest, all of which included paediatric samples. These articles can be categorised into three groups, according to the purpose of the telemedicine service application:

1. Articles related to *enhancing the quality of care.* The Children's ADHD Telemental Health Treatment Study (CATTS) is a comprehensive study conducted at Seattle Children's Hospital to determine whether treatment via interactive tele-video (ITV) is effective in addressing the mental health needs of children with ADHD [76]. After several partial studies, it was found that there was minimal patient dropout during the treatment (3%), significant symptomatic and functional improvements compared to children receiving standard treatment, reduce caregiver concerns for children with ADHD, and a high level of satisfaction regarding the use of Telemedicine [75]. The findings of these authors are relevant to this research, as they demonstrate the acceptance and adaptation of users involved in the study to new technologies.

2. Articles related to *patient consultations with physicians and the provision of direct services*. Between 2007 and 2008, Neufeld and Yellowlees sought to facilitate the connection between patients and healthcare providers in rural areas through the use of Telemedicine [77], [78]. In both cases, the authors observed significant improvements in the mental state of patients after a follow-up period of between three and six months by experts. Additionally, anecdotal reports suggest a high level of satisfaction and perceived benefit among rural providers [75]. Thus, the deployment of telemedicine services in rural settings may become a reality in the coming years. In relation to this research, this service is seen as a solution to the difficulty in accessing personalised therapies, regardless of location or the patient's profile.

3. Articles related to the *use of Telemedicine as a diagnostic tool to implement the evaluation guidelines of the American Academy of Paediatrics (AAP).* In 2008, Nelson et al. sought to evaluate the potential of Telemedicine to achieve adherence to AAP guidelines in the assessment of children with ADHD. The subjects and their parents participated in ninety-minute sessions via video conferences with the evaluation team, which consisted of a child psychologist and a developmental paediatrician, while being based at school. In this case, Telemedicine proved to be useful tool for connecting clinical professionals, patients, their families, and school staff [75].

Challenges in Technology Management

Despite the clear potential of Telemedicine in the healthcare sector, many interventions based on this service fail to be fully implemented in medical care. Generally, user-related barriers -such as attitude and technical literacy- are the primary limitations to the use of this service, followed by the characteristics inherent to the intervention itself (Figure 2.8.) [79].

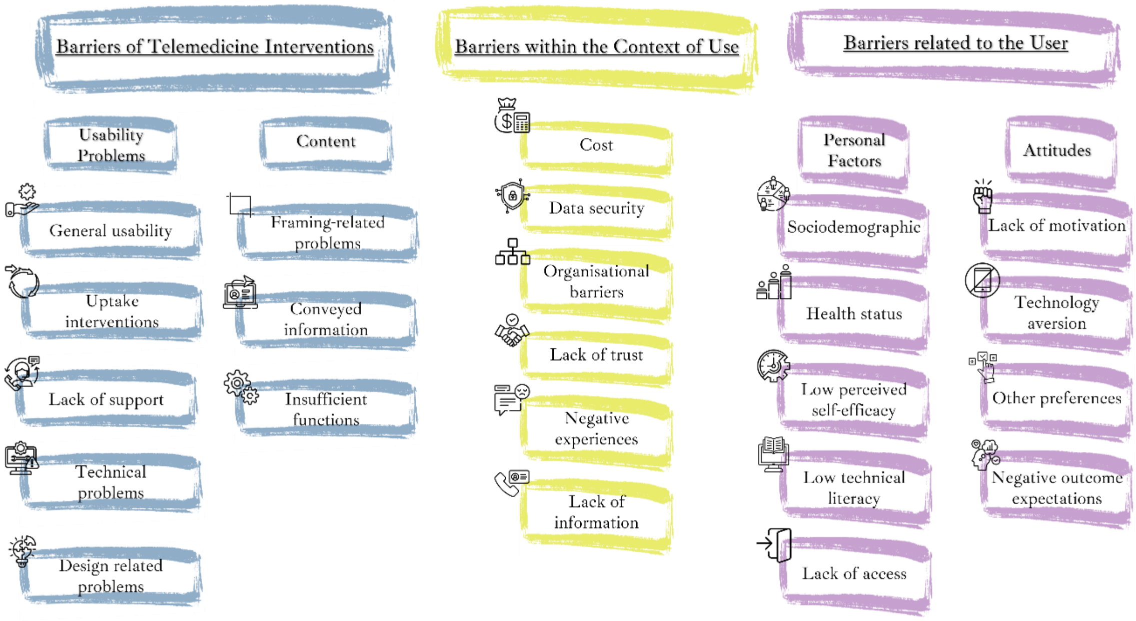


Figure 2.8. *Summary outline of barriers to the implementation of Telemedicine in healthcare (based on* [79] *).*

mHealth

Application Cases and Potential

Regarding mHealth, in 2018, Marcolino et al. conducted a systematic meta-review of more than twenty systematic reviews on the potential, various areas of application, and limitations of this eHealth service [80]. In this study, the authors highlight the growing use of these technologies in numerous healthcare areas, ranging from supporting the decision-making process to facilitating communication between patients and healthcare providers, as well as among professionals themselves. According to Labrique et al., the use of mHealth services can be categorised by their application domain into the following twelve groups [81]:

1. *Client Education and Behaviour Change Communication*. Primarily focused on the client, these strategies offer a novel channel for patients to access knowledge, improving their attitudes and influencing behavioural change [82], [83].
2. *Sensors and Point-of-care Diagnostics.* The use of mobile phones can facilitate remote patient monitoring, extending the reach of healthcare facilities into the community and patients' homes [80]-[82].
3. *Registries and Vital Events Tracking*. Mobile registration systems aim to identify and list patients eligible for specific healthcare services. These systems enhance program accountability by ensuring comprehensive and timely care, while addressing inequalities in health outcomes [87].
4. *Data Collection and Reporting.* Early mHealth projects enabled the transmission from paper-based systems to instant electronic submission of survey and patient data. These initiatives not only improve the efficiency of research and program evaluation but also reduce the reporting time at both local and national levels [88], [89].
5. *Electronic Health Records (EHRs).* The advent of mHealth has redefined the boundaries of EHRs, allowing healthcare workers to electronically record the services provided and send test result from the point of care via mHealth systems. In rural settings, professionals can access and contribute to longitudinal health records, ensuring continuity of care that was previously impossible in non-hospital environments [90].
6. *Electronic Decision Support: Information, Protocols, Algorithms, Checklist.* mHealth initiatives that integrate decision-support tools at the point of care with automated instructions based on algorithms or rules help ensure quality care. These tools guide frontline health workers to follow defined guidelines in task-shifting scenarios [91].

7. *Provider-to-Provider Communication: User Groups, Consultation*. Voice communication, one of the simplest mobile phone techniques, is a transformative application within the mHealth service package, enabling providers to communicate with each other or through hierarchies of technical expertise. Additionally, mobile devices like phones or tablets allow the exchange of images or even sounds for immediate remote consultations.
8. *Provider Work Planning and Scheduling*. Work planning and scheduling tools help keep healthcare workers informed with active reminders of upcoming or pending/overdue services. These tools also promote accountability by prioritising provider follow-up [92].
9. *Provider Training and Education*. Mobile devices are currently used to provide continuous training support to frontline and remote providers, offering access to educational videos, informational messages, and interactive exercises that reinforce skills gained during in-person training [93], [94].
10. *Human Resource Management*. Web-based dashboards enable supervisors to track the performance of community health workers at an individual or district/regional/national level [95].
11. *Supply Chain Management*. mHealth tools allow the tracking and management of essential product stocks and supplies. These relatively simple technologies enable remote clinics or pharmacies to report stock levels of medicines and supplies daily or request additional material electronically [96].
12. *Financial Transactions and Incentives*. The accelerated integration of mHelath and mFinance in financial transactions seeks to facilitate payments for healthcare, supplies, and medicines. It also simplifies the implementation and expansion of demand and supply-side incentive schemes [97], [98].

Challenges in Technology Management

The implementation of mHealth technologies involves a series of challenges that developers must consider. Form a technical standpoint, Gurupur et al. identify the most frequent barriers when deploying such services [99]:

1. Firstly, they refer to the concept of *Usability*, understood as *"the effectiveness, efficiency, and satisfaction with which an individual can achieve specified objectives in a particular environment."* In relation to this characteristic, the authors emphasise the importance of a simple user interface, which enhances user satisfaction and facilitates learning.

2. Secondly, reference is made to the term *Interoperability* and the complexity involved in integrating small information systems to create a more complex medical information systems.
3. Thirdly, the authors mention *Privacy and Security* of the data collected as key aspects in the development of such solutions, highlighting the need to ensure patient confidentiality, the secure or trusted storage of information, and access to that information through secure transmission channels.
4. Finally, the challenge of *Reliability* of the developed tools is highlighted, understood as *"a device or application functioning as intended when required."* Additionally, the authors underscore the importance of the quality of content within an application, noting that most available applications do not base their information on scientific evidence.

Serious Games

Application Cases and Potential

Similar to Telemedicine and mHealth, SGs are applicable in a wide variety of healthcare services [71], [100]. Examples of their use include games designed to manage pain in burn victims, educate patients with diabetes on insulin management, instruct asthmatic children about their condition and how to avoid triggers such as dust, smoke, and tobacco, or assist in the diagnosis of children suspected of having Central Auditory Processing Disorder (CAPD) [97]-[100].

Of particular interest for this work is exploring the potential of SGs in the field of psychiatric disorders, which directly affect individuals' mental health and range from anxiety disorders, addictions, schizophrenia, and phobias to neurodevelopmental disorders.

Regarding anxiety and depressive disorders, numerous studies aim to test the potential of SGs in preventing and improving symptoms of anxiety and depression in both children and adults [101]-[105]. In general, previous research suggest that, despite the need to increase sample sizes and extend patient follow-up periods to achieve scalable results, these games have the potential to serve as *"alternative models for delivering therapeutic techniques in mental health prevention"*.

Lado-Codesido et al. and Gülkesen et al. endeavour to improve the ability to recognise human emotions in individuals diagnosed with schizophrenia. They achieve this through the use of games that train the empathy of these patients by employing various tones of voice and changes in facial expressions [110], [111].

Precisely, in the case of ADHD, there is a wide variety of SGs aimed at addressing diagnostic processes and improving the skills affected by this disorder, primarily focusing on the treatment of children. These games produce various effects on patients due to the different technologies employed. In 2021, Zheng et al. conducted a review of serious video games available for ADHD, categorising them by the platform used for their implementation into console games, computer games, and mobile devices games [112] (Table 2.4.).

In general, children with ADHD exhibit deficits in executive functioning, making it challenging for them to complete tasks that require planning and organisation. The use of action and sport games, as well as engaging in physical exercise, can be employed to mitigate the effects and train this executive dysfunction. In 2010, Chuang et al. conducted an experiment to study the effect of playing Wii Play and Wii Sports on children diagnosed with this disorder. The results showed that the players experienced greater enjoyment and improved attention through the use of these types of solutions [113]. Similarly, in 2019, Bezing utilised and equipped the Microsoft Xbox One console to conduct an experiment aimed at determining the effect of exercise-based video games on patients with ADHD. This evaluation resulted in reduced inhibition in the players and an improvement in their response capacity and executive functioning [114].

In relation to computer games, Khaleghi et al. suggest applying a gamified approach to the DSM-IV diagnostic questionnaire for children with ADHD using a computer [115]. This method involves obtaining the diagnosis by assessing the player's clicks on irrelevant responses, the selected answers, and the time taken to complete the questionnaire. Analogously, Chen et al. designed a video game as a tool to support the ADHD diagnostic process in children, based on the DSM-V diagnostic criteria, by evaluating psychological information and data related to the player's movements [3]. Additionally, the authors of [116] propose a diagnostic support tool for this disorder based on the evaluation of EFs deficits. Through six mini-games, the authors assess planning, working memory, inhibition, and reaction time functions, concluding that the classification of players -based on whether they show sighs of ADHD or not- provided by their tool is satisfactory, and that computer-based SGs appear to be a valid tool for assessing specific strengths and weaknesses in children with ADHD. Furthermore, there is a wide range of computer-based serious games designed to train skills such as attention, inhibitory control, and various EFs [113]-[119]. These games aim to promote the inclusion of children with ADHD in society by improving their cognitive and social skills, thereby enhancing their quality of life.

Table 2.4. Characteristics of SGs by platform according to Zheng et al.

Platform	Key characteristics
Consoles	• Generally, refers to games that use the **television screen for display**. • Requires a gaming console: Switch, Nintendo, Xbox One, etc. • Can utilise **action-recognition technology** through optical devices and acceleration sensors. • **Capable of detecting the user's position and speed**, identifying their actions, and enabling interactive activities. • **Multiplayer mode**, promoting communication and reducing social isolation. • Consoles with somatosensory functionality allow individuals to exercise while playing.
Computer	• Includes **client-based and web-based games**. • Allows **connection to multiple devices** to achieve different effects. • Requires the use of a **mouse and keyboard to interact** with the game -control method-. • While this traditional control method may meet the needs of a general audience, **it does not provide a natural interactive experience** for users. • **Can be combined with Virtual Reality (VR) technology**, giving users the opportunity to shift from traditional operation methods and enhancing the game's authenticity and interactivity.
Mobile devices	• Utilise **touch-based interactive technology** for input. • Mobile games are **easier to operate and cater to a wider range of users**. • Facilitate the operation of certain electronic games and enhance user experience. • **Portability allows for gaming anytime and anywhere** with just a mobile device. • Animation effects are not as strong compared to computer or console games. • Tablet games offer a wider visual experience than mobile devices, with higher resolution and better image quality. Additionally, they allow for more player participation and are more user-friendly for eye health.

Lastly, there is a smaller variety of research focusing on mobile platforms to support the diagnosis or treatment of ADHD. This contrast with the statement made by Dewhirst and colleagues, who claim that *"it is important to design more games or adapt existing ones for use on tables or smartphones, as they are more frequently used, and their usage may increase over time"* [124]. Contributing to these types of solutions, Nayra et al. proposed a mobile phone application in 2020 that combines pre-diagnosis and treatment functions, based on a questionnaire. The app allows individuals involved with ADHD to communicate through it and ensures the security of the information exchanged. The data is then evaluated by a Naive Bayes classifier and set to the healthcare professional, who completes the child's diagnosis. In the application of SGs for the treatment of ADHD, Redondo et al. propose using mobile devices to study the effect of two video games, *Boogies Academy* and *Cuibrain*, on participants' visual attention [125]. Based on multiple intelligences, these two electronic games are suitable for mobile phones and tablets, respectively, and can be used to activate the individual's linguistic and interpersonal intelligence. Continuing with the improvement of skills in individuals with ADHD, Natalia et al. developed a game aimed at enhancing reading comprehension, which is related to working memory in EFs [126]. Developed for the iPad, this video game uses touch-sensitive interactive devices to develop working memory, improving daily performance. Furthermore, Elhan et al. introduced *EmoGalaxy*, a video game focused on emotional management to enhance social skills [127]. This game is primarily used to train the recognition, expression, and regulation of emotions.

The promising results obtained from each of the aforementioned serious games, combined with the conclusions reached by Lau et al. in their systematic review of ten SGs for mental health and meta-analysis of over six hundred and fifty patients [128], allow us to conclude that these games are technological solutions with great potential to assist in the prevention, treatment, and management of various psychiatric disorders (**Prem.7**). Yet, Lau and colleagues highlight that *"more randomised controlled trials (RCT) are needed to determine the effectiveness of such solutions."*

Technological Management Challenges

As with Telemedicine and mHealth services, SGs face various challenges during their development, implementation, and application in the healthcare field. Broadly speaking, these challenges are similar to those encountered in the process of creating solutions for the aforementioned eHealth services. However, due to their unique nature, SGs possess distinctive characteristics that guide their creation and, consequently, pose new questions for developers.

In their work *"How to Systematically Assess Serious Games Applied to Health Care,"* Graafland et al. provide a validation framework consisting of sixty-two elements, categorised into five main classes, aimed at assessing the rationale, functionality, validity, and data safety of a serious game in the healthcare sector [129] (Figure 2.9.).

Figure 2.9. *Issues for the validation of a serious game applied in the healthcare sector (based on [129]).*

In the first categorisation of these evaluation elements, *Game Description*, represented in green in the previous figure, the authors emphasize the need for developers to thoroughly describe and document the game in question. Additionally, attention must be given to the privacy policy concerning revenue generated from sponsorships and advertisements. Dewhirst et al. highlight *"the need for investment in research to measure the effectiveness of SGs by an industry that is not biased by its own interest"* [124]. This statement points to the potential existence of serious games in the market that lack scientific validation and effectiveness in their purpose.

Secondly, the *Rationale* category (orange group in Figure 2.9.) seeks to clarify the purpose of the game beyond the game itself. That is, the external purpose -such as assisting in the diagnosis process for children with ADHD- may differ from the actual goal of the game, which could involve connecting different nodes or organising game elements. This characteristic is unique to SGs, distinguishing them from mHealth solutions, which typically have a singular and obvious purpose. Naturally, the game's purposes -both external and real- must align with the intended user group and environment in which the game is expected to be utilised. Another noteworthy feature related to the game's rationale is the potential for integration into e-learning environments, which requires the technical requirements and established standards to enhance the interoperability of e-learning content [130].

The *Functionality* of a serious game (in purple), according to Graafland et al., *"clearly differs from that of a mHealth application."* During the use of a serious game, the user must interact with its content, with the ultimate goal of changing their behaviour in real life. In other words, learning. Therefore, it is important to document information regarding the management of the game's content. Finally, there may be cases where undesired outcomes or negative learning transfer occur. The authors state that *"if validation research is absent, there should at least be a logical connection between the gameplay and the behavioural or learning objectives, which must be disclosed by the developer"*.

Fourthly, Graafland and his research colleagues define the *Validity* of an educational tool as *"whether it resembles the construct it aims to educate or measure"* (in blue). Generally, validity research in medical education typically involves several phases:

1. A detailed examination of the game's content by healthcare experts to determine its legitimacy. ***Content validity.***
2. Assessment for the similarity between the developed instrument and the construct it aims to represent. ***Face validity.***
3. Evaluation of the instrument's ability to genuinely measure what it is intended to measure. ***Construct validity***.
4. Study of the correlation between the game's performance and the performance of an instrument believed to measure the same construct. ***Concurrent validity.***
5. Exploration of the game's performance: does the game's performance lead to better outcomes than real-life scenarios? ***Predictive validity.***

Validity research is often an extensive and costly process, which is why many newly developed serious games have yet to undergo such investigation.

Finally, the *Data protection* category (grey group in Figure 2.9.) addresses all issues related to the threats to user privacy. On this point, the authors are clear regarding data ownership: *"if the game collects data, it must be clear who owns the data and whether users can request its deletion."* The disclosure of personal data storage and analysis to users is essential and must comply with the laws in the countries where the game is distributed. Additionally, special attention must be given to the process of collecting patient information.

In the context of these categories, developers of such solutions face challenges ranging from the linguistic and cultural diversity of the target population to the availability of the games for that audience, while overcoming obstacles such as geographical location and economic resources. At the same time, they must ensure active and sustained high-quality engagement from users. To overcome the inherent difficulties in the development, implementation, and application of a serious game in the healthcare sector, the involvement of developers, healthcare professionals, and other stakeholders will be essential.

2.3.4. Development frameworks for SGs in Healthcare

The exploration of frameworks that guide the development of SGs in the healthcare sector yields approximately twenty-three thousand results in research-oriented repositories, such as Google Scholar. In general, all these frameworks are focused on specific domains within the healthcare field [131]. It was not until 2019 that the first regulatory resource was proposed to guide the development of SGs for health [132].

Framework Based on Research Community Insights

Recognising that SGs developers *"could benefit from the creation of a defined set of requirements representing the consensus views of stakeholders in health-related SGs,"* Verschueren et al. presented a consensus framework aimed at guiding developers in the creation of serious games for health [132]. By examining parameters such as the methodological approach, quality evaluation, project management approach, and others identified through the review of a total of sixty-seven articles, the authors propose a development framework grounded in theory and supported by evidence (Figure 2.10.).

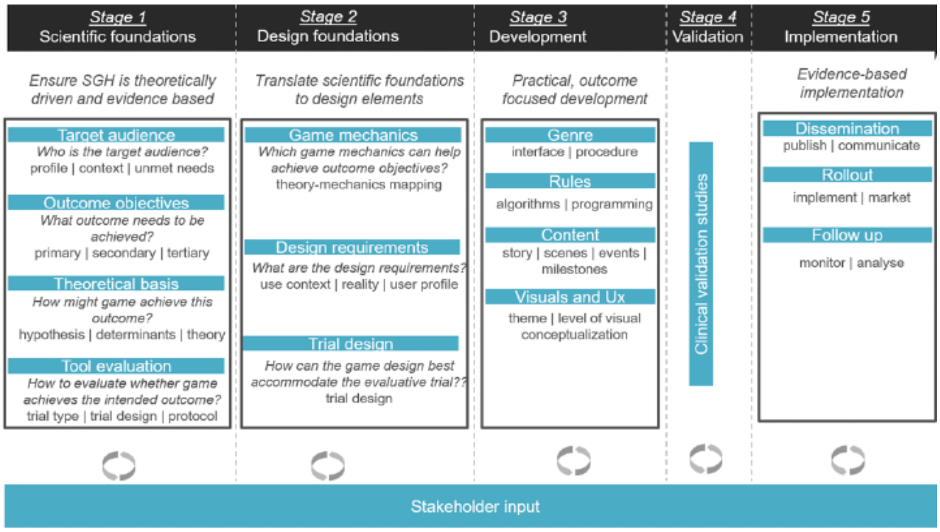


Figure 2.10. *Development proposal for SGs in the healthcare sector.*

(Taken from Verschueren et al. [132])

Each of the five phases of the framework are characterised by having a specific focus, based on the contributions of various stakeholders. Additionally, as can be seen at the bottom of Figure 2.10., within a single phase, multiple interactions of development may take place, with the aim of progressively refining the game.

- *Phase I: Scientific Foundations.* Solid scientific foundations for SGs are established through a conceptual and theoretical assessment in the early stages of development. This ensures that the final product is relevant, theoretically drive, and evidence based. The primary objective of this stage is to assess, conceptually and theoretically, whether there is a relevant medical need for a specific audience that could be addressed through such solutions. At this point, the target audience must be determined, creating a preliminary profile of the intended end-users. This profile can be expanded in later stages to include specific information regarding game design and the needs of the target audience. Moreover, clear outcome objectives are formulated, which must be medically relevant and based on objective criteria. In order to achieve this, a hypothesis must be developed on how the game could achieve the intended outcome objectives by identifying the determinants of the outcome. Finally, before beginning the development of the game, a plan is made for how to evaluate whether the game meets the intended objectives, including guidelines such as randomised clinical trials, self-reports, monitoring of side effects, and consultation with experts.

- *Phase II: Design Foundations.* Game developers can draw on various game mechanics, design elements, and technological features to build serious games for health. Nevertheless, to achieve the intended outcomes, the choice of these mechanics and features must be grounded in the scientific foundations established in Phase I. This stage aims to answer three key questions:
    - *What are the most suitable game mechanics to achieve the outcome objectives?* Game mechanics refer to the set of rules or methods that define the interactions and flow of a gaming session. The selection of these mechanics should be guided by the scientific foundations established in the previous stage, mapping outcome objectives, models, and theories identified in that stage to relevant game mechanics.
    - *What are the design requirements?* At this point, the profile of the target audience is expanded to guide design choices, gathering information about the context of use, audience realities, and user experience.
    - *How can the game design be best adapted for evaluation trials based on assessment?* Design considerations are explored in relation to the future evaluation of the game. If data collection is necessary, this is integrated into the design, Additionally, considerations for data collection outside the game format, researcher interventions during gameplay, and aspects relevant to clinical settings are assessed.
- *Phase III: Game Development.* Once Phase II is completed, developers have scientifically grounded information to guide the practical development of the game. This phase addresses key aspects such as:
    - *Game genre*. The most appropriate genre of interface and procedure is selected according to the target audience and the context in which the tool will be used, aligning it with the mechanisms and design requirements identified in earlier stages.
    - *Game authoring tools*. At this point, available tools are assessed, considering key aspects such as the technical capabilities of the team and the potential need for future modifications.
    - *Game rules*. The rules that specify how players' action affect the game environment are established. Depending on the game's purpose, the rules may be consistent and transparent or hidden and unpredictable.
    - *Game content*. Content must be developed that aligns with the intended objectives. Depending on the approach, more or less elaborate narratives may be desirable.

  - *Visuals and user interface.* A theme should be chosen based on the target audience. Additionally, developers should assess the necessary level of visual conceptualisation, considering the use of archetypal symbols or icons to convey complex concepts.
- *Phase IV: Game Evaluation.* Once the game has been developed, informally tested, and refined through user testing, it should be ready for clinical evaluation. After determining the trial sites, identifying the researchers who will conduct the experiment, and recruiting users for the study, the evaluation, analysis, and assessment of whether the tool successfully achieves the intended outcomes can begin. Ideally, this stage involves experts in relevant research, who can guide and oversee the evaluation studies and support the analysis of the data collected.
- *Phase V: Implementation.* Based on the results obtained in the previous stage, developers may choose to refine and re-evaluate updated versions of the tool or proceed directly with the game's implementation. Regardless of the outcomes of the evaluation studies, developers should strive to disseminate the study findings to the SGs research community, thereby contributing to the ongoing advancement of this field. Indeed, the communication and publication of null results can provide valuable insights into how to optimise SGs interventions in healthcare, offering guidance on best practices and mistakes to avoid. If a game is successfully validated and implemented or commercialised for the intended audience, efforts should be made -where relevant- to collect user data in the field to monitor adverse events.

Regarding the stakeholders involved in the game's development, Verschueren et al. suggest a more in-depth investigation when identifying which profiles should participate in the design process. This aims to provide developers with a deeper understanding of how to engage these stakeholders in the process and at which stage or stages of development each should be involved. To simplify this task, the authors of [132] recommend that developers consider at least the following four profiles:

1. *Subject matter experts.* Positioned in Phase I of development, experts can provide insights and guidance on the key questions that need to be addressed when establishing the scientific foundations.
2. *Target audience.* When determining the level of user involvement, it is essential to balance the need for their input with the availability of resources, such as time and funding. The inclusion of end-users should be limited to key points in Phases II, III, and IV, where their contributions are most likely to offer valuable and accurate insights.
   - In Phase II, it is suggested to involve end-users to expand the research on user profiles and identify specific design requirements crucial for the tool's effectiveness. This engagement aims to gather details about who the end-users are, identify subgroups,

understand their socioeconomic backgrounds and daily realities, as well as other aspects relevant to the game's design.

- In Phase III, active involvement of the target audience is recommended for evaluation early prototypes of the game, allowing for feedback on aspects such as user experience, content relevance, realism, and graphic design features. However, not all user feedback should be incorporated; subject matter experts should evaluate and prioritise which feedback to implement.
- Lastly, in Phase IV, end-users should be recruited for a quality trial to validate the game. It is important to note that uses involved in the final validation of the game should not have participated in earlier stages of development.

3. *Clinical research expert.* Research experts should be involved to advise on the scientific approach and trial design at an early stage of development, and ideally throughout the trial.
4. *Business experts.* To ensure market readiness and effective implementation and launch of the serious game, consultation with a business expert is essential.

In addition to these four stakeholders, it may be relevant to consult with other profiles, such as regulators, healthcare professionals, patient organisations, and others.

Working with multiple stakeholders involves a specific set of challenges, which can be overcome by (1) educating them about the development process and the tools and methods used, (2) establishing an advisory board that meets regularly to discuss the project, and (3) appointing a project manager who acts as the point of contact and can make final decisions in the event of conflict, in line with the project's objectives and within the stipulated resource constraints.

Framework on Adaptative and Personalised SGs

"Given the lack of methodologies, frameworks, and models for the creation of serious games" -not necessarily applicable in the healthcare sector- the authors propose a framework for the development of SGs based on an adaptative scheme (Figure 2.11.) [133].

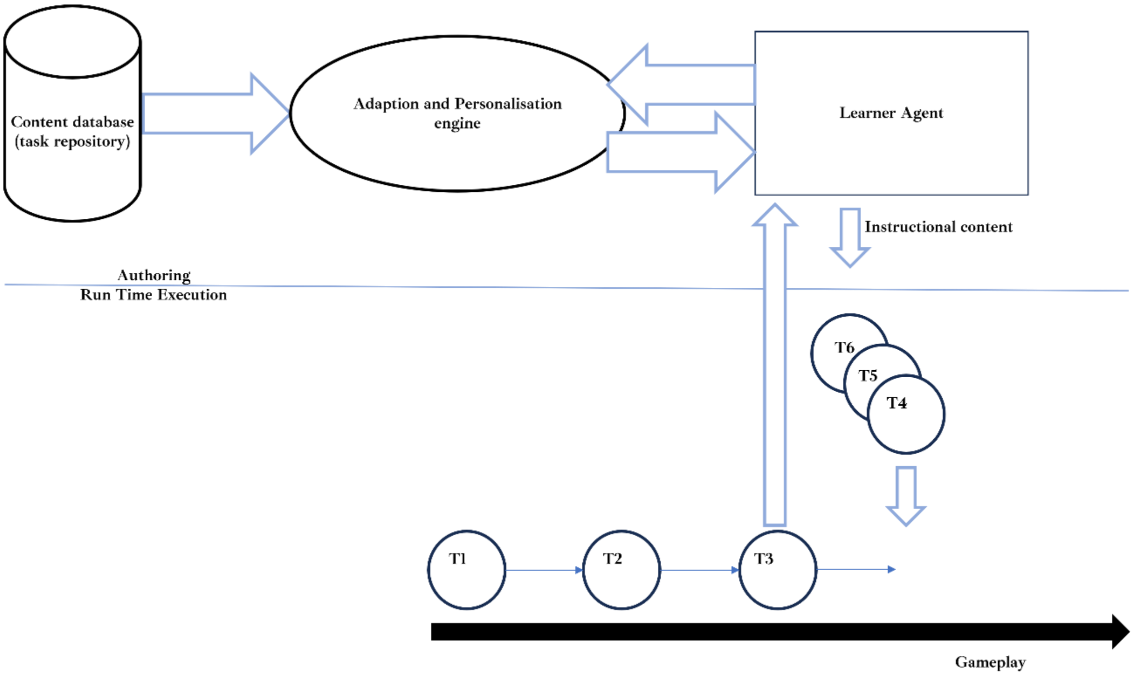


Figure 2.11. *Proposed framework for the development of personalised SG.*

(Taken from Spyridon and Ionnis [133])

The authors' aim is to *"dynamically assign tasks in a specific order based on the feedback from players' responses and the behaviour of learners."* Building on their previous work, where they had created a framework based on constructivist learning theory an employed a multi-agent system, the authors seek to further refine this framework, grounding the adaptation in the sequence of tasks that the adaptation and personalisation engine will dynamically create.

This approach provides the following features:

- It can easily differentiate between various game sessions.
- It greatly motivates players.
- It is independent of the application domain.
- It can be enriched with new tasks without needing to modify the existing code.

As previous research has indicated, prior knowledge affects the learning process, having a significant impact on educational outcomes. Therefore, in the initial phase of the game, the learner will be presented with a series of tasks designed to assess their prior knowledge. Subsequently, the adaptation engine will prioritise the following tasks based on the responses provided in the initial phase. Another challenge that must be addressed is co-adaptation. That is, with prolonged use of any game, the players' abilities and needs are not only complex and multivariate, but they also change over time in a non-linear manner. This dynamic can lead to situations where the system adjusts settings in a specific way, and the user adapts to manage these settings, even if they are not objectively optimal. In the most critical cases, this dynamic may result in interactions that tare detrimental to the player.

Framework for Reusable Design of Personalized SGs for Health

In their work *"A Software Engineering Framework for Reuse Design of Personalized Serious Games for Health: Development Study,"* Carlier et al. address two main issues [131]:

1. The **decline in long-term usage frequency**. Over time, the game may become predictable, and consequently, users may find less motivation, potentially abandoning the treatment provided by the serious game.
2. The **lack of reuse of knowledge gained from the previous development of other games.** *"Currently, the development of personalised SGs involves a complex and costly process, which requires the participation of various stakeholders,"* the authors state. Moreover, this process is generally repeated entirely for each serious game being developed, meaning that each stakeholder must share their expertise throughout the design process of each new game, regardless of the game's theme. In essence, the knowledge is neither formalised nor transferred to future solutions.

Thus, the proposed framework, form a software engineering perspective, seeks to optimise the design process of serous games by focusing on personalisation and reuse (Figure 2.12.). This framework can be applied to both existing SGs and the design of future tools. Additionally, by acting as a bridge between the conceptualisation and implementation of the solution, this framework plays a crucial role in reducing the gap between the design and effective execution of the game.

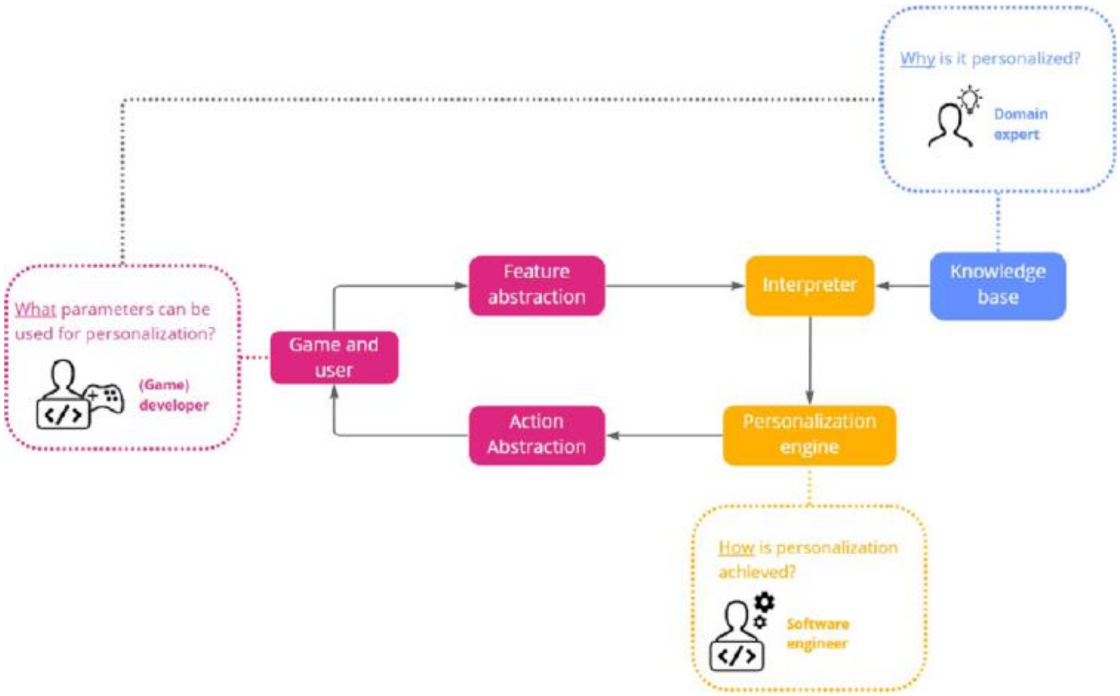


Figure 2.12. *Proposed framework for the development of personalised SGs and the reuse of acquired knowledge.*

(Taken from Carlier et al. [131])

The general framework consists of a total of three modules:

- *Knowledge base.* This is the fundamental core of the framework, aiming to address the question: *What is the need for personalisation?* This component is responsible for modelling the knowledge of domain experts, providing insights into the seriousness of the game. Such knowledge can be modelled or computerised through various approaches (databases, functions, or ontologies). The purpose of this module is to facilitate knowledge transfer, making it reusable or replaceable depending on the specific domain in which the game is applied.
- *Game-specific modules.* The three game-specific modules -*Game and User, Feature Abstraction, and Action Abstraction*- operate as a single abstraction layer between the game and the system. In collaboration with the domain expert, the developer identifies the necessary parameters for personalisation, addressing the question of which elements need to be personalised. At this point, two sets of parameters are highlighted:
    - *Features*. Characteristics, such as scores or physiological data, trigger personalisation, introducing a feedback loop to adapt to the user's needs.
    - *Actions*. These are parameters that can be personalised based on context, such as difficulty level.

- At runtime, features are sent to the *Feature Abstraction* module, where they are converted into a generic format that can be interpreted by game-independent modules.
- *Independent personaliser.* Thow critical modules in this framework are the *Interpreter* and the *Personalisation* modules, which are independent of the game and its application domain. Both modules focus on addressing the fundamental question of how to achieve personalisation without needing to interact directly with the game.
    - *Interpreter module.* This module communicates with the knowledge base and the game-specific modules to obtain relevant information and understand the input data. Based on this, it interprets and translates the information into a format understandable by the *Personalisation Engine*. This value encapsulates the necessary information for the *Personalisation Engine* to determine the need and degree of personalisation without relying on contextual information.
    - *Personalisation engine.* Equipped with one or more personalisation models, it executes the resulting action and sends it to the *Action Abstraction* module, which understands the game tasks associated with that action. In turn, this module issues a specific task order to the game, which can be adjusted accordingly, thus closing the personalisation loop.

As proof of effectiveness, Carlier et al. applied their development framework to transform an existing game into a serious game. The simulations conducted with this serious game demonstrated the interaction between the different components and how the framework was used to simplify the design process.

As can be observed, the frameworks guiding the development of SGs for the healthcare field generally focus on creating games that promote continued patient engagement through personalisation techniques. This aspect can be particularly relevant when developing games aimed at skill improvement, fostering behavioural changes, or games used in treatment processes for various disorders or diseases. Nevertheless, despite the potential for reusing certain features, no development frameworks have been found that focus on the application of SGs in diagnostic processes for psychiatric disorders, such as ADHD.

A defining characteristic of ADHD patients, among others, is their lack of attention. Therefore, using such solutions to enhance motivation -and thereby increase attention- during the diagnostic process could be counterproductive. If we were to assess the attention span of an excited child, would we be accurately evaluating their attention deficit? Under the application of the aforementioned frameworks, in the case of ADHD diagnosis, erroneous conclusions might be drawn from measuring skill performance (such as attention) that is not in tis baseline state.

Summary of the section *ICTs in the healthcare sector*

In recent years, ICTs have undergone a substantial transformation in the healthcare sector, significantly contributing to the optimisation of service delivery and the qualitative improvement of medical care.

Key components in the application of ICTs in healthcare include prominent services such as Telemedicine and mHealth. These services enable access to various practices, including remote healthcare, virtual consultations, education for both patients and professionals, monitoring of healthcare staff, and initiatives related to health promotion and disease prevention, among others.

Of particular interest in this context are services implemented through Serious Games (SGs). Designed or adapted with the primary aim for providing training, health, or social benefits, SGs address a range of areas within the eHealth landscape. Examples of their application include disease education, rehabilitation, and the promotion of healthy lifestyles. Specifically, when used for the diagnosis and/or treatment of psychiatric disorders, such as ADHD, SGs have shown great potential in enhancing patient motivation and engagement. In some cases, they offer ubiquitous use, meaning they can be accessed and applied in a variety of settings and situations. Yet, further trials are necessary to determine their overall effectiveness.

The development, implementation, and application of these services -Telemedicine, mHealth, and SGs- present various challenges for developers. Issues related to data security and privacy are pressing concerns that require robust standards. Additionally, the acceptance of these technologies by healthcare professionals and patients, along with adequate training, is essential. In the case of SGs, the development of effective content and its integration into the healthcare system necessitates the creation of experiences that are not only engaging and enjoyable but also educational and goal-oriented. Addressing the challenges posed by the implementation of these services requires a comprehensive and collaborative approach.

Given the lack of a defined set of requirements representing the consensus views of stakeholders, various authors have developed frameworks for the creation of serious games for application in the healthcare sector. In general, the key points in the development of these frameworks are the reuse of knowledge gained from previous developments, the personalisation of the games, and the promotion of long-term player adherence.

Still, these authors have not considered characteristics derived not only from each particular disorder or disease, but also from the specific context in which the game is to be developed. **In the case of ADHD diagnosis, fostering cognitive skills such as attention -through motivational elements included in the game- could lead to the underdiagnosis of these patients. To date, no framework has been found that guides the development of serious games, considering the specific characteristics of the ADHD diagnostic process.**

2.4. Process Mining for health

"Innovations improve healthcare, making it more effective, accessible, and efficient" [4].

Currently, healthcare systems globally face challenges that include the constant and rapid adaptation of clinical processes in line with emerging scientific evidence, as well as the provision of high-quality care with limited resources [134], [135]. In this context, healthcare organisations are increasingly aware of the need to manage and enhance both their clinical and organisational processes. To this end, healthcare organisations typically utilise Health Information Systems (HIS). The data entered into the database of such systems can be used to create an event log, which describes the sequence of activities performed, when they were cored out, by whom, and for what purpose [135]. Figure 2.13. provides an illustrative example of a -possible- set of activities carried out in a hospital setting and shows the associated event log.

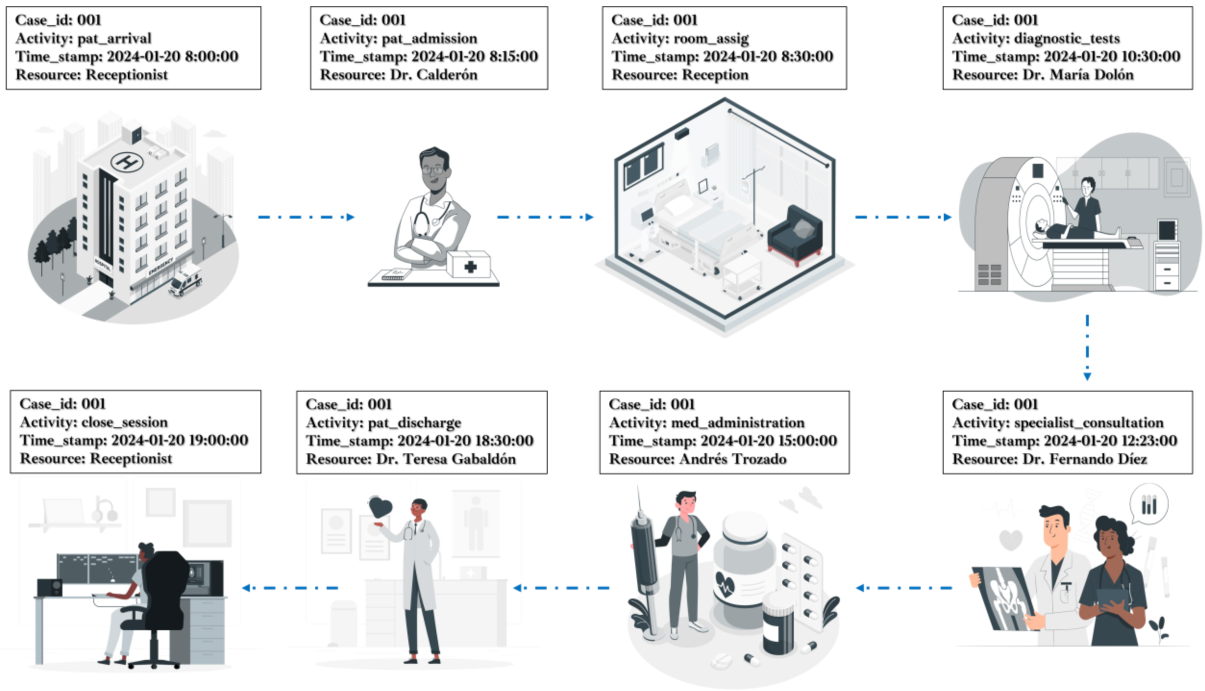


Figure 2.13. *Example of entries in a HIS and their associated event log.*

"Since the event log reflects how a process was executed in reality, it can provide support to clinicians, healthcare organisations managers, and other decision-makers when faced with a wide variety of questions related to processes in the medical field" [4]. Focused on obtaining valuable insights from the data generated during process execution, the use of Process Mining (PM) techniques can be highly useful in addressing these questions (**Prem.8**).

This section provides a brief introduction to the set of techniques that make up PM, as well as the challenges associated with their application in the healthcare sector. The development of this section is largely based on the study conducted by Muno-Gama et al. in 2022, which focuses on the use of PM techniques in the healthcare field (PM4H), highlighting the specific characteristics of this area and the challenges these techniques pose in their implementation [4].

2.4.1. Basic knowledge

PM is a set of techniques that combine data analysis, artificial intelligence, and data mining methods to discover, monitor, and improve processes based on the data generated during their execution. These techniques have been applied in a wide variety of areas, including healthcare, where their use is primarily focused on the analysis of diagnostic, treatment, and organisational processes [4]. Figure 2.14. illustrates the position of PM within the broader context of healthcare.

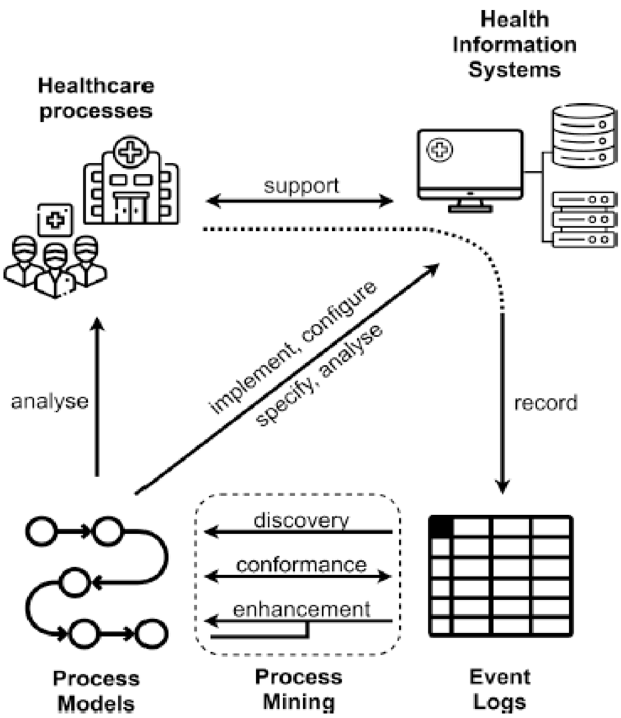


Figure 2.14. *Position of PM within Healthcare.*

(Taken from [4], based on [136])

In the healthcare setting, HIS, or more specifically, Electronic Health Records (EHR), record data on the execution of processes within a healthcare organisation. These execution data can be utilised to create event logs, which serve as the primary input for process mining algorithms.

An event log is composed of cases that represent different instances of processes. Each case, in turn, consist of a sequence of events that outline the steps or tasks carried out in each of the instances recorded in the log. Generally, event logs should capture the following information for each case:

1. *Case id*: a unique identifier for each of the cases recorded in the event log. In the example from Figure 2.13., the *case id* uniquely identifies the patient, with the ID 001, who is undergoing that specific set of steps, in that order and at those specific times.
2. *Activity*: the activities in the event log capture each of the steps taken in an instance of a process. In Figure 2.13., the recorded activities reflect the different phases the patient with *case id* 001 has gone through, from their admission to their discharge from the hospital.
3. *Timestamp*: this data reflects the date and time when the event recorded in the *Activity* field was performed by the instance with the given *case id*.

Additionally, indications regarding the type of transaction carried out (*Transaction type*) and information related to any resource involved in the event (*Resource*) may also be included. Given the heterogeneity of medical information resources, the provision of healthcare by distributed providers, and the recognition that some processes are not directly supported by HIS -non-connected processes- the creation of event logs in healthcare environments faces significant challenges.

By utilising these event logs, various PM techniques can be applied depending on the type of knowledge one wishes to gain from their application:

- *Discovery*. These PM algorithms are useful for obtaining process models that reflect the behaviour of a process based on an event log [136]. The majority of these algorithms focus on discovering the order of activities within a process form the input data. Moreover, they can be used to gain insights into how resources operate throughout the process -such as role discovery [137], [138], social networks [139], [140], and tasks prioritisation patterns [141]-.
- *Conformance checking*. These algorithms require a process model, either obtained through the discovery algorithms or pre-designed by researchers. The primary aim of this subset of PM techniques is to compare the behaviour recorded in the event log with the theoretical or expected behaviour. Thus, these algorithms enable the evaluation of whether the process is being executed as described in the process model and help detect deviations between the observed behaviour in the event log and the process model [142].
- *Enhancement*. The final subset of algorithms aims to enrich and extend an existing model using process data [136]. One possible improvement is model repair, which allows for the modification

of a process model based on events [143]. Another type is model extension, where information is added to enhance a process model with details such as time and roles [144].

2.4.2. Implementation challenges

In their work, Munoz-Gama et al. highlight the challenges posed by the implementation of these techniques in the clinical care sector, given its unique characteristics. *"At the research level,"* the authors state, *"the outlined challenges will require both fundamental and translational research, the latter being necessary to support the real adoption of fundamental research into practice"* [4].

C1: Desing Dedicated/Tailored Methodologies and Frameworks.

Given the characteristics D1-D9[3], the authors argue that the healthcare sector requires the development of new methodologies and frameworks specific to PM4H. These should guide researchers and professionals through the various phases of analysis. Furthermore, the importance of these methodologies and frameworks being flexible is emphasised, allowing for adaptation to local, national, and departmental particularities, among others.

Existing general PM methodologies have been key factors in the growing popularity of these techniques [139], [145], [146]. Relatedly, healthcare-specific methodologies for PM4H could enable stakeholders in the healthcare sector to incorporate PM4H into their analyses.

C2: Discover Beyond Discovery.

As mentioned in the *Basic Knowledge* section, PM techniques are generally classified into three types: *Discovery*, *Conformance checking* y *Enhancement*. In the early days of PM, *Discovery* techniques were the most developed, making them the predominant research focus. Subsequently, *Conformance checking* gained gradual prominence, and more recently, there has been a significant increase in the availability of *Enhancement* techniques.

Similarly, PM4H has followed a similar evolution, with the use of *Discovery* algorithms being the most predominant case in the literature. Despite the relevance of these studies, the authors highlight the need to develop new *Conformance Checking* and *Enhancement* techniques specifically adapted to the healthcare sector.

[3]Refer to Annex C for more information on the specific characteristics of clinical care highlighted by Munoz-Gama et al.

C3: Mind the Concept Drift.

Clinical practice guidelines and protocols often change over time. Even without formal changes, the execution of healthcare processes can vary due to the need to address unforeseen situations. Detecting and understanding these dynamic changes in medical procedures can be challenging. The authors suggest that the use of specific techniques can be beneficial in identifying changes in these processes and determining how such changes impact the delivery of medical services. Though, distinctive characteristics, such as the high variability of processes[3], complicate the identification and study of change patterns.

C4: Deal with Reality.

As with any general PM technique, synthetic data can be used in a controlled environment. Nonetheless, PM4H research aims to generate studies with social impact and must therefore focus on novel approaches capable of handling real-world data. Additionally, these techniques must be able to manage large amounts of data and adapt to input data that contains significant variability[3].

C5: Do It Yourself.

Characteristic D6[3] highlights the multidisciplinary nature of PM4H. To support the widespread use of PM4H, healthcare professionals should be able to conduct their analyses with little or no assistance from PM experts.

This direct or indirect involvement of healthcare actors has several implications:

- During the development of the technique, healthcare professionals should be considered the end-users. As such, these techniques should not require extensive expertise in PM to be used effectively.
- The output of these techniques must be easily understandable to healthcare professionals. Simple visualisation, such as Directly-Follows Graphs (DFG) [147] and process modelling diagrams, can be effective in achieving this.
- All tools or software developed through research must be user-friendly, with specific attention given to appropriate terminology, human-computer interaction, and visualisation methods.

[3]Refer to Annex C for more information on the specific characteristics of clinical care highlighted by Munoz-Gama et al.

C6: Pay Attention to Data Quality.

"The quality of all analyses ultimately depends on the quality of the data used as input" [4].

As mentioned in D9[3], real-world data from HISs tend to have quality issues, which can hinder their use for process mining purposes. The widespread presence of data quality issues highlights the need to develop techniques for systematically assessing and improving the quality of healthcare event logs. Additionally, while existing approaches often focus on data quality within the context of an existing event log, it must be recognised that data quality problems are also related to the management and extraction of these data.

Currently, raising awareness about the impact of data quality issues among stakeholders in the healthcare sector remains a challenge. Key actors, such as hospital managers and physicians, should consider the effect of data quality problems on potential PM analyses. Furthermore, the results of such analyses should include a reflection on the quality of the underlying data [148].

C7: Take Care of Privacy and Security.

PM4H primarily relies on sensitive patient data. Safeguarding the privacy and security of this data is of utmost importance, encompassing responsible data science aspects such as fairness and confidentiality [149]. In fact, in the broader process mining community, the significance of data privacy and security has been acknowledged in the Process Mining Manifesto[150]. However, even today, striking a balance between protecting privacy and preserving the value of the event log for PM purposes remains challenging [151].

Just as anonymisation and other privacy-preserving techniques can help organisations create suitable event logs for data sharing, PM4H could also leverage alternative operational modes to enable collaboration between researchers and healthcare organisations. Establishing efficient methods for configuring such collaborations can drive PM4H forward by reducing the risk of data breaches.

[3]Refer to Annex C for more information on the specific characteristics of clinical care highlighted by Munoz-Gama et al.

C8: Look at the Process through the Patient's Eyes.

In the context of a PM project, information needs can vary depending on the stakeholders involved. One of the defining characteristics of the healthcare sector is its multidisciplinary nature[3] with the most common stakeholders being hospital managers, doctors, nurses, patients, and their families. Although many current PM initiatives focus on hospital management, the emphasis of all processes must be, directly or indirectly, on the patient.

Consequently, it is essential to study healthcare processes through the eyes of the patients: What is the patient's journey while being diagnosed or treated for a specific condition? Examining a process from the patient's perspective can assist healthcare professionals in considering the entire patient journey when making decisions at a specific moment. Developing PM4H models from this angle could improve the patient experience. Additionally, the combination of data from various departments and even different healthcare institutions should be considered [148].

C9: Complement HISs with the Process Perspective.

Research in PM4H must focus on the source of the data, as well as its quality and potential uses. Complementing HISs with a process perspective -giving processes a more prominent role in these systems, recognising their importance, and how they affect organisational operations- would be beneficial [152]. This combination would pave the way for process mining to achieve many of the advantages found in systems with a strong process perspective. At the same time, there is a need for rigorous research and exploration of the inherent issues and future directions of both HIS and their integration with process awareness [153].

This study should consider how HIS must integrate various healthcare data sources[3] and manage unexpected behaviour when an unpredictable event occurs[3], or when a deadline is violated[3], while also being capable of making immediate decisions as data is analysed in real time [154].

[3]Refer to Annex C for more information on the specific characteristics of clinical care highlighted by Munoz-Gama et al.

C10: Evolve in Symbiosis with the Development in the Healthcare Domain.

Healthcare is a constantly evolving field, driven in part by innovations in medications, medical procedures, and technologies. To continuously support healthcare professionals, PM4H methods must evolve in symbiosis with advances in healthcare.

A notable evolution in healthcare is the rise of personalised medicine, where medical treatments are increasingly tailored to the needs of individual patients [155], [156]. To support personalised medicine, PM4H can develop techniques to efficiently assess the suitability of a particular treatment process for a patient with a specific profile. Valero-Ramon et al. recently proposed an approach to discover dynamic risk models for patients with chronic diseases based on sensor data [157]. These models can be utilised to personalise treatments according to each patient's unique behaviour.

Finally, when process data can be enriched with outcome and cost data, PM4H also has the potential to study in detail the effects of personalised treatment processes compared to standard practices.

Munoz-Gama and his colleagues conclude their work by stating that *"collaboration between experts from diverse fields is needed"* to address the challenges previously outlined. They also encourage the PM4H community to actively connect with and learn from more established fields, such as artificial intelligence and data mining, as the strengths of PM4H should be built upon the combination of knowledge from various research areas.

[3]Refer to Annex C for more information on the specific characteristics of clinical care highlighted by Munoz-Gama et al.

Summary of the section *Process Mining for health*

In the healthcare environment, the need for constant and agile adaptation to scientific evidence, as well as the provision of high-quality care with limited resources, necessitates continuous improvement in clinical and organisational processes. One example of this adaptation is Electronic Health Record (EHR) systems, which collect and store large volumes of medical event data. This information can be used to generate *event logs*.

An event log is composed of cases that represent different instances of processes. Each case, in turn, is formed by a sequence of events detailing the steps or tasks executed in each recorded instance. Typically, event logs capture information related to the case (*Case ID*), the steps taken in each process instance (*Activity*), and the date and time of the recorded event (*Timestamp*). Additionally, other fields such as *Transaction Type* or *Resource* can be included if required.

Process Mining (PM) is a set of techniques in data analysis, artificial intelligence, and data mining that enables the discovery, monitoring, and improvement of processes based on event logs. Depending on the type of insight desired, algorithms of the *Discovery*, *Conformance Checking*, and *Enhancement* types can be applied.

With regard to the challenges of implementing these techniques in clinical care (PM4H), in 2022, Munoz-Gama et al. identified a total of ten challenges. In general, these application challenges arise from the specific characteristics of the clinical environment, such as data quality issues or the high sensitivity of the data.

3 Hypothesis and Objectives

The current section establishes the premises, hypotheses, and objectives of this doctoral thesis. The foundations are based on the analysis of the clinical and technological context carried out in the previous chapter, where the identified needs in each of these areas with respect to the diagnostic process of ADHD in school-aged children were detailed. The identification of the underlying foundations and needs of these contexts leads to the formulation of the initial hypotheses, as well as the definition of the objectives and scope of this doctoral thesis.

3.1. Premises

The premises of this work, derived from the background outlined in the previous chapter, are listed below:

Prem.1	The early detection of ADHD is one of the fundamental pillars for achieving a significant improvement in the patient's symptoms, allowing for the alleviation of some of the difficulties that this deficit causes in affected individuals.

Prem.2	Teachers are key agents in detecting children who exhibit behaviours consistent with ADHD, gathering information about their behaviour in various areas of daily life, and, if the disorder is ultimately diagnosed, contributing to the child's therapeutic process.

Prem.3	The collaboration of healthcare professionals (paediatricians, paediatric neurologists, child psychologists...), teachers, and family members significantly influences the outcomes of any intervention.

Prem.4	Given the nature of ADHD, the assessment of maturational level and the proper functioning of executive functions is one of the most informative approaches currently used in the diagnosis and treatment of the disorder.

Prem.5	The clinical environment can make the child feel frightened and evaluated, which directly impacts their performance.

Prem.6	Games are a fundamental element in the development of a child's intelligence, as they represent their functional assimilation of reality.

Prem.7	The evolution of ICTs has enabled these technologies to be recognised as highly useful tools in supporting the diagnostic and therapeutic process of various psychiatric disorders.

Prem.8	Process mining techniques are based on the collection of real events, ensuring that the processed information produces results that accurately reflect the reality of the observed situation.

3.2. Hypothesis

As a result of the synthesis of the background presented in the *Background* section and the premises formulated above, the following hypotheses are outlined. These serve as the foundation for the subsequent definition of the main objective and its associated specific objectives.

Hypothesis.1	It is possible to implement effective screening tools for ADHD in the child's educational environment through the use of ICTs.

The clinical environment and the sense of being evaluated that the child perceives during assessment using traditional methods directly influence their performance on the various tests they undergo. Thus, the results obtained from these tests could be significantly altered when compared with the values observed under the child's baseline performance conditions.

Alongside family and friends, the educator is the person who spends the most time with the child. Teachers are able to assess how the child develops their social, cognitive, and emotional skills across various aspects of life during their growth. For this reason, the teacher is often the first to suspect the presence of ADHD in a child and bears the responsibility of initiating the evaluation process that may lead to a diagnosis of the disorder if it is indeed present.

Given this, it seems clear that the educational environment is an ideal setting for conducting screening tests for children. Under the attentive supervision of educators and in a familiar, stress-free environment suited for testing, the child can be evaluated with reduced interference from stressors that might otherwise distort the results.

If this hypothesis is accepted, the solution proposed in this work would pave the way for a set of ADHD screening tests with greater statistical sensitivity. By eliminating factors that could distort the child's actual performance, these tests would be more effective in detecting signs of ADHD.

Hypothesis.2	It is possible to model a child's behaviour during a screening test in a clinically unsupervised environment.

Inattention, impulsive decision-making, and difficulty in organising tasks are some of the characteristic symptoms of ADHD in children. Until now, such behaviours were recorded through observation by educators or healthcare professionals during screening, diagnostic, and therapeutic processes.

Thanks to advancements in new technologies and the use of data analysis tools such as PM, the proposed solution enables the creation of SGs that objectively collect and evaluate behaviour patterns. This approach allows for a more in-depth evaluation and has the added advantage of potentially discovering new standards. Supporting this hypothesis would reduce the burden of data collection on healthcare professionals, thereby increasing their available time to care for patients. Moreover, storing this knowledge in a repository would allow for analysis, not only from traditional perspectives, but also through innovative approaches that facilitate the characterisation of everyone.

Hypothesis.3	Serious games based on ICTs allow for the examination of the maturational level of executive functions in children with ADHD, yielding clinical results comparable to other traditional diagnostic tests, while being objective and free from human error.

The increasing use of SGs in healthcare stems from evidence demonstrating the effectiveness of these technologies in supporting healthcare professionals in their various daily tasks. At present, numerous studies focus on developing such technologies with the aim of assisting in the diagnosis and treatment of ADHD, yielding promising results.

The solution proposed in this thesis seeks to support healthcare professionals in the ADHD diagnostic process by studying EFs. One of the key aspects of the proposed solution is the use of serious games as an enabling tool for diagnosis. This design approach is based on the hypothesis that SGs can produce clinical results comparable to other tests, while adding an element of objectivity that is difficult to achieve through other methods. Confirmation of this hypothesis would pave the way for a new approach to diagnosing children with ADHD, enabling the creation of normative tests that could be automatically evaluated. These tests could serve as both a source of information for developing more specific therapeutic actions and a tool for large-scale screening.

3.3. Objectives

This doctoral thesis is part of the PhD Programme in Systems and Services Engineering for the Information Society, which aims to contribute to the advancement of modern society through the development of new technologies. In line with the concept of the Information Society (IS) and the goals set by the World Summit on the Information Society, the PhD programme offers three avenues of exploration through which researchers can contribute to the creation of *"a people-centred, inclusive, and development-oriented information society, where all (governments, businesses, institutions, and citizens) can create, access, use, and share information and knowledge"*.

Among the three main research avenues proposed by the Universidad Politécnica de Madrid (UPM) within this PhD Programme, this research falls under the track titled *Networks, Systems, Services, and Telecommunications Technologies*. This track encompasses, among other areas, *"critical fields such as e-health and e-accessibility, which demand the integration of accessible, mobile, and secure technologies that support systems and services with interfaces adapted for disabled users, vulnerable individuals, and those in situations of dependency"* [158].

Considering the objectives set for theses developed within this context, along with the background, premises, and hypotheses previously outlined, the objectives for this research were then established.

3.3.1. Main objective

Oriented towards addressing the objectives of the PhD Programme and resolving the needs identified within its scope, the ultimate aim of this doctoral thesis is:

"The advancement of procedures and tools for the diagnosis of ADHD in school-aged children, involving the stakeholders who interact with them in their natural environment."

Technology can help make certain therapeutic actions more available, providing the necessary conditions for carrying them out in the child's natural settings. Yet, it is essential to establish an appropriate technological development and integration strategy that not only enables the implementation of effective actions but also ensures minimal disruption to the lives of the child and their family. To this end, the **primary objective** of this thesis is defined as:

"The development and validation of a reference framework for the creation of serious games aimed at administering screening tests for children, within the school environment and under the supervision of the school's own staff."

3.3.2. Specific objectives

To address the achievement of the main objective from an engineering perspective, a series of specific objectives must be established, as detailed below:

- **Characterise the digitalisation of serious games for use in clinically unsupervised environments.** The implementation of screening tests will depend on the current hardware and software characteristics, which may necessitate changes in the fundamental features of the tests, potentially requiring their adaptation.
- **Define clinically significant events in the games developed.** These events will be considered contextualised groupings (in relation to the pathology being studied) of the player's interactions with the solution. This aims to acquire a deeper and more detailed understanding of the behaviour and individual characteristics of the players.
- **Develop a behavioural analysis model** that examines the gameplay mechanics of children using PM algorithms and statistical modelling techniques. The goal is to incorporate additional relevant information to the data currently collected, thereby facilitating the diagnosis of ADHD

within the target population and seeking a graphical representation of the results that can be easily interpreted by experts, educators, and families.

- **Validate the clinical effectiveness** of the proposed solution by testing the stated hypotheses.

3.4. Scope of the research

After outlining the context surrounding this doctoral thesis, the premises on which it is based, and the hypotheses it seeks to test, Figure 3.1. presents the scope of its research.

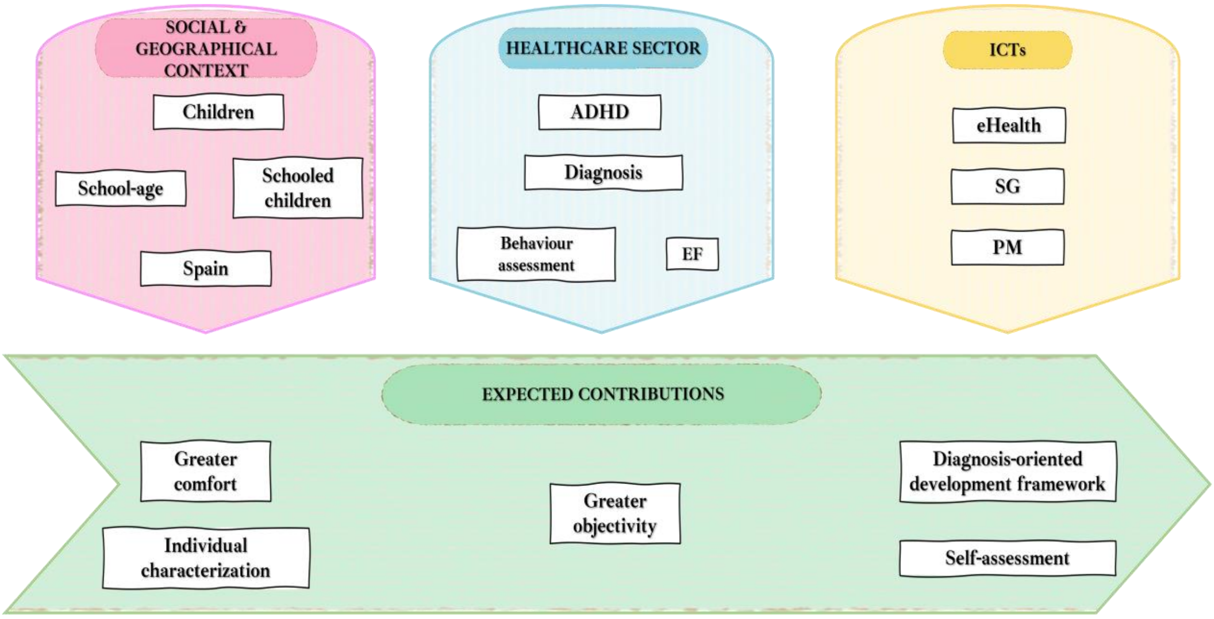


Figure 3.1. *Scope of the thesis and expected contributions.*

In social and geographical terms, this thesis focuses on the evaluation of school-aged children enrolled in schools within Spanish-speaking territories, specifically in Spain. This focus arises from the fact that the assessment of some EFs is directly related to the child's language, making it an important variable to consider and control in the evaluation process. In the healthcare context, the research presented in this thesis is centred on ADHD, within the realm of psychiatric disorders. More specifically, it addresses the diagnostic process of ADHD through behavioural studies and the evaluation of EFs in children. Finally, in the field of ICTs, the research focuses on eHealth services, particularly SGs solutions. Various data analysis tools will also be applied. Statistical tools will be used to assess the discriminative effectiveness of the screening tool, while process mining techniques will be employed to model the behaviour of children during the tests.

In this context, and in anticipation of testing the hypotheses outlined in the previous section, this thesis aims to contribute to the advancement of each of the three domains presented in Figure 3.1. By achieving the stated objectives, the thesis seeks to improve the child's experience during the diagnostic process, thereby increasing the objectivity of the results and, consequently, enhancing the decision-making process. This, coupled with an individualised characterisation of the player, could lead to greater effectiveness in the subsequent treatment process. Additionally, it is intended that the solution's evaluation of the player’s results will reduce *human error* and increase the healthcare professionals’ available time for patient care.

4 Methodology and Materials

The current section outlines the research method employed during the course of this doctoral thesis, detailing each of its phases. Meanwhile, the *Materials* section describes the various types of resources required for the development and validation of the proposed solution.

4.1. Justification of the research method

As seen in previous sections, this doctoral thesis spans areas related to clinical practice and the use of ICTs, in addition to their integration into the natural environments of the child. Due to its multidisciplinary nature, the development of the proposed solution must be approached by a team comprising actors representing the various fields involved.

At present, there is a wide range of project development methodologies that guide research teams in the planning, execution, and completion of initiatives in an efficient and effective manner. Each of these methodologies provides a framework that enables the management of resources, timelines, risks, and objectives to ensure the project's success. As well, some of these methodologies serve as a guide for developing software solutions, ensuring that tools are created to allow users to interact with various computing devices more efficiently.

Considering the above, the research method employed in this thesis has been conceived as a combination of a methodology focused on validating the proposed hypotheses and a widely accepted engineering methodology for the agile development of solutions [159]. This approach enables the integration and utilisation of the knowledge acquired to formulate hypotheses and objectives that deliver effective and accessible solutions for the target audience, tailored to the unique characteristics and needs of each sector involved.

4.2. Research Method

This section presents the method employed in this doctoral thesis for the implementation of the proposed reference framework for the development of SGs deployed in natural environments, aimed at supporting clinical decision-making (Figure 4.1.).

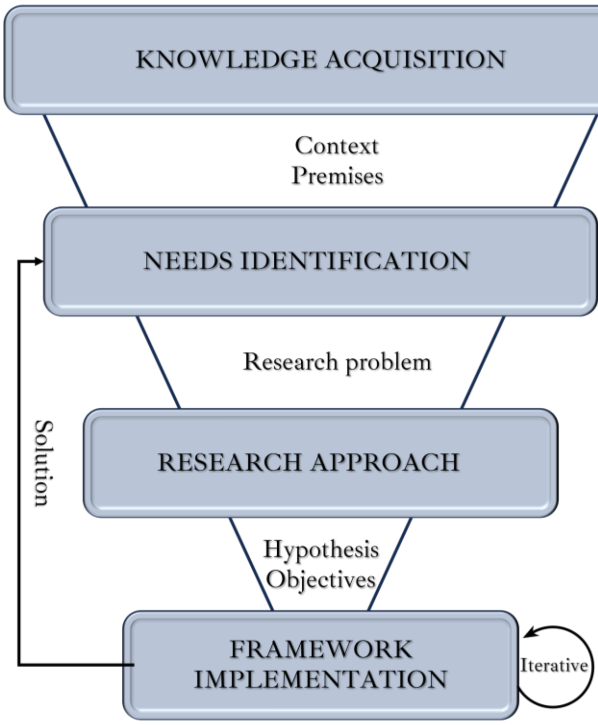


Figure 4.1. *Research method employed in the present study.*

As previously mentioned, the proposed research method combines various methodological approaches to address both the main objective and the testing of the hypotheses upon which it is based [160], [161]. The following outlines each phase of the process.

4.2.1. Knowledge acquisition

This phase involves the review and analysis of the available literature in relation to the following areas of knowledge:

1. *ADHD in childhood*. This includes the ethology of ADHD, the conditions that manifest with its presence, and the diagnostic process.

2. *eHealth*. Information regarding the use of ICTs in clinical practice.

3. *Behavioural analysis*. Evaluation of available techniques for modelling human behaviour.

Additionally, as an expert source of knowledge, continuous communication with professionals from each of the aforementioned areas of expertise was considered, serving as an additional validation of the previously established premises.

The execution of this phase provided the author with contextual knowledge and facilitated the establishment of the premises upon which the thesis problem statement, hypothesis formulation, and objective generation are based. The knowledge acquired through communication with experts and the literature review has been detailed in the *Background* section of this document.

4.2.2. Needs identification

The previous contextualisation enabled the author to identify the needs and specific characteristics of each of the environments in which this thesis is situated. This set of demands is detailed in the *Contextualisation and thesis problem* section of this doctoral thesis.

As seen in that section, the execution of this phase culminates in the articulation of the thesis problem, which is formulated from ***"the need to develop a framework for generating ICT-based solutions to enhance the accessibility and objectivity of the ADHD diagnostic process for school-aged children."***

4.2.3. Research approach

Once the problem to be addressed has been defined, the next step is to select the research approach through which an effective solution will be sought. Based on the knowledge acquired and the needs identified in earlier stages, the hypotheses are formulated to underpin the concretisation of this approach, and consequently, the set of objectives for the thesis are established. The results obtained from the execution of this phase are detailed in the *Hypothesis and Objectives* section.

4.2.4. Framework implementation

In order to achieve the objectives, set in the previous phase, and test the formulated hypotheses, the next step is the definition and development of the framework for generating serious games, identified as the solution to the research problem. Figure 4.2. schematically presents the different steps to be followed for this implementation.

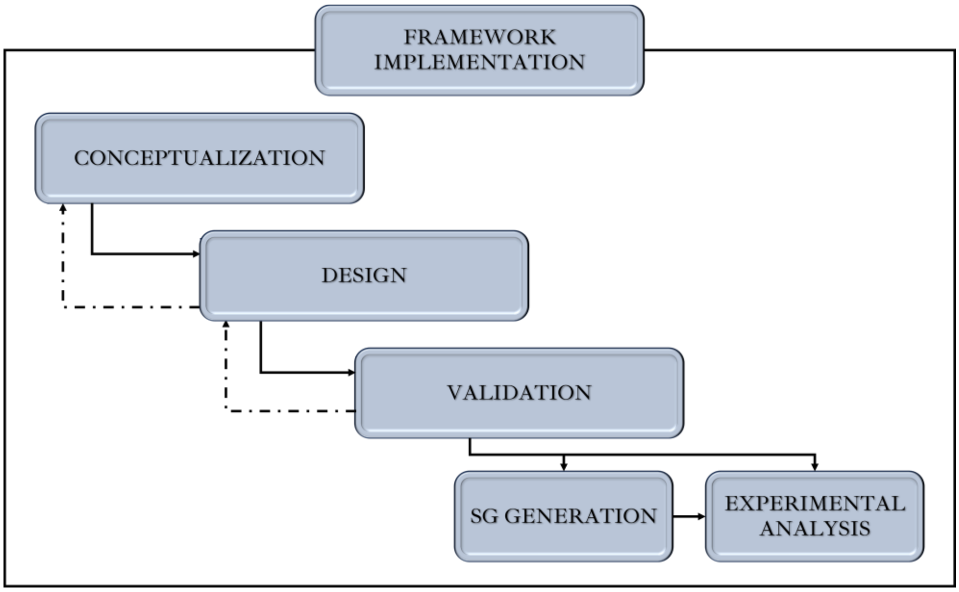


Figure 4.2. *Framework implementation phase structure.*

As can be seen in the previous figure, the implementation of the framework involves the completion of the following stages:

1. ***Conceptualisation***. Considering the specific characteristics and previously identified needs, this stage defines the ideas, concepts, components of the framework, and the relationships between them, ensuring that the proposed solution addresses and rectifies these elements. The results from this stage are presented later in this document, in the section on *Conceptual Results*.

2. ***Design.*** This stage involves the detailed planning of how the development framework will be constructed and used. In other words, the ideas generated in the previous stage are translated into a concrete and practical plan. Consequently, at this point, the *Materials* to be used are determined, as outlined in the next section of this document.

3. ***Validation.*** In order to ensure that the developed framework meets the objectives set in the earlier stages, actions such as the generation of serious games from the framework and experimental analysis are carried out. The results of this phase are presented in the *Technological Results* y *Experimental Results* sections of this document.

Both clinical and technical information are gathered and used as inputs for the next iteration of this methodology.

4.3. Materials used

4.3.1. Neuropsychological resources.

In 2009, Hogrefe TEA Ediciones published a battery of tests for the Neuropsychological Assessment of Executive Functions in Children (ENFEN) [29]. As a set of neuropsychological tests, ENFEN aims to relate the child's cognitive performance with the different areas that process each cognitive function, thereby evaluating the relationships between EFs and the individual's nervous system.

Specifically, ENFEN measures the maturational development of EFs in children aged between six and twelve years within the following populations:

1. *Children with normative development.* For children with an (apparently) normative (neuro)development, this battery of tests allows for:
   a. *Clinical diagnosis* which evaluates the individual's overall level of neurocognitive maturity through the assessment of EFs performance.
   b. *Educational guidance*, enabling the identification of schoolchildren with nervous system immaturity or dysfunction (increasing the risk of academic failure). The results obtained with ENFEN facilitate curricular adaptations and the preparation of rehabilitation and/or cognitive stimulation programs.
   c. *Evolutionary control*, allowing for monitoring the progress of children undergoing rehabilitation programs and conducting reviews for those receiving psychopharmacological treatment.
   d. *Attention to populations at neurobiological risk*, which includes individuals with pathological perinatal history, a family history of neuropsychological disorders, and preterm children.
2. *Clinical samples*. In the case of children referred for neuropsychological evaluation due to concerns about their cognitive and/or behavioural performance, ENFEN allows for the assessment of difficulties in neuropsychological development. In this population, the primary goal is to identify and characterise potential developmental difficulties, as well as to determine the nature and extent of any neuropsychological diagnosis -such as ADHD, Specific Language Disorder (SLD), among others-. The results obtained from ENFEN in this population aim to inform diagnosis, treatment planning, and interventions to address the child’s specific needs.

Through the administration of the four main tests that comprise ENFEN, this battery allows for the psychometric evaluation of a total of six neuropsychological indices: *Fluidez fonológica y semántica, Construcción de Sendero gris, Construcción de Sendero de Color, Anillas y Resistencia a la Interferencia*[4]. Each of these tests includes an initial trial or practice run, which allows the child to become familiar with the task, followed by an assessment test that evaluates the child's maturational level of EFs (Figure 4.3.). Furthermore, all tests must be administered under the close supervision of a qualified healthcare professional -such as a psychologist or paediatric neurologist- who is responsible for gathering all relevant information for the subsequent calculation of scores.

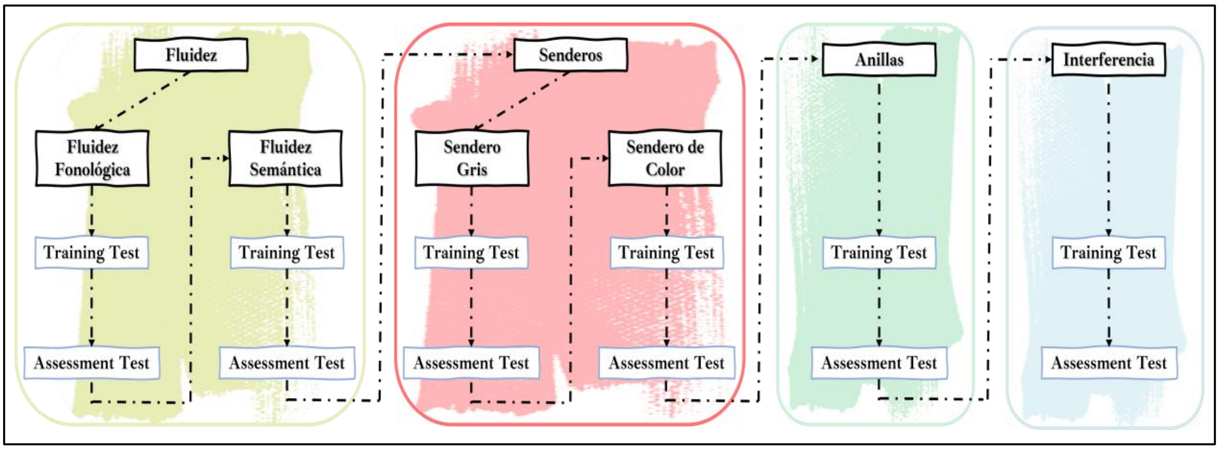


Figure 4.3. *Order of execution of the ENFEN test battery.*

At this point, it should be clarified that, in order to safeguard intellectual property rights, various aspects related to the measurements of each test and the final scores calculated with ENFEN could not be included in this document. Yet, this does not affect the results presented in this thesis or their validation. Should the reader wish to learn more about how ENFEN final scores are calculated, they should refer to [29].

[4]Refer to Annex D for more information on the subfunctions assessed by the ENFEN test battery.

Fluidez

The Fluidez test consists of a verbal fluency task that assesses the child's linguistic abilities. More specifically, it is used to measure the child's ability to generate words within a specific category - phonological or semantic- within a given time limit. This test evaluates *cognitive flexibility*, *processing speed*, *working memory*, and vocabulary through the execution of the *Fluidez Fonológica* and *Fluidez Semántica* tasks.

- *Fluidez Fonológica.*

An expressive language tasks that increases activity in the left hemisphere, activating areas such as Broca's area and Wernicke's area.

In this task, the child **is required to say as many different words as possible that begin with a given letter within a predetermined time interval**.

- *Fluidez Semántica.*

In general, semantic fluency demands greater cognitive effort than phonological fluency, leading to a higher degree of activation in extensive prefrontal areas. Specifically, the need to recall words belonging to a particular semantic category increases activity in the left hippocampus, which is more closely associated with verbal memory tasks.

In this task, the child **is required to say as many different words as possible that belong to a given semantic category within a predetermined time interval**.

Both phonological and semantic fluency are linked to working memory capacity. Generally, children with a higher level of knowledge tend to perform better on this task, as it is closely related to crystallised intelligence acquired through cultural experience. In these two tasks, the healthcare professional overseeing the administration of ENFEN must explain the procedure to the child, ensure that the established time limit is followed, and record various parameters of interest for the subsequent calculation of scores.

Senderos

The construction of the two trails that make up this test is based on the *Trail Making Test*, which requires the activation of planning and decision-making strategies. Specifically, the two parts of Senderos test allow for the evaluation of various subfunctions, such as:

1. *Cognitive flexibility*. Enables the child to avoid perseveration, allowing them to change strategies to achieve the goal.
2. *Ability to use strategies.* Allows the child to plan behaviour aimed at successfully completing each trail in the shortest time possible.
3. *Inhibitory control.* Helps the child avoid distraction while performing the task.
4. *Working memory*. Actively associates the last connected element with the next one in the sequence.
5. *Prospective memory*. Enables the child to anticipate and predict the next element in the sequence.
6. *Selective and focused attention.* Facilitates the search for the next element in the sequence.
7. *Visuospatial skills.* Allow for the quick identification of each element in the trail.
8. *Graphomotor dexterity*. Enables the consecutive connection of trail elements as smoothly as possible.

The following describes the task to be executed in each of the two tests that make up the trails construction tasks.

- *Sendero Gris.*

In this first part of the Senderos test, the child will find a series of numbered nodes scattered pseudo-randomly across the sheet. The task consists of **connecting these nodes in descending order** (Figure 4.4., A)).

- *Sendero de Color.*

In the second part, the Sendero de Color task increases the complexity of the previous task. Similar to Sendero Gris, the child encounters a series of scattered nodes on the sheet. However, in this case, the nodes are printed in two different colours. The task is **to connect the numbered nodes in ascending order while alternating between the two colours** (Figure 4.4., B)).

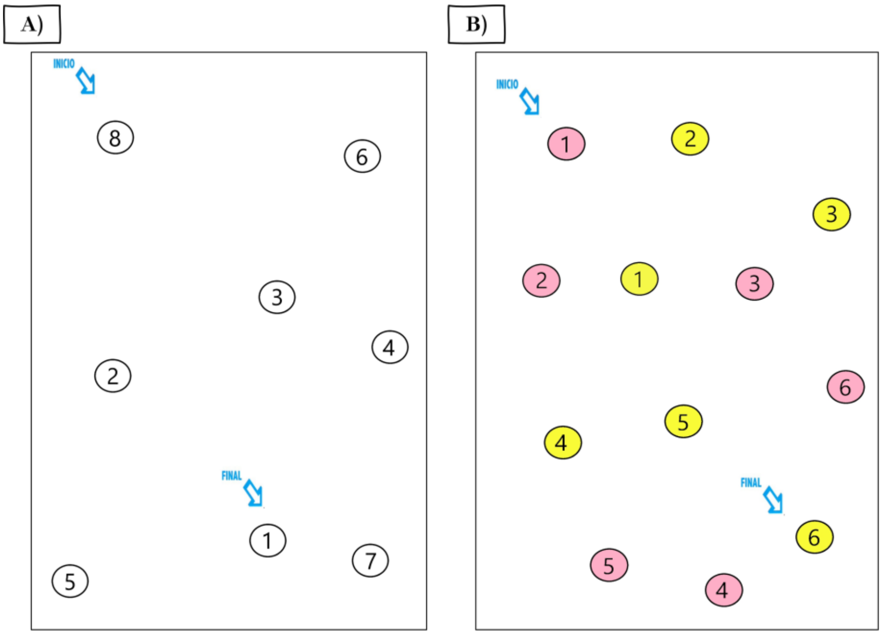


Figure 4.4. *Senderos test. A) Sendero Gris training; B) Sendero de Color training*

In these two tasks, the healthcare professional in charge must explain the procedure to the child, measure the time required to complete the tests, ensure that the tasks are performed in the correct order, and assess various aspects of interest for the accurate calculation of the final scores.

Anillas

The Anillas test is inspired by the *Tower of Hanoi*. More specifically, the test consists of a total of fifteen trials in which the child must replicate fifteen different models depicted on a sheet (Figure 4.5.). To do this, **the child is provided with a set of rings in an initial position** on the left axis, **which they must move to reach the desired figure** on the right axis, **using the fewest possible moves and in the shortest possible time**. Any of the three available axes can be used as an intermediate step to achieve the final figure.

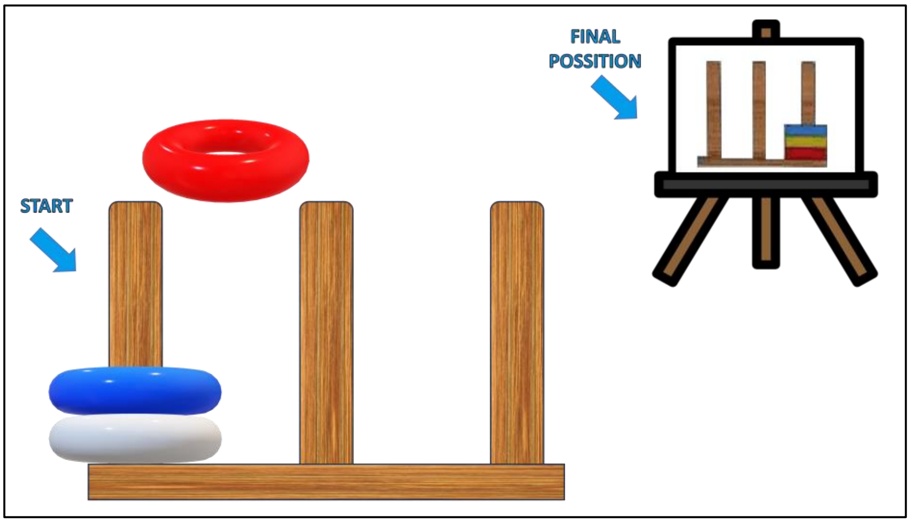


Figure 4.5. *Anillas training test*

The Anillas test assesses aspects related to prefrontal executive functions, such as:

1. *Behavioural planning ability*. Facilitates the sequencing, planning, and forecasting of actions aimed at achieving a goal.
2. *Aptitude for problem decomposition.* Evaluates the child's ability to break down a global problem into different stages and to discern the rules governing the construction process.
3. *Cognitive flexibility.* Prevents the impulsive and unplanned placement of rings, promoting deliberate and considered actions.
4. *Abstraction and prospective memory ability*. Enables the configuration of the final position of the rings before making the movements.
5. *Motor dexterity*. Required to complete each model in the shortest possible time.
6. *Operative memory*. Allows the retention of both the construction of the design and the potential outcome of manipulating the rings for each model.

In this test, the healthcare professional must explain the task to the child and record the total execution time for each of the fifteen trials, as well as collect various parameters of interest for subsequent measurements.

Resistencia a la Interferencia

Inspired by the third part of the *Stroop Test*, the Interference test primarily evaluates the child's attentional control. Specifically, this test assesses:

1. *Selective attention*. Facilitates the control needed to correctly identify the colour in which each word is printed.
2. *Inhibition ability*. Prevents the incorrect naming of the colour in which each word is printed.
3. *Mental flexibility*. Allows the test to be performed smoothly and without errors.

In a template -sheet- various colour names are printed in different ink colours. **The name of the colour and the ink colour in which it is printed do not coincide in any case. The task requires the child to state the name of the colour written on the sheet, while avoiding interference from the ink colour in which it is printed** (Figure 4.6.).

In this test, the healthcare professional must instruct the child on how to proceed, record the total time taken for the test, and collect various parameters of relevant information for the subsequent calculation of ENFEN scores.

Figure 4.6. *Example of Resistencia a la Interferencia test.*

Once the four tests in the battery have been completed, the scores for each are calculated. Subsequently, by consolidating these scores, a profile of the child's developmental level of EFs is generated (Figure 4.7.) [162]. This profile reveals the child's strengths and weaknesses. Thus, **ENFEN provides an individual characterisation of the developmental level of EFs in each child,** offering the healthcare professional support for their decision-making and, if necessary, guidance on how to direct the subsequent treatment for each specific patient.

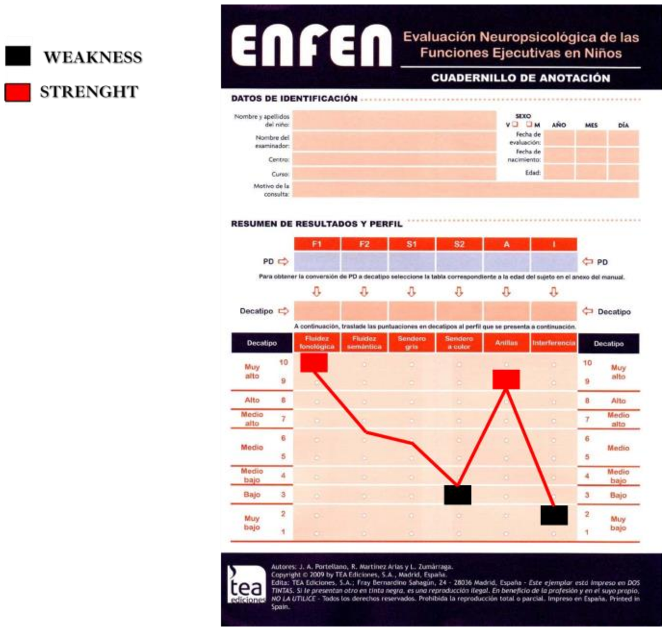


__Figure 4.7.__ Example of the profile generated for an individual after completing the ENFEN test battery.

Based on the aforementioned knowledge, it can be stated that ENFEN offers two notable advantages within the screening process:

1. It is a set of tests that ***enhances the objectivity of the diagnostic process***. As can be identified throughout the preceding paragraphs, ENFEN bases its scores on the individual's performance in each of the tasks, without considering the perspectives or experiences of individuals close to the child.

2. Additionally, it is capable of ***providing an individualised characterisation of the developmental level of EFs for each child***. Generally, behavioural questionnaires and/or neuropsychological tests evaluate the potential presence of a deficit as a whole -either the deficit is present, or it is not-. In contrast, ENFEN allows for the understanding of the specific characteristics of the potential existence of a deficit in everyone, assessing the extent of impact it may have had on their various abilities.

Though, despite the invaluable support that this tool provides to healthcare professionals, ENFEN has a number of characteristics that could be optimised (Table 4.1.).

Table 4.1. *Potential improvements identified based on the current features of ENFEN.*

Potential enhancement	Description
Displacement is mandatory	The current paper-based format of the tests and the urgent need for the presence of a healthcare professional to monitor their administration requires the child to travel to a specialized centre. Consequently, the child may experience a decrease in performance due to feeling observed and/or evaluated in an unfamiliar environment for them (see Section 2.2.3.).
One child at a time	As the specialist is directly responsible for collecting the information and conducting the test, they need to closely observe how the child performs the task.
Prone to real-time assessment error	When scoring manually, due to fatigue or insufficient experience, the evaluator may make mistakes that can potentially impact the results.

The implementation of such tests through ICTs could minimise, or even eliminate, the difficulties outlined in the previous table. By transforming these tests into ICT-based SGs, children could access them from any location, including their natural environment, thus avoiding any disruption in their performance. Furthermore, as the SG is capable of guiding the child and collecting relevant information for each task, it allows for the simultaneous assessment of more than one individual. To conclude, since the SG itself records the information of interest and performs the calculations, provided the system has been adequately validated by experts in real-world settings, the potential for human error in evaluation is significantly reduced.

4.3.2. Team and participants in the research

Professionals and Experts

As illustrated in Figure 1.1., the proposed solution in this doctoral thesis is situated within the intersection of clinical and ICTs fields. Consequently, throughout this research, collaboration from professionals in both domains was essential.

At this point, it is crucial to consider the information abstracted from Figure 2.3. and the section on the *Relevance of Collaboration among Key Stakeholders*. Given the understanding that *"a close relationship between family members, educators, and healthcare professionals is crucial,"* it was deemed appropriate to include the participation of various individuals from these roles.

In relation to **educational professionals**, this research work benefitted from the collaboration of technical, administrative, and teaching staff from various educational institutions and associations. The essential involvement of educational personnel facilitated the research team's access to the target audience, as well as the validation of the solution in a natural environment for the child.

Simultaneously, the research integrated various **professional profiles within the clinical practice domain**. Specifically, occupational therapists, clinical neuropsychology experts, and child development psychologists supported the development team during the phases of generation, optimisation, and validation of the proposed solution.

In the ICTs and data analysis domain, the experience and knowledge of the research team, along with the assistance of some external users, were utilised. Cooperation between ICTs technicians, IT experts, and information analysis professionals enabled the implementation of the software through which the framework presented in this work was validated.

Participants in the Study.

The participants in the administered tests were required to meet the following criteria:

1. **Children aged between six and twelve years** (inclusive). As detailed in previous sections, the human prefrontal lobe reaches maturity by the age of six. From this point onwards, it is feasible to study the developmental level of executive functions. Additionally, ENFEN is designed for children up to twelve years old, setting this as the age limit for participants.
2. **No diagnosed visual and/or auditory impairments.** The ENFEN battery is designed in such a way that it does not guarantee the correct performance of the tests under conditions of auditory

and/or visual difficulty. Thus, a child with auditory and/or visual problems might obtain biased scores on certain tests within the battery due to these conditions.

3. **Native Spanish speakers who are currently attending school.** This ensures that tests such as *Fluidez* and *Resistencia a la Interferencia* will not have biased scores due to unfamiliarity with the language in which they are administered.

4. **With or without a diagnosis of ADHD or any other neurodevelopmental disorder.** To validate the discriminatory power of the developed solution, it was necessary to include both children with an ADHD diagnosis and those without such a diagnosis.

4.3.3. Technological resources

For the development and evaluation stages of the serious games, which would be used to test the validity of the proposed framework, a range of available hardware and software tools were required.

In addition to the requirements specified by the identified needs, **one of the desired characteristics for the proposed solution is its sustainability**, both in terms of development and execution. This means not only that the solution should be cost-effective and available to communities with limited resources but also that it should be designed to be easily scalable and adaptable as user needs and conditions evolve.

To this end, **general-purpose hardware was selected**, specifically **mobile devices**. Paraphrasing Zheng et al., *"these devices allow access to the game at anytime, anywhere"* [112]. Consequently, these tools facilitate meeting the availability requirement in the child's natural environments, as outlined in the primary objective of this thesis.

Regarding software, **free tools were used for game development, cloud storage, high-level programming languages, and data analysis applications using PM algorithms** that are flexible, secure, and oriented towards teamwork. Furthermore, it was sought that these **software tools be user-friendly for non-experienced users**, thus enabling the research team to develop and deploy effective solutions in unfamiliar domains.

5 Results

The current section outlines the results obtained in the doctoral thesis, categorised into three types based on their scope: conceptual, technological, and experimental. Firstly, the conceptual results refer to the synthesis of the knowledge acquired, and the needs identified within the framework of a coherent SGs generation. Secondly, the technological results generated from the aforementioned framework are detailed, which serve as the means to assess the validity of the proposed solution. Lastly, this section describes the experimental results obtained from the engagement of the solution with the target audience for whom it was developed.

5.1. Conceptual results

5.1.1. Guiding principles of the framework

Thus far, throughout the development of this document, the current state of each of the domains in which this doctoral thesis is situated has been addressed. However, within the process of conceptualising the proposed solution, a more detailed synthesis of this knowledge is required. Specifically, the aim is for the generated framework to be capable of reusing key aspects already integrated into some existing frameworks -avoiding the need to "reinvent the wheel"- while simultaneously capturing the specific requirements of the field of application for which it has been designed, requirements that are not currently addressed by any known framework.

Basic Pillars

In light of the identified needs, the serious games generated using the framework to be developed must be objective, available, and oriented towards the behavioural analysis of the target individuals. Consequently, three basic pillars are defined: ***objectivity*** in the collection and analysis of player performance, ***availability*** of the serious game, and, finally, the ***behavioural analysis*** of the individual during interaction with the tool.

Objectivity Factor

The strong influence of personal opinions and experiences in the current ADHD diagnostic process can result in either underdiagnosis or overdiagnosis of the disorder [163]. In contrast, there are currently tools -such as neuropsychological tests- that increase the level of objectivity in this process by measuring neurobiological parameters related to the presence of the deficit. Consequently, **the serious games developed using the proposed framework must focus on the collection and subsequent analysis of markers related to these neurobiological factors**.

Availability Factor

Despite the added objectivity provided by neuropsychological tests, their format perpetuates a level of stress for the child. This feeling of being evaluated has been shown to be strong enough to affect the child’s performance, thus biasing the results they might achieve during the tests.

Thanks to new technologies, it is now possible to bring these tests closer to the child's natural environment. Given the nature of SGs, they can be ubiquitous, making them more available to the target users. Though, one of the greatest challenges posed by ubiquity in such solutions is the accurate transmission of relevant information to the players, as well as the proper collection of significant data. Traditionally, it is the healthcare professional who is responsible for communicating and ensuring that patients understand the test procedures. Similarly, once the player has understood the instructions, it is the professional who collects all the relevant parameters from the tests.

In this research, **the solution generated through the proposed framework must assume the role of conveying instructions to the players in a clear and understandable manner, while also accurately reflecting all relevant information in the files generated by the game.**

Behavioural Analysis Factor

In addition to neurobiological factors, it is evident that the behaviour of individuals suspected of having ADHD is one of the most decisive factors in diagnosing the presence of this deficit. Therefore, an objective analysis of the player’s behaviour must be included among the indicators collected by the game, and thus, it becomes one of the key features of the serious game development framework.

To this end, **the framework must incorporate behavioural analysis techniques into the operation of the games generated through its use.**

Although these three factors serve as the guiding pillars for the development of the proposed framework, general considerations related to the implementation of such solutions in clinical practice should not be overlooked. To address this, a review of pre-existing SGs development frameworks was conducted.

Discrepancies with Existing Frameworks

Through a systematic review of the literature, the author identified a significant number of frameworks guiding the development of SGs for their application in the health sector. Generally, these frameworks focus on leveraging acquired knowledge to promote long-term player engagement and the personalisation of the generated games. However, **the emphasis on long-term adherence and player motivation in these frameworks is inconsistent with the nature of the ADHD diagnostic process.**

Firstly, all the tests involved in the ADHD diagnostic process are administered to the patient on a single occasion. For instance, a child does not need to take the *Stroop Test* more than once for it to serve as a diagnostic tool. Thus, **elements like adherence and personalisation are irrelevant in this case**. Furthermore, in the frameworks reviewed, adherence and personalisation are achieved by motivating players and enhancing their focus. In the ADHD diagnostic process, neuropsychological tests, rating scales, and healthcare professionals aim to evaluate the child's abilities in their baseline state. Therefore, **games designed as ADHD screening tools should minimise motivational and distracting elements as much as possible**. In other words, features that promote player adherence and game personalisation should be limited.

In conclusion, the framework for developing games as screening tools for childhood ADHD should exclude elements of motivation, personalisation, and adherence. Instead, **the generated games should feature a simple interface that avoids *overly* motivating the players.**

Commoon Characteristics with Existing Frameworks

Despite the differences identified between the framework to be developed and those already in existence, certain factors or characteristics must be present in both, given their shared nature.

Firstly, it has been concluded that any SGs development framework must encompass the five stages outlined by Verschueren in his study [132] (Figure 2.10.). These stages logically organise the steps required for the development of a serious game in the clinical domain, covering the stages of such solutions regardless of their focus on a specific disorder or process. Additionally, incorporating the questions proposed by Graafland et al. in [129] (Figure 2.9.) during the execution of the various stages of the framework could help ensure its eventual validation.

Therefore, **the framework proposed as the result of this doctoral thesis will need to adapt Verschueren's five generic stages to the specific requirements of ADHD screening, with each stage incorporating relevant questions to facilitate validation.**

5.1.2. Framework for the generation of SGs as support tools for the diagnostic process of childhood ADHD.

Figure 5.1. schematically presents the framework proposed by the author for the generation of solutions based on SGs, aimed at supporting healthcare professionals in their decision-making process. As indicated in the figure, a total of five stages are proposed, each aimed at addressing various aspects related to the identified needs and the specific characteristics of the application context. For each stage and depending on the nature of the tasks it comprises, the different actors involved in its execution are detailed at the bottom of the image. In general, it is assumed that a team will be formed with at least the following professional profiles: healthcare professionals with experience in the diagnostic field of childhood ADHD, experts in the field of new technologies and informatics, and specialists in data management. The integration of the knowledge and skills of each of these professional profiles is considered a fundamental pillar for the development of effective solutions.

Additionally, the image suggests a recursive approach within each stage of the reference framework. Integrated for the continuous validation and improvement of the developed solutions, this recursiveness is implicitly reflected in the cycle of enhancement and validation, where the results obtained in one phase serve as inputs to iterate and refine the subsequent ones. Similarly, the framework collects both technical and clinical information, allowing the solutions to be adapted and evolved according to each of the contexts in which it is integrated.

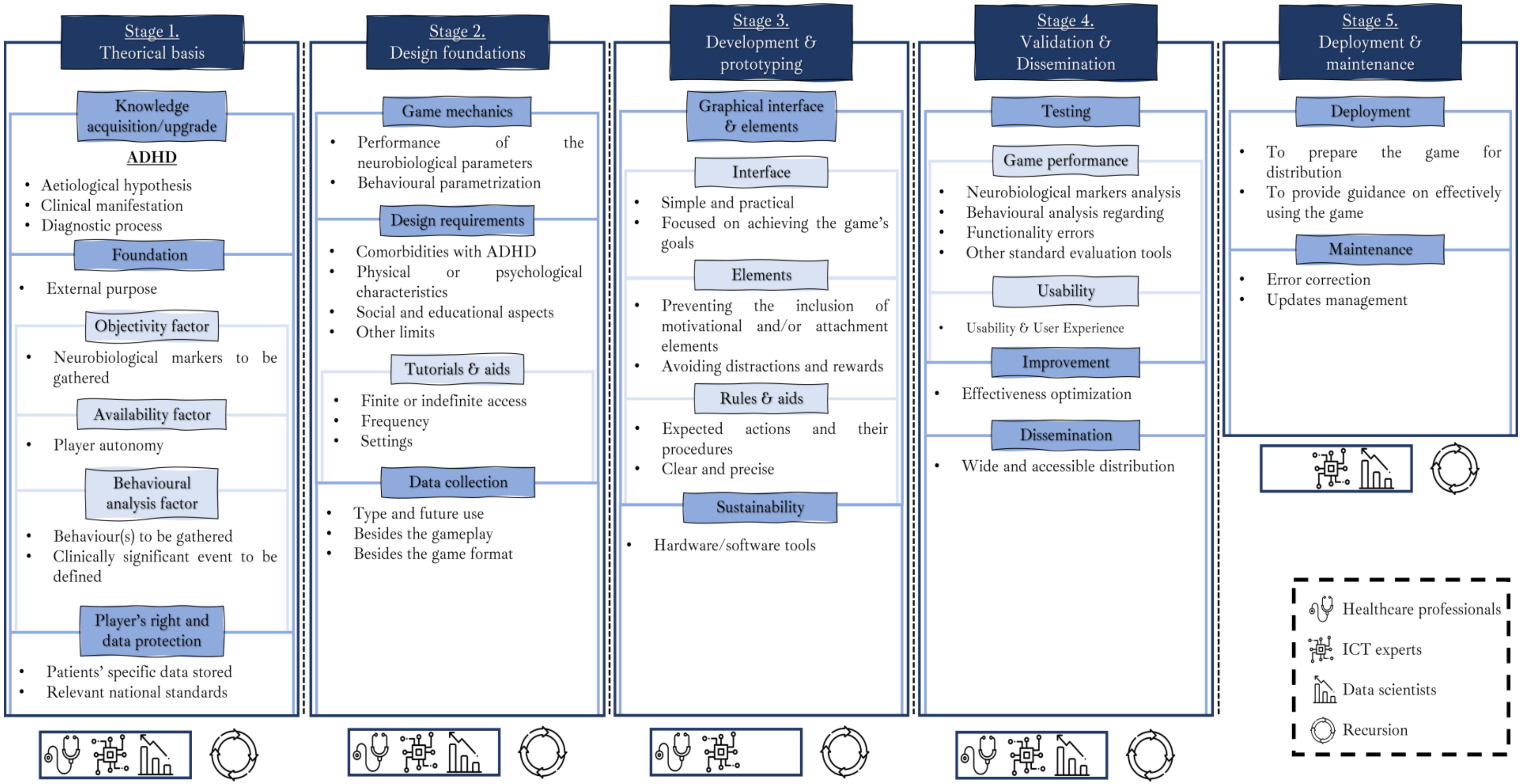


Figure 5.1. Reference framework for the generation of SGs aimed at childhood ADHD screening.

Stage 1. Theorical Basis

Initially, the theoretical foundations upon which the development of the games from the framework is based must be established. This phase not only aims to ensure that the games are developed based on scientific evidence but also promotes the creation of solutions with practical utility that provide a positive therapeutic impact. To achieve this, the following tasks are proposed within this first stage of development.

Task 1.1. Knowledge Acquisition/Upgrade

This task is based on a systematic review of the existing literature regarding the current understanding of ADHD. Depending on the knowledge of the research team, they must acquire or update their understanding of the foundations of ADHD, its clinical manifestations, and the current diagnostic process. This procedure allows for the identification of needs and, consequently, the detection of potential solutions to address them. At this stage, the research team must assess whether the type of solution generated by the proposed framework in this study aligns with the identified requirements or whether other types of tools might be more suitable.

Task 1.2. Game Foundation

Once SGs are established as a potential solution to the problem, the next step is determining the game's foundation. At this stage, it may also be beneficial to address the questions posed by Graafland et al. regarding the external purpose of the game, aligning it with the target audience and the application environment (Figure 2.9., category *Rational*).

Additionally, this task involves specifying the factors of objectivity, availability, and behavioural analysis. Based on the identification of relevant neurobiological factors that trigger the behavioural symptoms in patients, clinically significant events will be defined. This, combined with the specification of various availability requirements, ensures the inclusion of the three basic pillars identified from the specific needs of the application domain.

Task 1.3. Players' Right & Data Protection

Lastly, the task concerning the rights of the players, and the security of the data collected by the game is addressed. At this stage, issues related to national security standards, the storage of sensitive patient data, and the generation of informed consents must be resolved to minimise potential future threats to user privacy.

As seen at the bottom of Figure 5.1., this phase requires the involvement of all professional profiles that make up the research team: healthcare professionals, experts in the ICT field, and data analysis specialists.

Stage 2. Design Foundations

In the second phase, the game design is developed, based on the foundations established in the previous phase. At this stage, the game mechanics that will enable the collection of relevant information are determined, along with the design requirements and their adaptation for future evaluation.

Task 2.1. Game Mechanics

Regarding the game rules, user interface, progression, and other elements that directly impact the player's experience, this is the stage where the set of actions through which the player interacts with the virtual world is defined. It also determines how these actions influence the development of the game environment and the player's progress within it. In this way, the mechanics of the serious game are created similarly to those of other games, but with a specific focus on meeting the screening objectives.

Task 2.2. Design Requirements

The expansion of the target user group profile is proposed to gain a better understanding of the context of use and the realities of the intended audience. As previously mentioned, ADHD is often comorbid with other mental disorders -such as anxiety and depression-. Furthermore, it is possible that some of the neurobiological factors to be collected are strongly influenced by the child's social, economic, or cultural environment. For example, tests evaluating the user's semantic or phonological fluency may be significantly affected by the individual's native language. Similarly, certain physical conditions could hinder the player's ability to properly engage with the game, thus biasing the results. Understanding the players' realities and their context allows for meeting the needs and expectations of the intended audience, as well as delivering successful solutions.

In line with the above, and in relation to the availability factor of the games, this stage determines aspects related to the tutorials and assistance available to the user. Given the characteristics of the users -school-aged children- and the goals set in the first phase, the research team may aim to strike a balance between the availability of the game and any aspects that could *compromise* the quality of its results.

Task 2.3. Data Collection

Regarding the collection of relevant information, the research team must establish the theoretical foundations on how this data will be gathered and stored by the game. For instance, the nature of the data to be stored is one of the key aspects to be determined at this stage. Depending on whether the data will be used for clinical purposes or for validating the tool, whether it involves personal information about the users or, alternatively, their performance during interaction with the solution, the development team can set different parameters for how and when this information will be collected.

Moreover, the team may consider the possibility of collecting information about the player in sections of the game that do not strictly involve gameplay -such as registration screens-. To end, they may explore the option of gathering data from users when they are not actively interacting with the tool, through surveys or questionnaires.

Stage 3. Development & Prototyping

The third phase of the framework implements the theoretical and design foundations established in the previous stages. This is the phase where the resources and skills of the development team come into play to address the complexities identified.

Task 3.1. Graphical Interface and Elements

Paraphrasing Verschueren et al., *"the scientific and design foundations developed in previous stages should now enable developers to select the most appropriate interface genre for the intended target audience and context of use"*. In the case of screening ADHD, the goal is not to develop games that motivate users or encourage long-term adherence. Instead, the focus is on creating minimalist visual elements that allow the user to interact with the solution easily while maintaining, as much as possible, the baseline state of the mental faculties being evaluated. Consequently, a simple and practical user interface (UI) is proposed, designed solely to achieve the game's objectives. Similarly, game elements should prevent user distraction and avoid excessive reward generation.

In line with this, and given the availability requirement of the framework, the presentation of the game rules, as well as any assistance provided to the player if needed, must be tailored to the player's profile, clearly and precisely explaining how to correctly interact with the solution.

Task 3.2. Sustainability

When developing the game, it is essential to select hardware and software tools that meet the desired specifications for the game and its intended context of use. In addition to choosing these tools based on their alignment with the theoretical and design foundations, the inclusion of sustainability features is also proposed. General-purpose hardware devices, as well as the integration of open-source software, simplify the development of such solutions, making them more available to users. This approach not only reduces development costs but also promotes wider adoption and usability in diverse settings.

Stage 4. Validation & Dissemination

Once the game has been developed, the next step is to introduce it to the users for whom it was designed, allowing for the validation of various aspects. Following this, the results and insights can be published for the benefit of the wider scientific community.

Task 4.1. Testing

Regarding the concept of *Validity* as defined by Graafland and his colleagues, as well as the various types of validation for a health-related serious game they propose (section *Serious Games, Technology Management Challenges*), this phase of the development framework raises several considerations.

First of all, concerning the performance level of the game, the development team must focus on analysing the neurobiological markers collected, as well as the behaviour of the players. This not only enables the achievement of certain validity objectives -such as *Construct validity*- but also aids in detecting errors in the data collection process. Additionally, during the implementation of the solution, potential errors and/or improvements in its functionality may be identified. Lastly, whenever possible, the framework incorporates a comparison of the results obtained from the developed game with those derived from the use of standard, previously validated evaluation tools. This enables an assessment of its *Concurrent validity*. In parallel, incorporating usability and user experience (UX) tests into the product validation process allows for the evaluation and improvement of its interaction with users.

Task 4.2. Improvement

Once the game's testing phase has been completed, all identified aspects of its functionality and usability are improved.

Task 4.3. Dissemination

To conclude this phase, it is recommended that the research team publish the knowledge gained throughout the entire process, allowing the scientific community to benefit from it.

Stage 5. Deployment and Maintenance

Once the game has been developed and optimised, and its clinical validity has been demonstrated, it can be distributed for general use.

Task 5.1. Deployment

At this point, the development team should conduct a final quality control to ensure the absence of critical errors and, if deemed necessary, generate user manuals, installation guides, and other support documents.

Task 5.2. Maintenance

Finally, ongoing maintenance must be guaranteed to the users of the game, ensuring user support and the management of patches and/or updates as needed.

As can be seen at the bottom of Figure 5.1., the game development framework is proposed as an iterative process. This means it is a dynamic and adaptable process that allows for the continuous improvement of the game's quality, its discriminatory effectiveness, and its capacity to positively impact the health of its users.

5.2. Technological results. ENFEN App

To enable the validation of the proposed framework, a total of four serious games were developed. These video games are specifically inspired by the tests from the ENFEN battery.

As described in the *Materials* section, each of these tests evaluates specific skills of the player through various tasks, thereby assessing the performance of EFs during gameplay. In other words, they analyse the performance of neurobiological factors. Once the tests are completed, the scores are standardised, resulting in a comprehensive profile of the child's EFs developmental level. Consequently, it was decided to integrate the implementation of the four video games into a single platform, called ENFEN App. Figure 5.2. illustrates the general operational scheme proposed for the application developed using the reference framework.

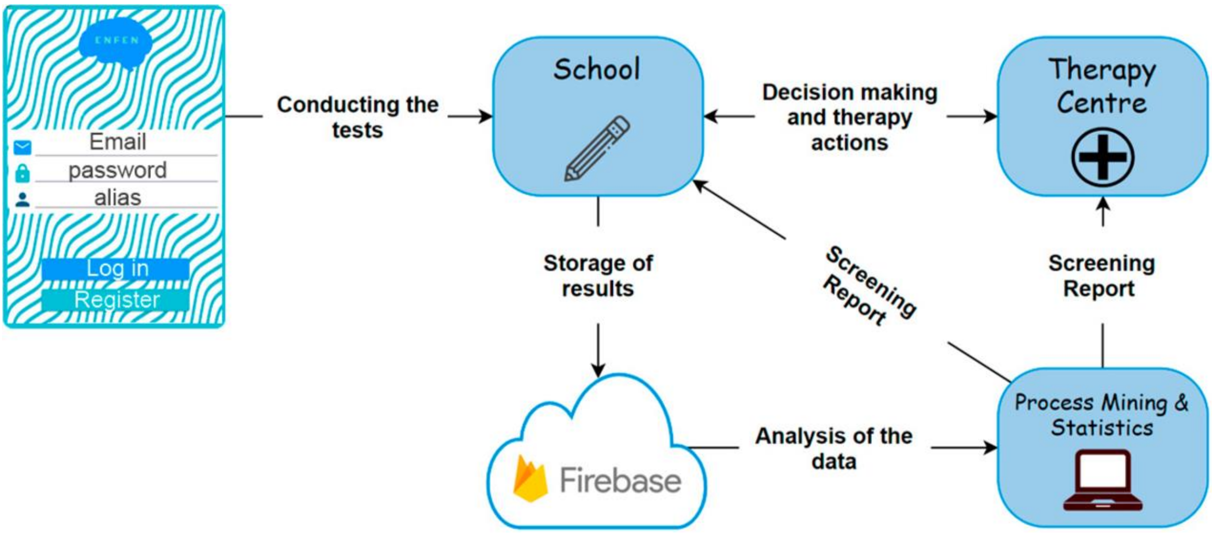


Figure 5.2. *General operating scheme of the ENFEN App.*

(Taken form Gabaldón et al. [164])

The ENFEN App is a tablet-based application developed using Kodular [165], which bases its clinical functionality on the Hogrefe TEA Ediciones test battery. Kodular is an online platform that allows users with limited experience in game development to create mobile applications for Android using a visual block-based interface. It offers a wide range of predefined components and widgets, compatibility with extensions, integration with web services and APIs, and tools for real-time testing and debugging. Kodular is aimed at developers seeking an accessible and fast way to create games. Specifically, Kodular includes a feature that enables developers to access Firebase [166] functionality for reading and writing real-time data. This feature was seamlessly integrated into the game, allowing for ubiquitous access to the data generated by a child while performing the tests in their school environment. This data can then be used for analysis or, later on, for clinical decision-making.

5.2.1. Test configuration phase

As mentioned, the application presented in this section serves as a container for games, consisting of different screens that allow the player to access and activate the various functionalities of the tool. More specifically, the navigation UI comprises essential screens that act as a bridge between the player and the main gameplay. These screens include registration and login screens, the main menu, configuration menus, and other related interfaces.

Registration and Login Screens

Figure 5.3. presents -from left to right- the login screen, the new player registration screen, and the screen for creating a new alias.

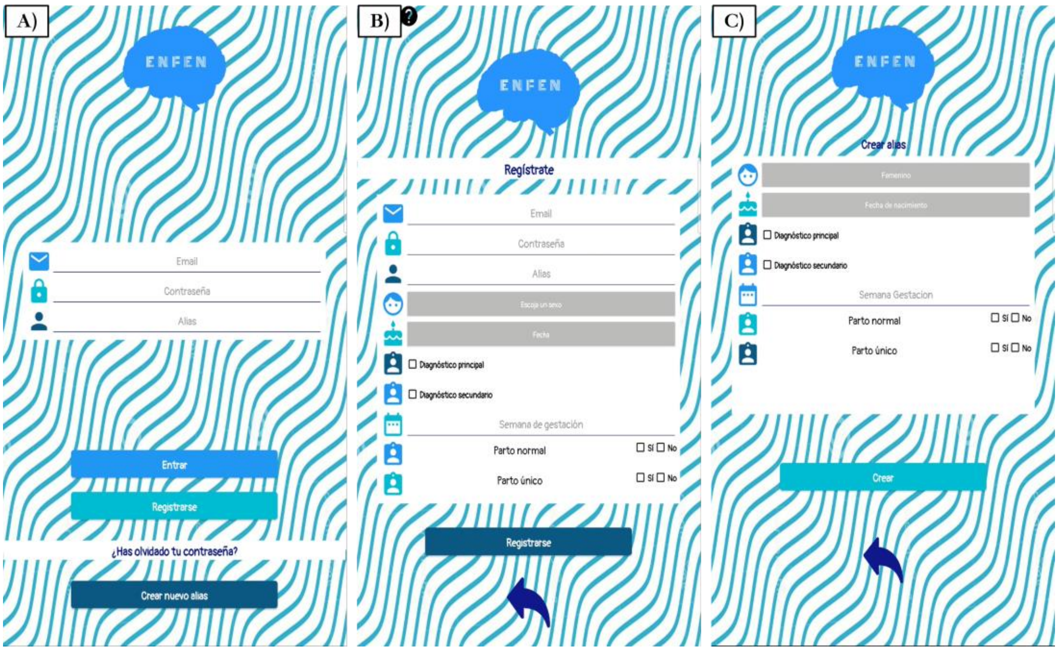


Figure 5.3. *Login, user registration and alias creations screens.*

The login screen (image A in Figure 5.3.) allows the user to access the app's content by filling out identification fields.

If the player is accessing the service for the first time, they must register in the game (image B). As shown, this screen requests information from the player for identification, communication, and clinical purposes. To ensure the accuracy of the data entered by the user, the app performs a validation check (Figure 5.4.). For instance, if a user attempts to enter a date of birth that is more than twelve years or less than six years from the system date, an error message will appear, preventing registration until the data is corrected. This functionality ensures data validity, proper registration of relevant information, and consistency with the context for which the app was developed.

Also, the app allows the registration of multiple aliases for a single user (image C in Figure 5.3.). This means that an educational institution can register once and manage all its students under one account, uniquely and independently. This not only simplifies the app's availability but also enhances user security by reducing the need to provide individual information for each user.

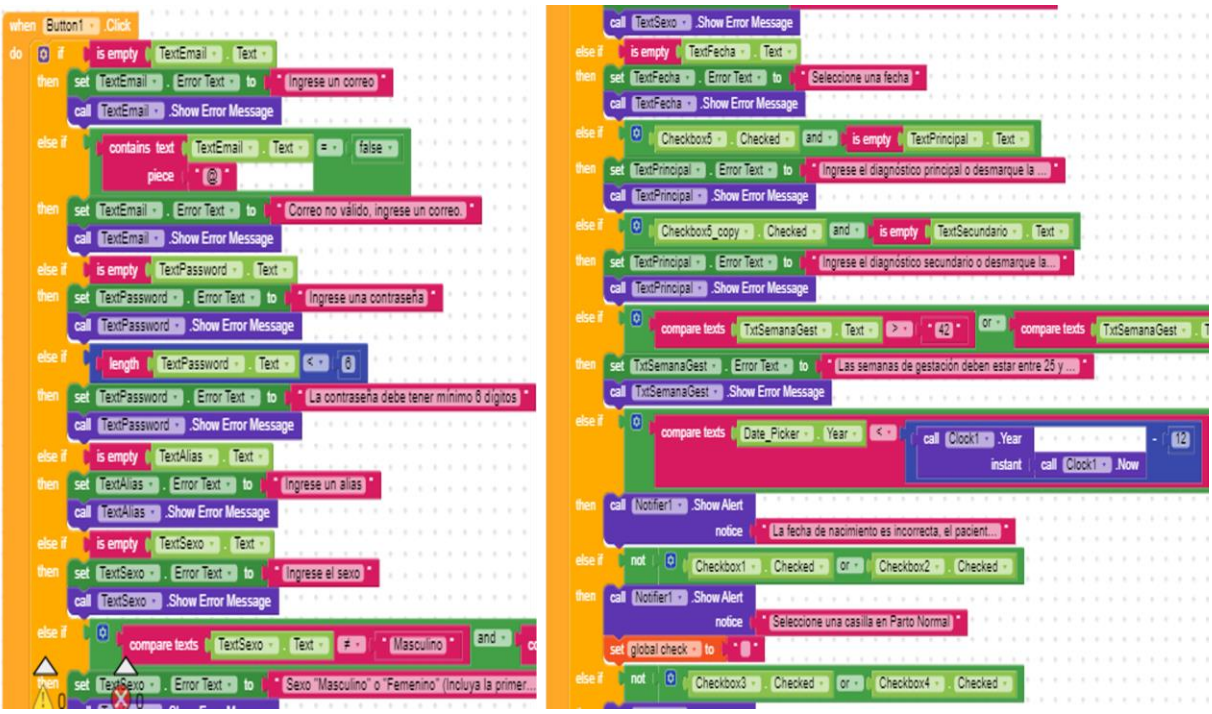


__Figure 5.4.__ Kodular blocks for user registration data validation.

Main Menu and Configuration Screens

Once the user has successfully registered, they can proceed to log in. Figure 5.5. presents -from left to right- the main game menu, the various configuration options, and the test selection menu.

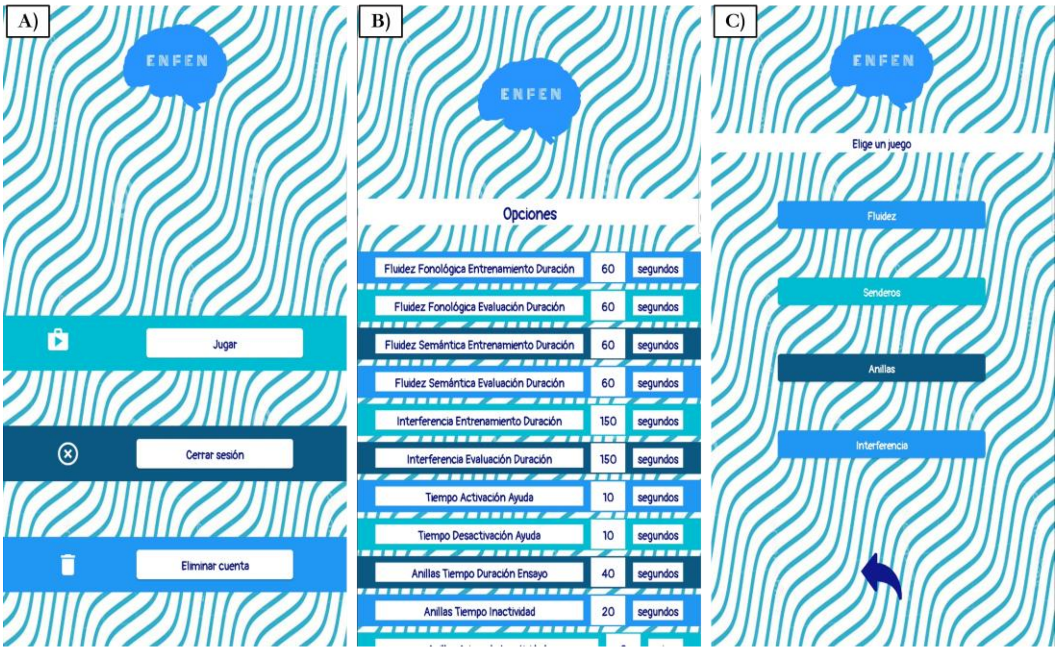


Figure 5.5. *Main many, configuration panel, and game selection screen*

The main menu (image A in Figure 5.5.) allows the user to access the tests, log out, or, if desired, delete their account, which deactivates their login credentials.

The main menu also offers access to the game configuration panel (image B in Figure 5.5.); still, this option is hidden to prevent unqualified or improperly informed individuals from modifying the default settings of the game parameters.

Due to the availability feature of the solution, the development team had to define certain parameters for the tests that were not present in their original version. One example is inactivity timing. In the original format, the healthcare professional guiding the child through the test assesses when the child becomes distracted and needs to refocus. Since the professional is not present in the app, the application itself must detect periods of inactivity and send a prompt to the player to redirect their attention back to the test.

This functionality allows the game to standardise the evaluation criteria concerning attention loss and the need for assistance, thereby eliminating a source of subjectivity present in the original test format. Moreover, this feature makes the solution more flexible, facilitating its adaptation to the original test and thereby simplifying its concurrent validation.

Finally, the game selection screen allows the player to begin the evaluation tests (image C in Figure 5.5.). At this stage, the child is expected to interact with the solution entirely independently. It is important to note that the tests must be carried out in the order they appear on the screen, as in the original version. To prevent premature access to any game, the application checks if the previous tests have been completed, and if the requirements are not met, it displays a message guiding the player on how to proceed.

5.2.2. Test execution phase

As previously mentioned, the ENFEN App bases its clinical functionality on the original ENFEN test battery. One of the most interesting aspects of this battery -from an implementation perspective- is that all the tests it comprises are presented in, or are easily adaptable to, a game format (Figure 4.4.-Figure 4.6.). This not only simplified some aspects of game development but also, according to Graafland et al.'s definition, enhanced its *content and face validity*.

However, the implementation process for each test was influenced by the hardware and software tools used. As a result, adjustments had to be made to each test, both graphically and in terms of specifications, to achieve the highest possible level of similarity to the appearance and mechanics of the original tests.

Additionally, each game incorporated elements that enabled the fulfilment of the objectivity, availability, and behavioural analysis requirements set by the framework.

Below, the implementation process and key features for each of the four tests included in the app are outlined.

Fluidez Test. Fluidez Fonológica y Semántica

Figures Figure 5.7. y Figure 5.7. present, from left to right, the instruction screen and the game screen corresponding to the Fluidez Fonológica and Fluidez Semántica tests, respectively.

As shown (image A in Figure 5.7. and Figure 5.7), when the player decides to start the test, the application provides instructions visually on the screen and simultaneously delivers them audibly through narration. This feature facilitates the comprehension process for players, particularly for younger children who may not yet fully master reading comprehension.

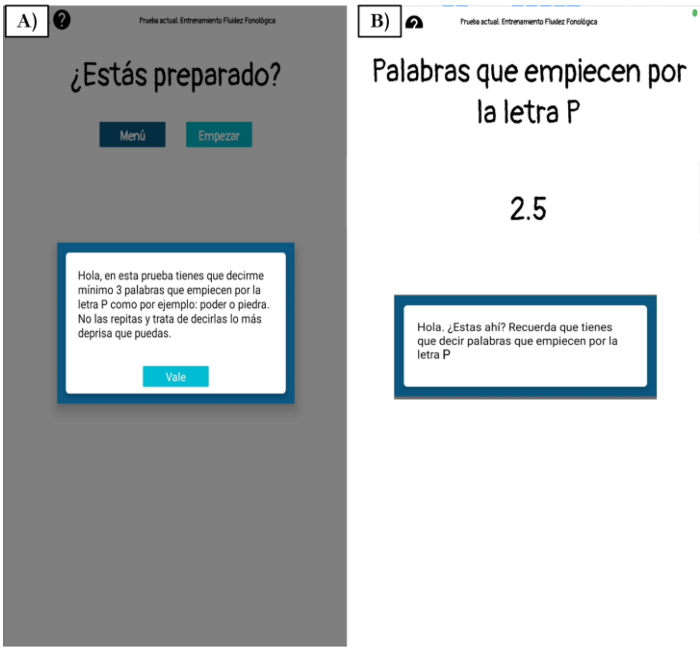


Figure 5.6. *Fluidez fonológica. Instructions and game screen (with help window).*

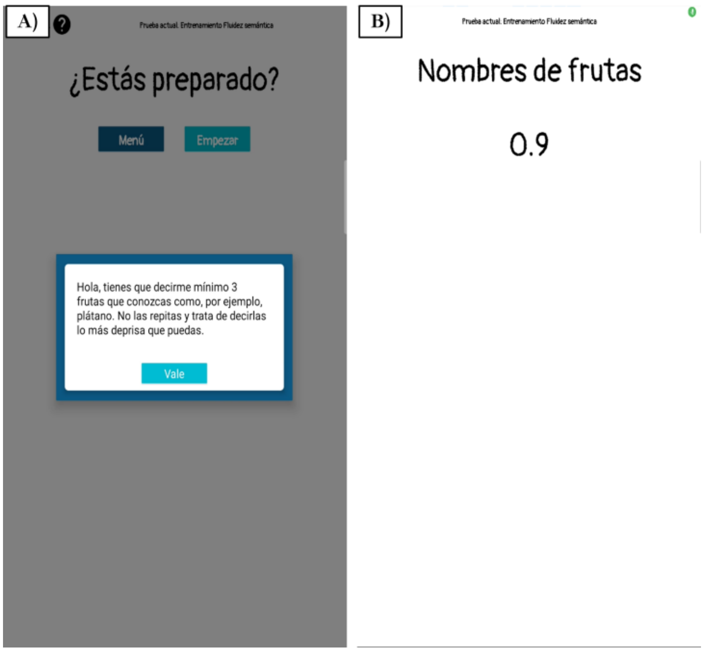


Figure 5.7. *Fluidez semántica. Instructions and game screen.*

Once the user feels they have understood the task, they press the *"Vale"* button, and the game begins (imagen B de Figure 5.7. y Figure 5.7). The application activates the device's microphone -with pre-granted permission-, recording the various words that the player enumerates according to the given instructions. Simultaneously, alongside storing the words spoken by the player, the application activates two timers to track:

1. The *total time elapsed during the test*. This allows for the detection of inactivity periods, determined by the *inactivity_time* parameter, and stops the test when the time limit set by the *duration_time* configuration parameter is reached.
2. The *time interval between consecutive words*. Storing the time elapsed from the start of the test to the first spoken word, as well as the interval between two consecutively spoken words, allows for the evaluation and detection of impulsivity patterns in the player.

If necessary, the configuration parameters *duration_time* and *inactivity_time* can be modified by the user in the settings screen shown in Figure 5.5.

Senderos Test. Sendero Gris y Sendero de Color

Once the user has completed the Fluidez test, they are redirected to the game selection menu. As the total duration of all tests is estimated to be around thirty minutes, this functionality allows the player, if they so wish or need, to take a break after completing each test. As in the previous case, once the player starts the Senderos test, the application displays and narrates the instructions for the current game (Figure 5.8.- Figure 5.9.).

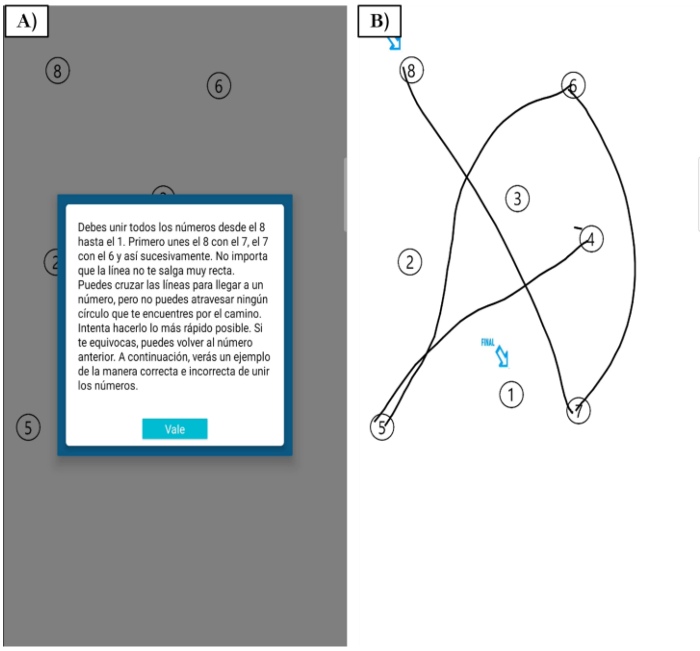


Figure 5.8. *Instructions and game screen for Sendero Gris.*

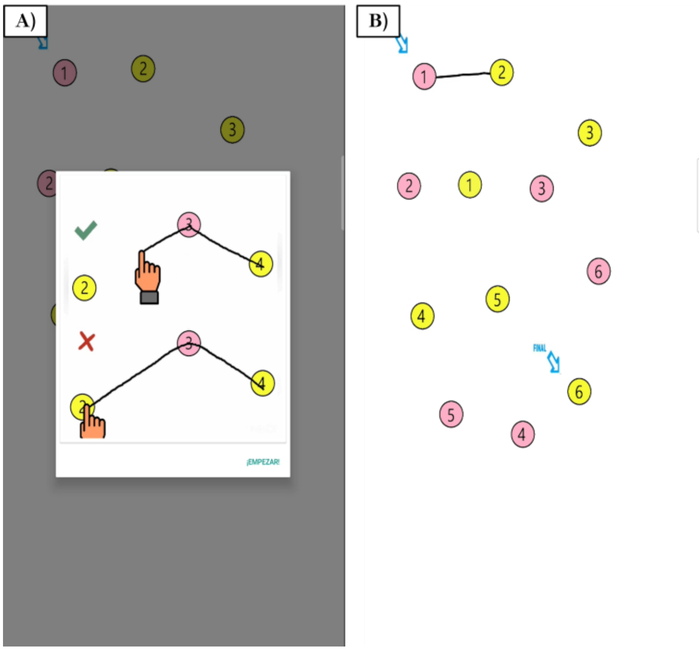


Figure 5.9. GIF and game screen for Sendero de Color.

Despite the apparent simplicity of this test, there are several fundamental aspects of its implementation that must not be overlooked (Figure 5.10.).

Screen	Problem description	Date	Status
Training-Evaluation	Evalutaion trial must start immediatly after training trial (Image)	19/07/2022	Implemented (Review)
Training	Must record the time from when the child presses the start buttom and touches tl	20/07/2022	Not started
	Must record the times between the joining of the nodes (Image)	19/07/2022	Not started
	Must record the total time taken to complete the test (Image)	19/07/2022	Implemented (Review)
	Must record a single trace per player	19/07/2022	Not started
	When the child reaches node 1 the game dos not end directly, but they have to p	19/07/2022	Poorly implemented (review)
Evaluation	Must record the time form when the child presses the start buttom and touches tl	19/07/2022	Not started
	Must record the times between the joining of the nodes (Image)	19/07/2022	Not started
	Must record the total time taken to complete the test (Image)	19/07/2022	Implemented (Review)
	Must record a single trace per player	19/07/2022	Poorly implemented (review)
Score	Redefine the calculation of the parameters	19/07/2022	Not started
JSON	JSON structure (Neurobiological markers and behaviours)	19/07/2022	Not started
General implementation	Should not count when the player passes over a node on the path between two nc	19/07/2022	Not started
	Be careful with node 1!! If touched "by accident" the game should not end	19/07/2022	Not started
	Repeated traces because the child does not like it, how can we discount it?	19/07/2022	Not started
	Save the final picture of the graph drawn by the child	19/07/2022	Poorly implemented (review)
	Would it be possible to record it on video?	19/07/2022	Not started

Figure 5.10. Tasks identified for the proper digitalisation of Senderos Test.

In the original format of the tests, while connecting two consecutive nodes, the player can pass over any other intermediate node without it affecting their final score. In this case, it is the healthcare professional overseeing the test who determines whether the player is "just passing through" the node or if it was an intentional connection.

For the digitalised version of the test, the game must determine whether a node was intentionally selected by the player or if they were merely passing over it. To differentiate the player's intent, a new rule was introduced in this test (image A in Figure 5.9.). Through an explanatory GIF, the application informs the player that in order for two nodes to be considered connected, they must lift their finger from the screen upon reaching the target node.

Regarding the behavioural analysis of the individual, once the test begins, the application initialises two timers (Figure 5.11.):

1. The *total time elapsed* during the test. As in the previous test, this timer allows the application to detect periods of inactivity in the player and display help messages if deemed necessary.
2. The *time interval between the connection of two nodes*. The time taken from when a child selects an origin node until they finally connect it to a target node is recorded for all connections made by the player.

As with the previous test, the storage of this information, along with the ordered sequence of nodes selected by the player, enables the analysis of behavioural patterns associated with the presence of ADHD.

Lastly, to facilitate the review of the test, at the end of each Senderos test, the application takes a screenshot that reflects the player's actions during the test.

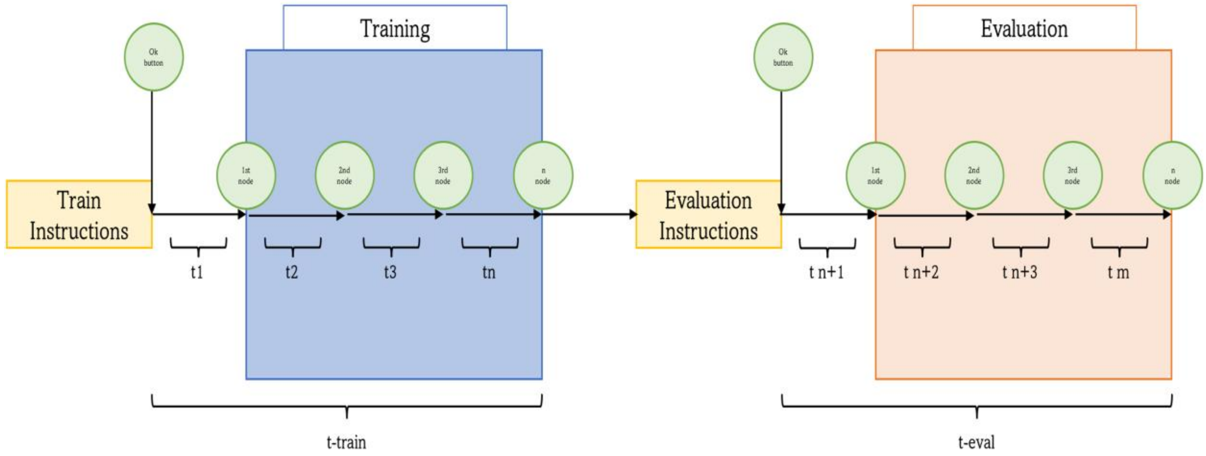


Figure 5.11. *Structure of the time data collected for the Senderos test (Image referred to in Figure 5.10.).*

A more detailed report on the implementation process of the Senderos test can be found in the work carried out by the author in [164].

Anillas Test

The digitalisation of the Anillas test is shown in Figure 5.12. As with the Senderos test, despite the apparent graphical simplicity of the test, its implementation required the definition of new parameters to adjust the original game mechanics.

As seen in the referenced image, the final required position for the rings is displayed to the player in the top right corner of the game screen. To enhance the game's accessibility, a feature was added allowing this reference image to be enlarged. If a player is unable to clearly see the required final position, they simply need to tap the image, which will then expand to fill the entire screen.

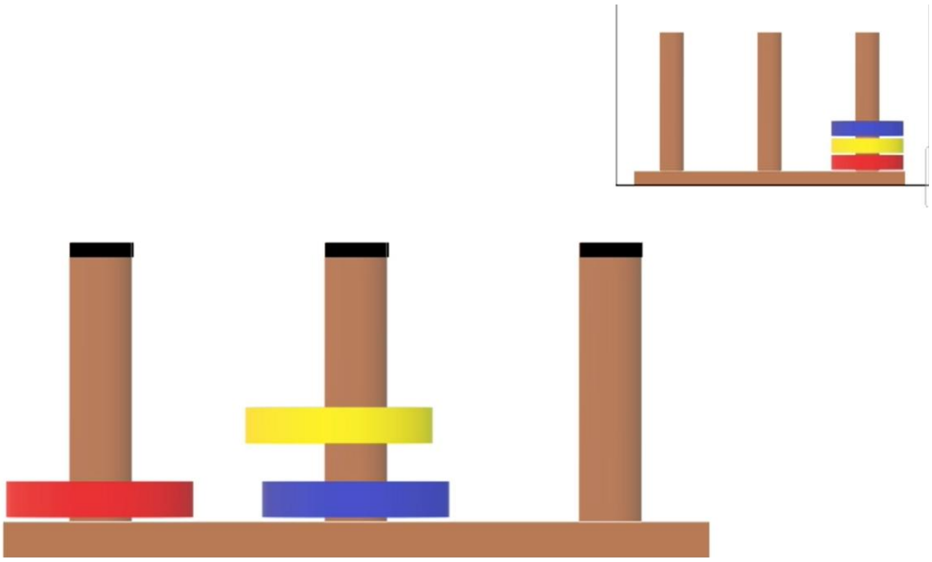


Figure 5.12. *Training trial for the Anillas test.*

Similar to the Senderos test, the definition of the area for the pegs and the rings required careful consideration by the development team. Various aspects needed to be determined to specify the point at which the game would recognise that a child has intentionally placed a ring on a peg, or alternatively, if it was an unintentional movement.

In relation to the behavioural analysis requirement set by the framework, and following a structure similar to that presented in Figure 5.11., timers were defined to measure:

1. The *total time elapsed* during the test up to that point.
2. The *time interval between the completion of one movement and the start of the next*. This refers to the time elapsed from when a child places a ring in the desired position until they decide to initiate a new movement.
3. The *time taken to perform a complete movement*. This refers to the time elapsed from when the player selects the desired ring until they place it in its final position.

By defining these time intervals, the test is able to detect periods of inactivity, during which the player's attention may need to be refocused on the task. The test can also terminate entirely if no further interaction is detected.

Interferencia Test

Lastly, the Interference test follows a very similar programming structure to the Fluidez test (Figure 5.13.).

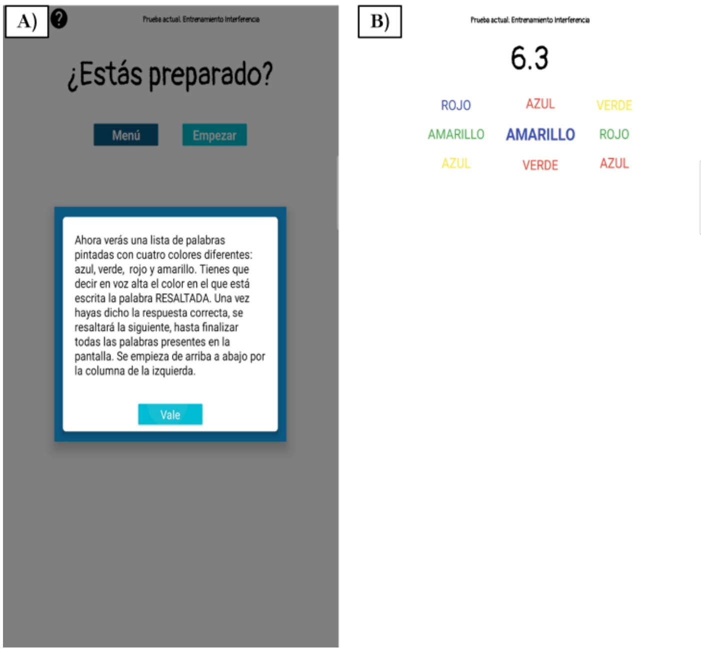


Figure 5.13. *Instructions and game screen for the Interferencia test.*

Once the test begins, the player must say aloud the colour in which each word displayed on the screen is written. Internally, the application uses a reference vector to check whether the word spoken by the player is correct. If correct, the application highlights the next colour to be named. If incorrect, the game keeps the current word highlighted until the player correctly verbalises it.

As with the other tests, in addition to collecting the original test parameters, the application records the time taken from the start to the end of the test, as well as the time required by the player to correctly name each colour.

Once this test is completed, the player has finished the game and is redirected to the main menu screen.

5.2.3. Information storage

When the user interacts with the solution, all information collected by it -personal data, neurobiological factors, etc.- is sent to a database in Firebase Realtime Database (Figure 5.2.). Access to this database is restricted, allowing only a few members of the research team to access it.

In a JSON file, for each user registered in the application, a property is generated, within which all the different aliases that the player has created in their profile are stored (image A of Figure 5.14.). Furthermore, for each alias, keys are defined relating to their personal data -which may not necessarily coincide with the user's actual data- and each of the tests they have completed (image B). As shown in image C), the user data contains all the information entered by the player in the game's registration screen. If a player has not filled in one of the fields on this screen, the corresponding key will not be generated in the JSON file.

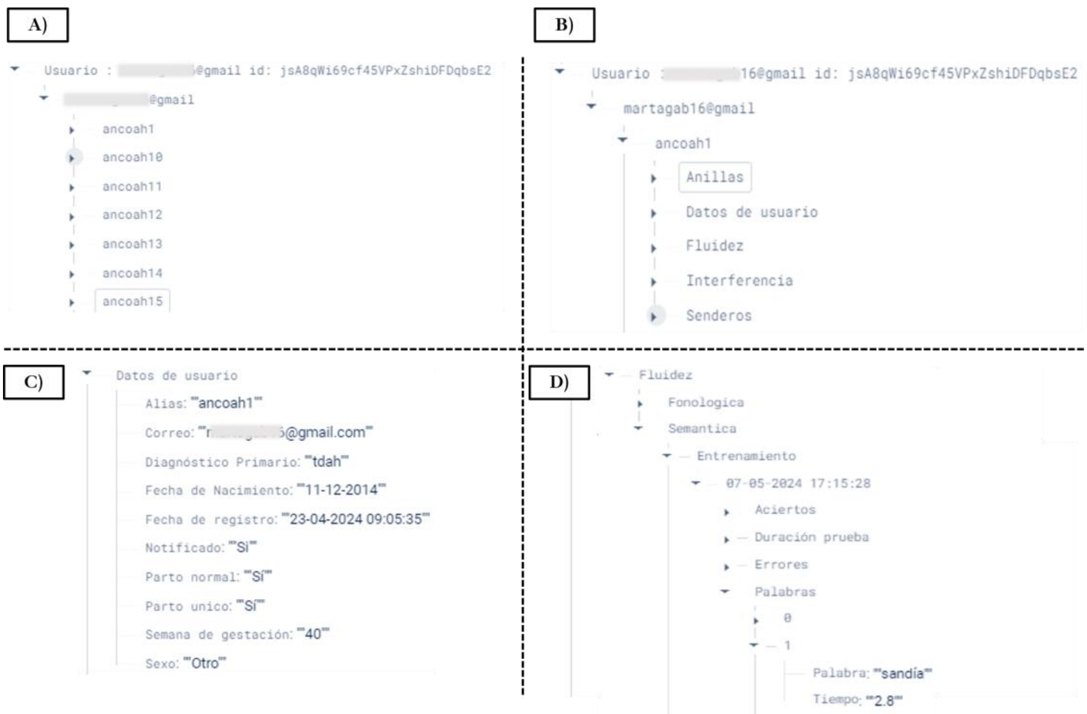


Figure 5.14. *JSON file generated after the execution of tests in the ENFEN App.*

In relation to the execution of the tests, the game generates a property for each one, within which all the defined parameters of interest are stored. For example, image D) of Figure 5.14. shows the data storage schema for the information collected during a player's execution of the Fluidez Semántica training test. From this image, it can be deduced that the player started the test on 7th May 2024 and that they said the word "Sandia" as their second word, 2.8 seconds after stating the first.

5.3. Experimental results

5.3.1. Trial I. Sendero Gris

Hypothesis and Experimental Protocol

Among all the tests currently integrated into the ENFEN App, the Sendero Gris test was the first to be fully digitalised. In 2023, the author conducted an initial study, the primary objective of which was to perform a comparative analysis of the screening power of the Sendero Gris test in its two existing formats: paper and digital [164]. Specifically, the hypothesis tested in this study was stated as: *"There is no statistically significant difference between the results obtained from the Sendero Gris test in its different available formats*". Therefore, **if the hypothesis were accepted, it could be assumed that the generated serious game has the same screening capacity as the original test, while offering greater ubiquity and objectivity.**

To test the validity of the formulated hypothesis, a Repeated Measures experiment with random assignment [167], was designed, in which each child within the same group was required to complete the test in both formats. For the paper-based version, a healthcare professional was present to guide the child through the task, supervise the test, record the various parameters of interest, and calculate the final score. In the case of the digital version, the player was provided with a tablet device with the application installed. No additional explanation regarding the procedure or task was given to the child, allowing them to interact with the tool entirely independently.

Sample Summary

For this study, a total of 28 children participated (12 girls and 16 boys), aged between 6 and 12 years (mean age 9.21, SD 2.01) (Table 5.1.).

Table 5.1. *Number of children by age and sex (trial 1).*

Age (Years)								
	6	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
Female	2	2	1	1	3	1	2	12
Male	1	3	1	3	2	4	2	16
Total	3	5	2	4	5	5	4	28

Table 5.2. shows the distribution of participants by sex and whether they have an ADHD diagnosis. Among the girls, 33.33% have a current diagnosis of ADHD. In the case of the boys, 62.5% of the sample have a previous diagnosis of ADHD.

Table 5.2. *Number of children according to ADHD diagnosis and sex (trial 1).*

ADHD Diagnosis			
	Yes	**No**	**Total**
Female	4	8	12
Male	10	6	16
Total	14	14	28

Statistical Method

For the analysis of the results obtained, and in order to test the previously formulated hypothesis, two different statistical analyses were conducted. Firstly, a statistical comparison based on the averages of each parameter of interest collected during the test was performed. Secondly, to evaluate the statistical significance of the difference between the mean scores obtained in each format of the test, the non-parametric Wilcoxon signed-rank test was employed [168]. This test allows for comparing the locations of two populations in paired samples with small sample sizes (at least sixteen individuals).

Obtained Results

Neurobiological Factors

For the comparison between the two available formats, an analysis was conducted on the defined measurement parameters of interest achieved by each child during their evaluation. It is important to note that, due to issues in the data collection process, the analysis was based on the results of 24 children from the original 28.

In the case of the paper version of the Sendero Gris test, Table 5.3. shows small differences between the scores obtained by the players, depending on whether they have an ADHD diagnosis or not. For example, children with a diagnosis, with an average of 18.69 correct answers, are only 0.22 points behind those without a diagnosis. Similarly, for the time required to complete the test, there is a difference of approximately 5 seconds between the two groups.

Table 5.3. *Marks for the paper-based Sendero Gris test.*

	Hits Avg.	**Substitutions Avg.**	**Omissions Avg.**	**Time Spent Avg. (s)**	**Final Score Avg. (s)**
ADHD	18.69	0.23	0.38	92.69	19.50
No ADHD	18.91	0.08	0.25	87.83	21.15

In the case of the test on tablet devices, Table 5.4. shows greater discrepancies between the scores obtained by the different groups of players. The group of players without a diagnosis achieved an average of 18.75 correct answers -similar to the paper version- while the group of players diagnosed with ADHD saw their average decrease to 16.84 correct answers. Additionally, the difference in the time required to complete the test between the two groups is 8 seconds.

Table 5.4. *Marks for the Tablet-based Sendero Gris test*

	Hits Avg.	Substitutions Avg.	Omissions Avg.	Time Spent Avg. (s)	Final Score Avg. (s)
ADHD	16.84	2	0	108.76	13.64
No ADHD	18.75	0.17	0.08	100.83	18.34

Subsequently, the scores obtained by each player in the two versions of the test were analysed (Figure 5.15. and Figure 5.16.). Notably, in the case of Id_2 from the group with an ADHD diagnosis in the digital version of the test (Figure 5.16.), a negative score was recorded. As can be observed, this participant connected the nodes in ascending order (from 1 to 20), contrary to the instructions provided by the tablet. When reviewing the paper version of the test, it was impossible to determine whether the child performed the test correctly or, due to human error, completed the test in ascending order without it being accurately recorded. Regardless, the presence of this score significantly lowers the group's average correct answers, thereby increasing the difference between the diagnosed group and the non-diagnosed group.

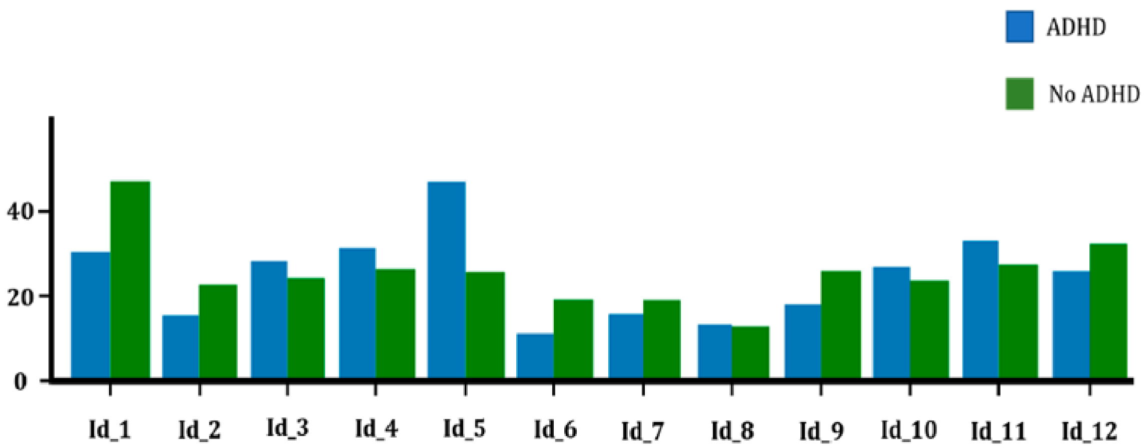


Figure 5.15. *Final scores for the paper-based test.*

(Taken from Gabaldón et al. [164]*)*

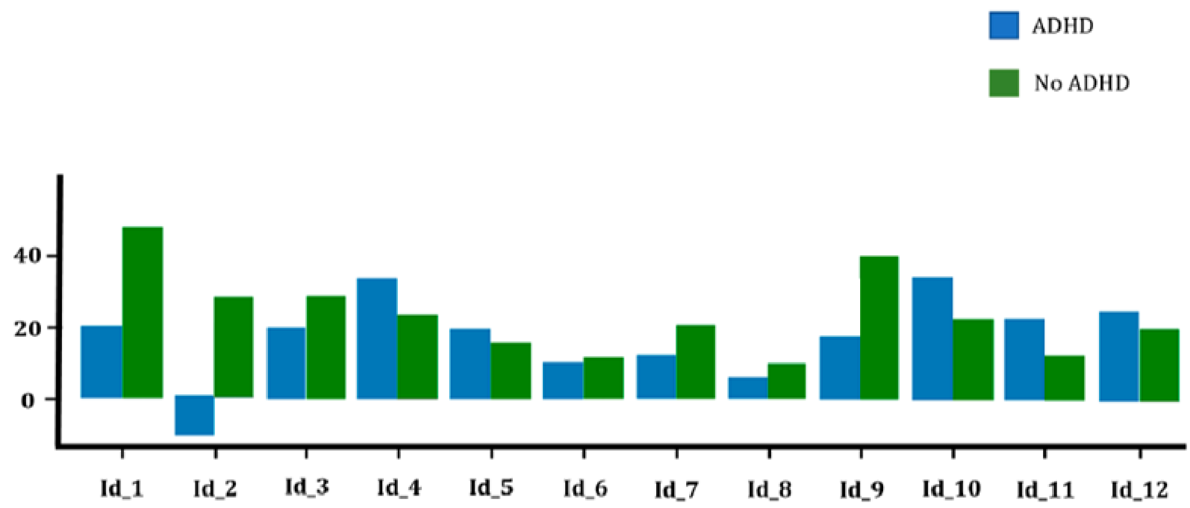


Figure 5.16. *Final scores for the tablet-based test.*

(Taken from Gabaldón et al. [164]*)*

Lastly, to compare the discriminative power of the test in its two available formats, the Wilcoxon W statistic was calculated. With a value of W = 219 (p = 0.49; alpha = 0.10) and a confidence level of 90%, **there is no statistical evidence to reject the hypothesis of equal results between the two tests.**

User Experience

Regarding the UX, participants were given a questionnaire consisting of six statements. Using a scale from 1 ("strongly disagree") to 5 ("strongly agree"), the children were asked to rate their intention to use the test on tablet devices and the difficulties they encountered during its use. The results obtained are presented in Figure 5.17.

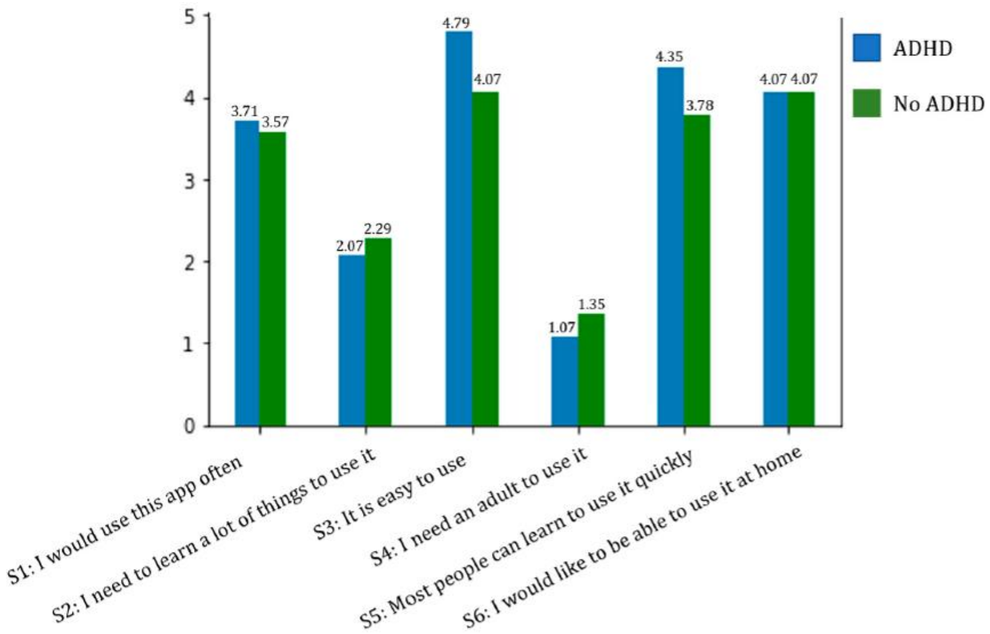


Figure 5.17. *Results obtained for the UX test and distributed according to whether the child had a diagnosis of ADHD.*

(Taken form Gabaldón et al. [164]*)*

Regarding statements S1 and S6, which assess the intention to use the developed system, both groups showed average scores above 3.5, with maximum values of 3.71 and 4.07, respectively. For S2 to S5, both groups exhibited very similar average scores, with the most notable differences relating to the perceived difficulty of the game. Specifically, for the group of children diagnosed with ADHD, the game was found to be easier, indicating a reduced need for adult supervision.

5.3.2. Trial 2. ENFEN App

Based on the results achieved in the previous experiment, the potential of the proposed solution as a screening tool for ADHD, offering greater ubiquity and objectivity, was recognised. Similarly, introducing the solution to the target audience helped identify a series of errors in the game's functionality, as well as aspects that needed optimisation and revision. For instance, the lack of results related to player behaviour was highlighted, which stemmed from errors in the process of collecting relevant informational parameters.

As a result of the aforementioned findings, and in accordance with the defined framework, the remaining tests from the ENFEN battery were digitalised and incorporated into a single game container. Additionally, the implementation of the Sendero Gris test was optimised.

Hypothesis and Experimental Protocol

For this second test, the hypothesis remains the same as in the previous case, but is generalised to cover all the tests included in the ENFEN App. The hypothesis to be tested in this case supports the claim that: *"There is no statistically significant difference between the results obtained from the ENFEN tests in their two available formats"*. **If the hypothesis is accepted, it can be assumed that the serious games generated using the proposed framework have the same screening capability as the original tests, but with greater ubiquity and objectivity.**

Regarding the experimental protocol, the same approach was followed as in the first experiment. A group of children completed the tests in both formats, with a time gap between the two, and the order in which each format was administered was assigned randomly. As in the previous case, each version of the ENFEN tests was conducted under the appropriate conditions: for the paper format, healthcare professionals were present to guide the tests, whereas in the digital format, the children were allowed to interact freely with the tool, without any external guidance.

Sample Summary

For this second experiment, a group of 31 children participated (16 girls and 15 boys), aged between 6 and 12 years (mean age 9.56, SD 0.85) (Table 5.5.).

Table 5.5. *Number of children by age and sex (trial 2).*

	Age (Years)							
	6	**7**	**8**	**9**	**10**	**11**	**12**	**Total**
Female	0	1	2	3	3	4	2	16
Male	2	1	3	1	3	3	2	15
Total	2	2	5	4	7	7	4	31

Regarding the presence of an ADHD diagnosis in the sample, 31.25% of the girls participating in the study had a previous diagnosis of the disorder, while in the group of boys, this figure was 46.66% (Table 5.6.). Thus, the sample of participants with a previous ADHD diagnosis represents 38.71% of the total sample. Additionally, only 3 of the participants diagnosed with ADHD had comorbid disorders, including Dyslexia and Conduct Disorder (CD).

Table 5.6. *Number of children according to ADHD diagnosis and sex (trial 2).*

	ADHD Diagnosis		
	Yes	**No**	**Total**
Female	5	11	16
Male	7	8	15
Total	12	19	31

Statistical Method

To test the hypothesis formulated for this experiment, a three-phase statistical analysis was conducted:

1. *Descriptive analysis*. For each of the four games that make up the ENFEN battery, descriptive statistics were calculated for the results obtained by the players in each of the available formats, categorised by whether the user had a prior ADHD diagnosis.
2. *Normality Tests*. To select the appropriate statistic for comparing the results obtained in the two formats, tests were conducted to assess whether the sample distribution conformed to normality. Specifically, the Shapiro-Wilk test was applied.
3. *Difference of Means*. Based on the result of the previous test, the corresponding statistic was calculated to determine whether the observed differences between the two formats were statistically significant.

Obtained Results

Neurobiological factors

Table 5.7. presents the mean scores and corresponding standard deviation for each format of each test, categorised by whether the player has a prior ADHD diagnosis or not.

Table 5.7. *Average and standard deviation of scores for each test by ADHD diagnosis presence.*

		ADHD Diagnosis	
Test	**Format**	**Yes**	**No**
Fluidez fonológica	Paper	8.5 (5.95)	8 (3.53)
	Tablet	10.33 (4.44)	8.31 (3.64)
Fluidez semántica	Paper	18.25 (3.74)	13.94 (5.08)
	Tablet	18 (6.62)	16.05 (6.66)
Sendero gris	Paper	23.05 (11.18)	25.35 (11.02)
	Tablet	21.80 (21.09)	14.02 (8.86)
Sendero de color	Paper	12.08 (4.66)	14.79 (8.23)
	Tablet	11.92 (9.10)	12.04 (6.90)
Anillas	Paper	168 (39.01)	200.11 (87.42)
	Tablet	464.5 (172.82)	447.16 (134.57)
Interferencia	Paper	73.28 (23.66)	79.29 (31.46)
	Tablet	66.70 (30.32)	70.62 (22.14)

As can be observed in the previous table, in general, the mean scores obtained by players in both versions of the tests appear similar at first glance, with the exception of the Anillas test. In this case, there is a noticeable increase in the score in the digital format, which is double the results obtained in the paper-based version of the same test.

With the aim of verifying whether the differences observed in the previous table are statistically significant, the Shapiro-Wilk test statistic was obtained for each of the two user groups that comprise the total sample. In this case, for both groups, the normality hypothesis was accepted and, consequently, the Student's t-test for paired samples was calculated (Table 5.8.).

Table 5.8. *Hypothesis testing for H_0 using Student's t-test between the two available formats for ENFEN.*

Test	t-test value	p-value	H_0 (Alpha = 0.05)	H_0 (Alpha = 0.01)
Fluidez fonológica	-1.15	0.25	Accept	Accept
Fluidez Semántica	-1.05	0.30	Accept	Accept
Sendero Gris	2.46	0.02	Reject	Accept
Sendero de Color	1.63	0.11	Accept	Accept
Anillas	-11	4.91E-12	Reject	Reject
Interferencia	2.70	0.01	Reject	Accept

Student's t-test contrasts, in this case, the hypothesis H_0: *There is no statistical difference between the means obtained by the players in the two available formats for each test*. Thus, with a 95% confidence level (alpha = 0.05), it can be concluded that, in the case of Fluidez fonológica, Fluidez semática, and Sendero de color, there is no statistically significant evidence to reject the null hypothesis. Adjusting the confidence level of the calculated statistic to a 99% probability of committing a Type I error (alpha = 0.01), it can be concluded that five of the six implemented tests exhibit the same discriminatory power as their paper-based versions.

For those tests where the null hypothesis was rejected at a significance level of alpha = 0.05, the players' behaviour was evaluated individually across the different formats. In the case of the Sendero gris test, it can be observed in Figure 5.18. that, in the digital version, negative scores were recorded for a total of five users. In all instances, this score was due to completing the test in the reverse order from what is prescribed by the guidelines. As occurred in Trial I, given the lack of a record of the execution direction in the paper format, it is impossible to determine whether the player repeated the same pattern across both tests and this was a human error, or if, conversely, the player correctly executed the test in its paper version.

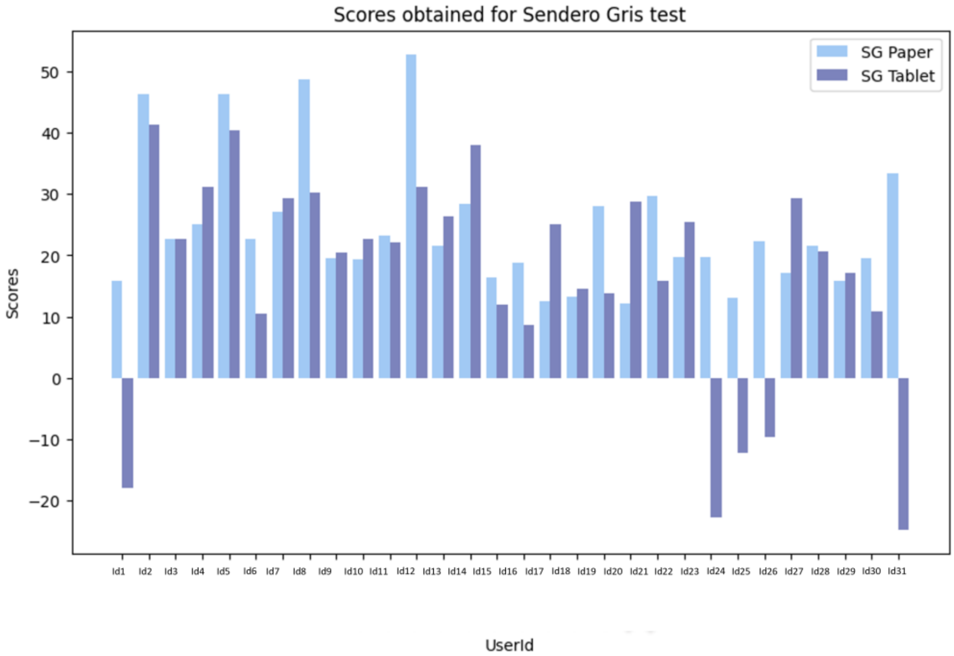


Figure 5.18. *Scores obtained by each player in the two formats of Sendero Gris test.*

For the Anillas and Interferencia tests, Figure 5.19. presents the players' scores in the two available formats for each test. In the case of the Anillas test, it is evident that, for all players, the time required to complete the test in the digital format is significantly longer than that demanded for the paper version. This suggests a possible error in the calibration of the test parameters. Lastly, in the case of the Interferencia test, no clear pattern was immediately apparent that could explain the difference between the formats.

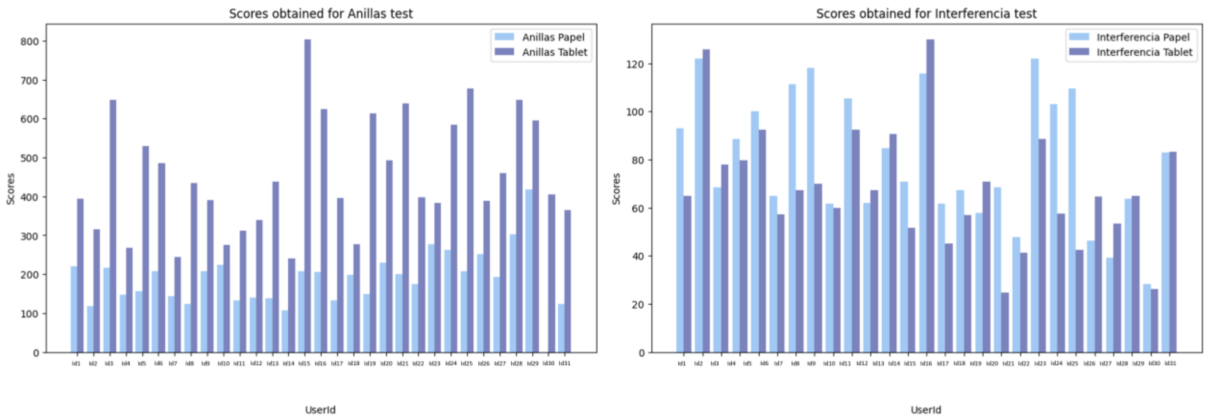
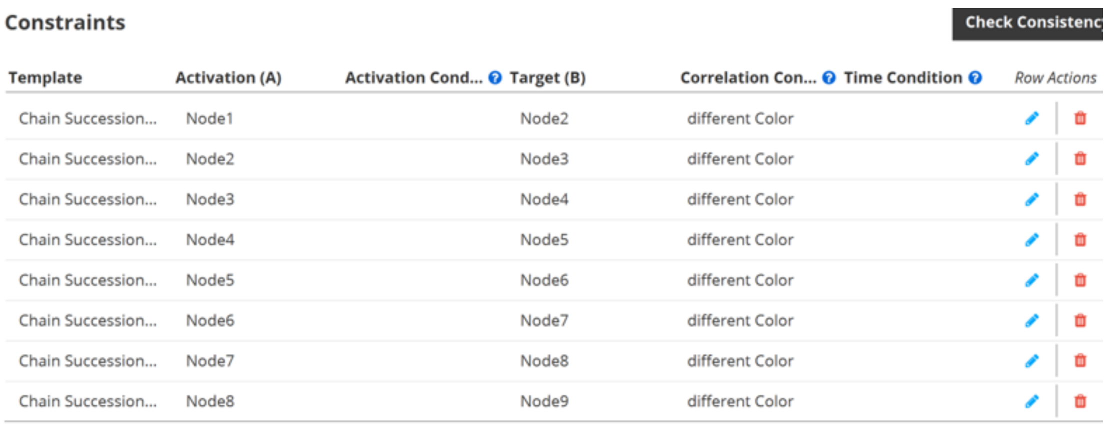


Figure 5.19. *Scores obtained by the players of the Anillas and Interferencia tests.*

Clinically Significant Events: Exploratory Assessment

In relation to the study of the behaviours of interest defined during the conceptualisation phase of the game, this subsection refers, by way of example, to the analysis of users' behaviour during their execution of the Sendero de color test.

As initial step, a Conformance Checking [169] was carried out to compare the behaviour recorded in the game's event logs with the optimal behaviour. For this purpose, the process model for the test in question was first defined, establishing the necessary constraints based on the parameters of interest (Figure 5.20., Figure 5.21.).



Constraints | Check Consistenc

Template	Activation (A)	Activation Cond...	Target (B)	Correlation Con...	Time Condition	Row Actions
Chain Succession...	Node1		Node2	different Color		
Chain Succession...	Node2		Node3	different Color		
Chain Succession...	Node3		Node4	different Color		
Chain Succession...	Node4		Node5	different Color		
Chain Succession...	Node5		Node6	different Color		
Chain Succession...	Node6		Node7	different Color		
Chain Succession...	Node7		Node8	different Color		
Chain Succession...	Node8		Node9	different Color		

Figure 5.20. *Definition of the process model for the Sendero de color test.*

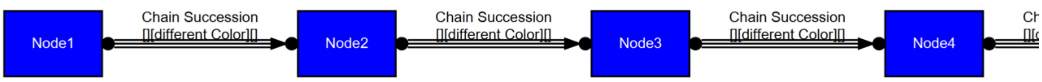


Figure 5.21. *Graphical representation of the process model for the Sendero de color test.*

Once the reference model was defined, each trace was assessed for its level of conformity to the theoretical model, and general statistics regarding this conformity were obtained (Figure 5.22.). More specifically, as shown in Figure 5.23., it was possible to evaluate the sequence of connections made by each user, as well as the categorisation of each of these connections.

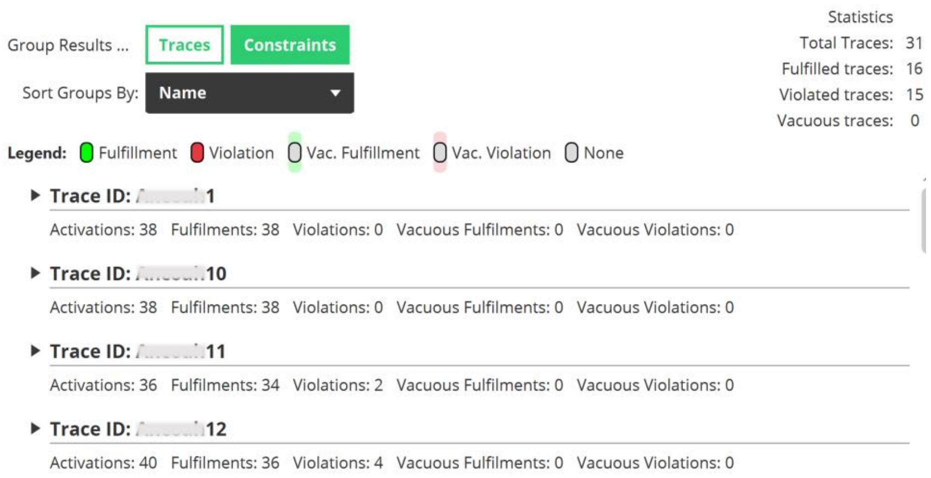


Figure 5.22. *Conformance checking by trace.*

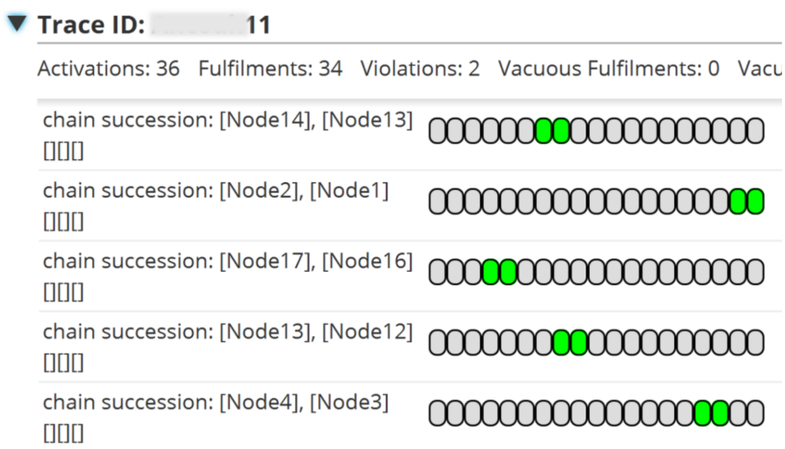


Figure 5.23. *Detailed assessment of violations committed by a specific user.*

Additionally, the information obtained through the execution of Conformance Checking was supplemented with the application of Discovery-type PM algorithms, with the aim of analysing the actual behaviour of players based on their event logs. For instance, Figure 5.24. reports that 96.8% of all players begin the game at the node numbered 1, which is coloured pink, and that all of these players subsequently move towards node 2, which is coloured yellow, as the next step.

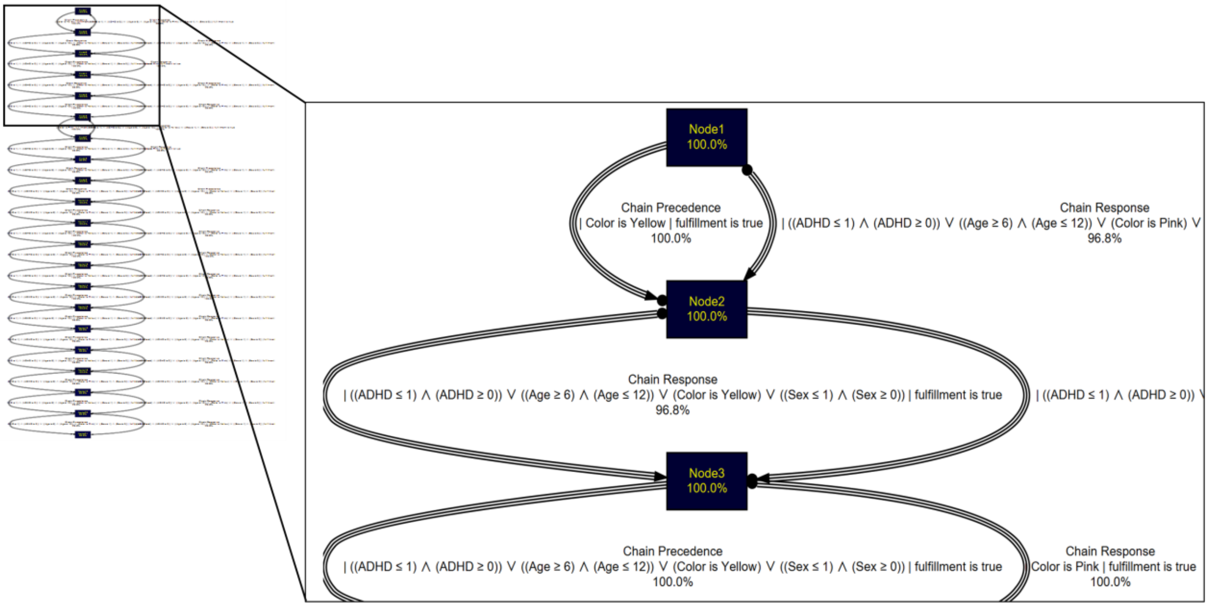


Figure 5.24. *Application of Discovery PM algorithms to the event log of the Sendero de color test.*

Another more interpretative way to visualise the information contained in the previous image is presented in Figure 5.25. This figure displays each of the event sequences recorded in the log, along with their frequency of occurrence. Specifically, the first event sequence shown in the image is executed by a total of 21 players (67.74%); the remaining event sequences in the log represent *less frequent behaviours*, which warrant more thorough review.

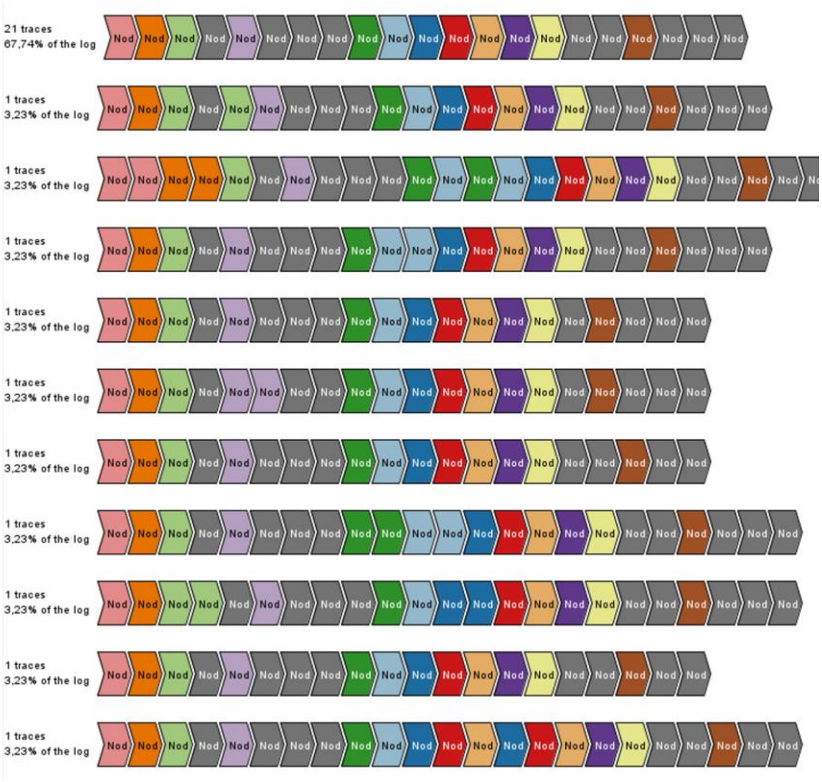


Figure 5.25. *Frequency of occurrence for each trace present in the event log.*

Furthermore, the aforementioned information was filtered according to the diagnostic group to which the players belonged (Figure 5.26., Figure 5.27.). From these images, it can be observed that the group of diagnosed children exhibits more varied behaviour, presenting a greater number of possible sequences than the control group, and consequently, a higher number of errors in the test execution.

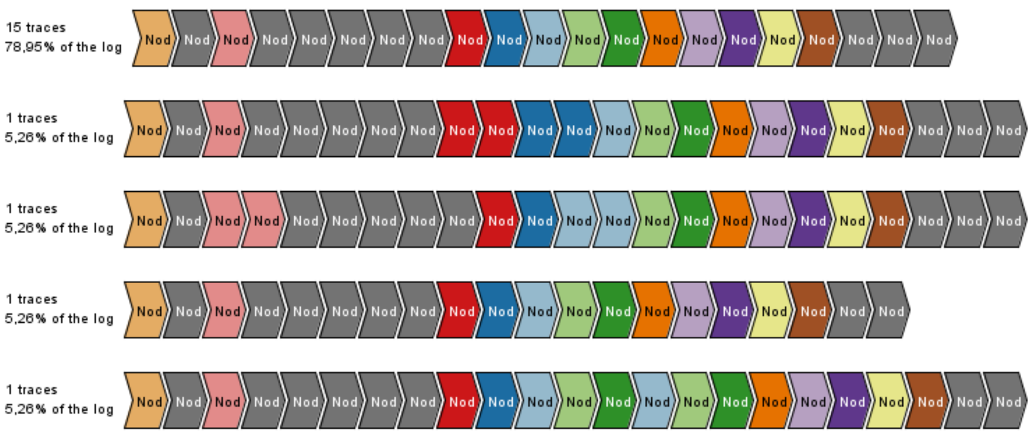


Figure 5.26. *Frequency of each trace for players without ADHD diagnosis.*

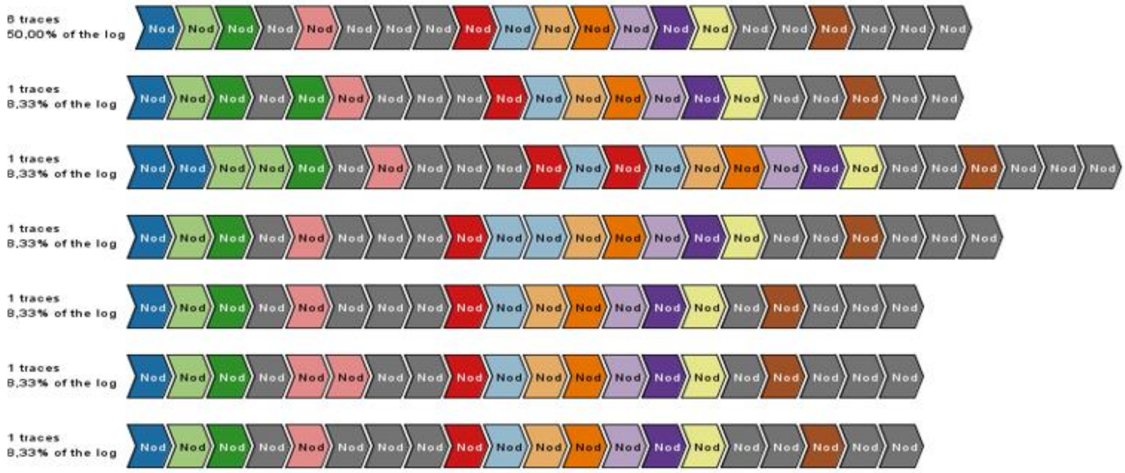


Figure 5.27. Frequency of each trace for players with ADHD diagnosis.

User Experience

In order to assess the suitability of the solution for the target audience, a UX[5] questionnaire was developed, based on the adaptation of the System Usability Scales (SUS) for use by children [170].

However, for the purposes of this study, not all the questions formulated by Putman and colleagues were deemed informative, and consequently, some of these were excluded from this experiment (Figure 5.28.).

[5]Refer to Annex E for more information on the UX questionnaire used in relation to the ENFEN App

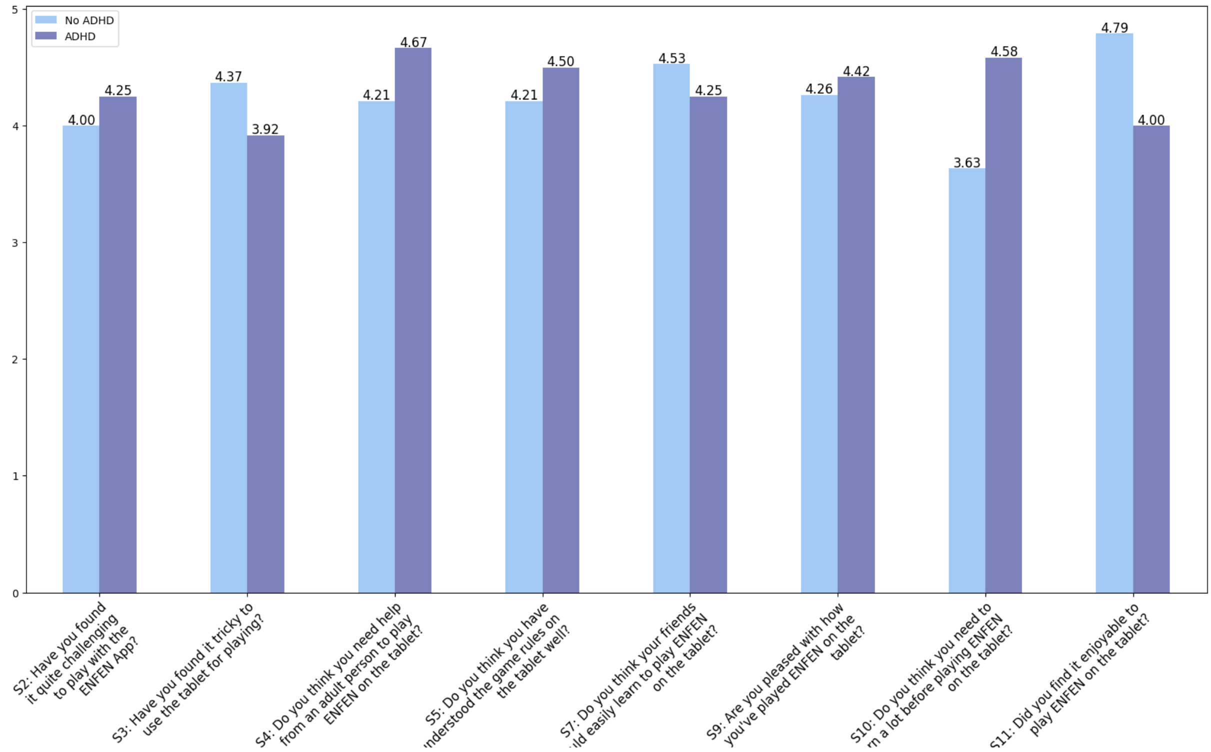


Figure 5.28. *UX questions of the ENFEN App*

As can be observed in the previous image, most of the statements retained from the reference questionnaire focus on understanding the level of difficulty perceived by the players when interacting with the tool. Within the range of possible values considered for this particular case -[1, 5]- the lowest score reflects a high degree of difficulty experienced by the player. Conversely, higher scores, such as 4 or 5, indicate a perception of the game as being simple. Thus, in general terms, it can be concluded that users perceive the game as an easy task, which can be executed in its digital format autonomously. At this point, it is worth noting that the group of children with a prior diagnosis of ADHD rated the simplicity of the app more positively and achieved a higher level of satisfaction when performing the tests compared to the group without a diagnosis, a finding already observed in the first trial (Figure 5.17.).

6 Discussion and Conclusions

This section presents the discussion of the conceptual and experimental results obtained in the research work, detailing the conclusions drawn in relation to the established hypotheses and objectives. Additionally, it includes the main contributions made and explains the scientific and technological innovations contained within. Lastly, indicators are provided regarding current and future research directions that are especially relevant to ensuring the continuity and transferability of the results obtained.

6.1. Discussion of the conceptual and experimental results

Throughout the development of this doctoral thesis, the validity of the solutions adopted, and possible alternatives have been technically compared and discussed. This section provides a specific discussion on the validity of the results achieved, addressing the hypotheses posed and assessing their consistency with the determined objectives.

6.1.1. Validity of the working hypothesis

Hypothesis.1	It is possible to implement effective screening tools for ADHD in the child's educational environment through the use of ICTs.

This working hypothesis was formulated to assess the potential of ICTs to reduce the evaluative pressure on children suspected of having ADHD during the diagnostic process, while maintaining at least the same discriminatory power as traditional solutions. To achieve this, the availability of the proposed solution had to be evaluated from various perspectives -hardware and software, suitability for the target users, data collection, etc.- so that the solution presented in this thesis would generate tools tailored to the desired environment of use. Also, different methods of adapting traditional tests to the digital format were studied, aiming to preserve the graphical characteristics, game mechanics, and discriminatory power as closely as possible to the original.

Through the execution of two experimental trials, the four tools generated from the proposed solution were tested with the target audience in environments familiar to the players, such as schools and associations. The results of these experiments demonstrate that, for five out of the six tests implemented, statistically similar outcomes were achieved when compared to the original format, under conditions of greater ubiquity and objectivity. Furthermore, the feedback provided by the players regarding their experience with the developed tool indicates a high level of suitability for the intended audience. Consequently, the conduct of these experiments and their results clarify the verification of this hypothesis.

Hypothesis.2	It is possible to model a child's behaviour during a screening test in a clinically unsupervised environment.

In relation to the aspect of ubiquity previously mentioned and given the diagnostic relevance of the behaviour observed in patients suspected of having ADHD, such behaviour had to be parameterised by the solution generated in this study. By acquiring knowledge about the clinical manifestation of ADHD, clinically significant events were defined for each of the implemented tests. These events capture individual behaviours that can be extrapolated to the diagnostic group to which the individual belongs.

The verification of the current hypothesis is linked to the experimental results obtained during the validation test of the ENFEN App. As noted in that section, the use of SG-based tools makes it possible to model player behaviour during their execution of screening tests. This allowed for the collection of data on each player's specific behaviour, which could be contrasted with both the expected behaviour and the general behaviour of other users.

Hypothesis.3	Serious games based on ICTs allow for the examination of the maturational level of Executive Functions in children with ADHD, yielding clinical results comparable to other traditional diagnostic tests, while being objective and free from human error.

Given the evidence that the presence of ADHD directly affects an individual's performance in EFs, these neurobiological factors must be considered informative during the diagnostic process. As previously mentioned, tests that assess these factors are not free from subjectivity: personal judgments by professionals regarding the need for assistance during the test, when a patient becomes distracted and needs to be refocused, and so on. Moreover, when assigning scores, it is possible that each professional may have their own interpretation of the established scoring rules, leading to variability in the scoring criteria depending on the individual responsible. Finally, it is evident that human errors may occur during the calculation of these scores, which directly impact the subsequent decision-making process.

Throughout the execution of the two experiments conducted, several healthcare experts participated in guiding the tests in their traditional format. When analysing the results collected by each, different interpretations of the scoring rules established by ENFEN were identified, as well as various human errors in the recording and calculation of the final scores. Additionally, due to the paper format of the tests, it was impossible to review the exact execution process and correct or corroborate these errors.

The solution proposed in this study standardises the criteria for support and attention redirection. For all users, the type of assistance, the frequency, and the maximum number of times this support will be provided were predetermined. Moreover, regarding data collection, the rules are the same for all users, ensuring equal treatment. The final scores are automatically calculated, eliminating the possibility of human error.

6.1.2. Research objectives and results

This section discusses the adequacy of the results obtained in achieving the objectives set forth in this doctoral thesis.

The main objective of this research was formulated as follows:

"The development and validation of a reference framework for the generation of serious games aimed at the application of screening tests for children under suspicion of ADHD, within the school environment and under the supervision of school personnel"

The achievement of this main objective is based on the fulfilment of the specific objectives into which it is divided.

Specific Objectives

A total of four specific objectives were formulated in this thesis to address the research problem from a technical perspective. Each of these objectives is listed below, followed by a discussion of how the work carried out has achieved them.

1. *Characterise the digitalisation of serious games for use in clinically unsupervised environments*.

The development of the reference framework has specifically fulfilled this objective by characterising the games from three different perspectives: objectivity, behavioural assessment, and availability. Each of the tools developed based on this framework ensures a clear transmission of information to the user and autonomously collects parameters related to neurobiological factors and clinically significant events. This promotes the ubiquity of the solution, thereby making it more available.

2. *The games developed will define clinically significant events.*

Given the current reality of the ADHD diagnostic process, the characterisation of the behaviour of children is considered an essential feature to be included in the solutions generated in this work. Consequently, the definition of clinically significant events was established as one of the fundamental pillars of the proposed framework. This definition has been thoroughly analysed through the execution of experimental trials.

3. *Develop a behavioural analysis model*.

The inclusion of user behavioural analysis during the tests enabled the creation of reference behavioural models. First, a theoretical model was developed, representing the optimal expected behaviour during the execution of each test. Secondly, a behaviour model was generated based on the information contained in the events recorded in the game logs.

4. *Validate de clinical effectiveness of the proposed solution through the testing of the formulated hypothesis.*

The execution of the two experimental trials conducted throughout the research period allowed for the testing of the formulated hypotheses. More specifically, the construct and concurrent validity of the SGs generated from the reference framework became evident from the results obtained when the tool was tested with the target users.

6.2. Original contributions

Throughout this research, several original scientific and technical innovations have been developed. The current section presents the original contributions of the doctoral thesis, enabling their evaluation and potential use in future research.

1. *Framework for the generation of SG*

In general, reference frameworks for the development of serious games for health are oriented towards increasing player engagement, aiming to enhance their commitment to the corresponding clinical process. However, the characteristics of the games developed based on existing frameworks are counterproductive when applied to the diagnostic context of ADHD.

The proposed framework combines the specific characteristics of the application environment with relevant aspects from other existing frameworks to address the particular needs identified during the research process of this thesis. More specifically, the reference framework provided as a solution in this doctoral thesis is recognised as the first development framework for serious games aimed at supporting healthcare professionals during the diagnostic process of ADHD.

2. *Inclusion of behavioural analysis*

Currently, several tools based on SGs aim to support healthcare professionals in their decision-making process in cases of suspected ADHD. Generally, these solutions focus on cognitive function analysis and the adaptation of evaluation scales. Yet, in the former case, player behaviour during the test remains unrecorded. Similarly, in the case of SGs based on evaluation scales, the behaviour of children under suspicion is analysed through the subjective opinions of individuals close to them.

The SGs generated using the reference framework proposed in this work integrate user information related to their personal characteristics and clinical capacities, as well as the performance of neurobiological factors of interest. As well, they capture and analyse the behaviour exhibited by the user during their interaction with the tool.

3. *Increased level of objectivity*

The integration of screening tools that unify the criteria for guiding and evaluating tests, as well as automate the calculation of final scores, within the ADHD diagnostic process, enhances its level of objectivity. By eliminating personal considerations, subjective interpretations, and potential human errors, the criteria for directing and correcting the game are standardised for all players. This ensures a fair and unbiased scoring system for everyone involved.

4. *Increased availability*

The design of the game generation framework allows the ADHD diagnostic process to be brought closer to the natural environments of children under suspicion. This not only contributes to greater objectivity in the data collected by the solution, but also facilitates access to these types of tests for a larger portion of the population.

6.3. Conclusions

The development of this doctoral thesis leads to the following conclusions:

1. *Overdiagnosis of ADHD*

Currently, there is an overdiagnosis of ADHD, mainly due to the process followed for its diagnosis. Despite ongoing efforts by the scientific community, the lack of understanding of neurobiological factors that would allow for a differential diagnosis, combined with the strong element of subjectivity involved, has led to the misassignment of ADHD diagnoses.

2. *Multidisciplinary approaches*

A multidisciplinary approach plays a crucial role in generating useful and effective solutions in the context of this doctoral thesis. The proposed generation framework as a solution requires collaboration between various professional profiles, ensuring that the tasks detailed in the framework can be executed using existing knowledge bases or those created ad hoc to meet specific needs.

3. *Evolution of the SGs generation frameworks*

Primarily designed with treatment and rehabilitation processes in mind, existing frameworks promote aspects of games that may not necessarily be desirable or compatible with the purpose of a diagnostic process. Therefore, the use of the reference framework proposed in this thesis represents a shift in the current paradigms established for generating serious games useful in ICT-based health solutions.

4. *A new role for patients*

Increasingly, patients are taking a more active role in the prevention, diagnosis, and treatment of various health conditions and chronic diseases thanks to ICTs. Additionally, this shift enables individuals to feel more informed and secure regarding the management of their health.

6.4. Future lines of work

This section outlines future lines of work aimed at evolving and deepening the concepts, technologies, and use cases presented in this thesis.

1. *Adjust and optimise the current digitalisation of the tests*

As observed, some of the digitalised ENFEN tests do not accurately capture the defined parameters of interest. Furthermore, through interaction with the target audience, certain characteristics of the application were identified that can be optimised to enhance its performance and suitability for the context of use and its users.

2. *Evaluate the developed system with a larger number of users*

Despite the promising results obtained in the two experiments presented in this thesis, only the inherent potential of using SGs as screening tools for ADHD in children's natural environments has been evidenced. Due to the difficulty of accessing the target population, the sample sizes available for the two experiments were limited, making it impossible to extrapolate the conclusions to the broader population and, therefore, to determine the clinical validity of the solution. Consequently, once the tests have been adjusted to improve their functionality, a third round of user testing will be conducted.

3. *Correlation analysis between tests*

The various ENFEN tests evaluate the developmental level of several EFs in the individual. However, overlap exists in this evaluation, meaning that two tests can assess common EF. To date, the correlation between EFs performance across different tests has not been analysed, nor has how cognitive ability performance varies depending on the test. Analysing this information could complement and contextualise current knowledge, shedding more light on each user's particular case and, in general, on the symptomatology of ADHD.

4. *Development of a knowledge base*

Since the proposed generation framework allows for the development of an indefinite number of games with similar clinical objectives, it may be useful to unify and integrate the results obtained across all of them. This would provide a more generic, contextualised, and complete profile of children under suspicion, while also allowing for comparison with the profiles of other users who have used the games.

5. *Application of the framework to other neurodevelopmental disorders*

Although the framework developed for this thesis is intended to address the specific characteristics of the ADHD diagnostic process, the evaluation of certain neurobiological and behavioural factors may be relevant for diagnosing other neurodevelopmental disorders. At this point, applying this reference framework to develop games that support decision-making processes for the detection of other deficits (dyslexia, Language Development Disorder, Auditory Processing Disorder, etc.) could be of interest.

6. *Distribution of the ENFEN App*

Lastly, the goal is to refine the application so that it can be used in non-experimental environments. Through the development of user manuals and continuous support, the solution created from the reference framework aims to become a daily resource for educators in schools when there is a suspicion of childhood ADHD.

7 References

[1] G. Xu, L. Strathearn, B. Liu, B. Yang, and W. Bao, "Twenty-Year Trends in Diagnosed Attention-Deficit/Hyperactivity Disorder Among US Children and Adolescents, 1997-2016," *JAMA Netw Open*, vol. 1, no. 4, p. e181471, Aug. 2018, doi: 10.1001/jamanetworkopen.2018.1471.

[2] C. Conde *et al.*, *Guía para la Evaluación Neuropsicológica del Trastorno por Déficit de Atención e Hiperactividad*. Accessed: Oct. 24, 2023. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.aepap.org/sites/default/files/documento/archivos-adjuntos/guia_evaluacion_neuropsicologica_tdah.pdf

[3] Y. Chen, Y. Zhang, X. Jiang, X. Zeng, R. Sun, and H. Yu, "COSA: Contextualized and Objective System to Support ADHD Diagnosis," *Proceedings - 2018 IEEE International Conference on Bioinformatics and Biomedicine, BIBM 2018*, pp. 1195–1202, Jan. 2019, doi: 10.1109/BIBM.2018.8621308.

[4] J. Munoz-Gama *et al.*, "Process mining for healthcare: Characteristics and challenges," *J Biomed Inform*, vol. 127, Mar. 2022, doi: 10.1016/j.jbi.2022.103994.

[5] A. Tchang Sánchez, D. Falcó de la Cierva, and J. Peris Escribá, *Todo lo que necesitas saber sobre el TDAH en la etapa de aprendizaje: Introducción al Trastorno por Déficit de Atención e Hiperactividad*, 1st Edition. Cuadernos de Pedagogía, 2020.

[6] R. A. Barkley, *Taking Charge of ADHD. The Complete, Authoritative Guide for Parents.* New York: The Guilford Press, 2005.

[7] G. F. Still, "Some abnormal psychical conditions in children: Excerpts from three lectures," *J Atten Disord*, vol. 10, no. 2, pp. 126–136, Nov. 2006, doi: 10.1177/1087054706288114/ASSET/1087054706288114.FP.PNG_V03.

[8] B. Albrecht, H. Uebel-von Sandersleben, K. Wiedmann, and A. Rothenberger, "ADHD History of the Concept: the Case of the Continuous Performance Test," *Curr Dev Disord Rep*, vol. 2, no. 1, pp. 10–22, Mar. 2015, doi: 10.1007/s40474-014-0035-1.

[9] F. De, P. Olvera, J. David, P. Ortiz, and E. Barragán Pérez, "Declaración de Cartagena para el Trastorno por Déficit de Atención con Hiperactividad (TDAH): rompiendo el estigma Cartagena's Declaration for Attention Deficit Hyperactivity Disorder (ADHD): breaking the Stigma".

[10] S. J. Kooij *et al.*, “European consensus statement on diagnosis and treatment of adult ADHD: The European Network Adult ADHD,” 2010, Accessed: Apr. 18, 2023. [Online]. Available: http://www.biomedcentral.com/1471-244X/10/67

[11] J. T. Hansen, *Netter. Cuaderno de Anatomía para Colorear*, Elsevier España. Barcelona, 2019.

[12] A. L. Krain and F. X. Castellanos, “Brain development and ADHD,” *Clin Psychol Rev*, vol. 26, no. 4, pp. 433–444, Aug. 2006, doi: 10.1016/j.cpr.2006.01.005.

[13] S. H. Mostofsky, K. L. Cooper, W. R. Kates, M. B. Denckla, and W. E. Kaufmann, “Smaller prefrontal and premotor volumes in boys with attention-deficit/hyperactivity disorder,” *Biol Psychiatry*, vol. 52, no. 8, pp. 785–794, Oct. 2002, doi: 10.1016/S0006-3223(02)01412-9.

[14] F. Xavier Castellanos *et al.*, “Developmental Trajectories of Brain Volume Abnormalities in Children and Adolescents With Attention-Deficit/Hyperactivity Disorder.” [Online]. Available: https://jamanetwork.com/

[15] F. X. Castellanos and M. T. Acosta, “[The neuroanatomy of attention deficit/hyperactivity disorder].,” *Rev Neurol*, vol. 38 Suppl 1, pp. S131-6, Feb. 2004.

[16] W. R. Kates *et al.*, “MRI parcellation of the frontal lobe in boys with attention deficit hyperactivity disorder or Tourette syndrome,” *Psychiatry Res Neuroimaging*, vol. 116, no. 1–2, pp. 63–81, Nov. 2002, doi: 10.1016/S0925-4927(02)00066-5.

[17] S. Durston *et al.*, “Magnetic Resonance Imaging of Boys With Attention-Deficit/Hyperactivity Disorder and Their Unaffected Siblings,” *J Am Acad Child Adolesc Psychiatry*, vol. 43, no. 3, pp. 332–340, Mar. 2004, doi: 10.1097/00004583-200403000-00016.

[18] K. E. Watkins *et al.*, “Structural Asymmetries in the Human Brain: a Voxel-based Statistical Analysis of 142 MRI Scans,” *Cerebral Cortex*, vol. 11, no. 9, pp. 868–877, Sep. 2001, doi: 10.1093/CERCOR/11.9.868.

[19] A. L. Reiss, M. T. Abrams, H. S. Singer, J. L. Ross, and M. B. Denckla, “Brain development, gender and IQ in childrenA volumetric imaging study,” *Brain*, vol. 119, no. 5, pp. 1763–1774, Oct. 1996, doi: 10.1093/BRAIN/119.5.1763.

[20] J. N. Giedd *et al.*, “Quantitative Magnetic Resonance Imaging of Human Brain Development: Ages 4–18,” *Cerebral Cortex*, vol. 6, no. 4, pp. 551–559, Jul. 1996, doi: 10.1093/CERCOR/6.4.551.

[21] P. A. Filipek, M. Semrud-Clikeman, R. J. Steingard, P. F. Renshaw, D. N. Kennedy, and J. Biederman, “Volumetric MRI analysis comparing subjects having attention-deficit

hyperactivity disorder with normal controls," *Neurology*, vol. 48, no. 3, pp. 589–601, Mar. 1997, doi: 10.1212/WNL.48.3.589.

[22] S. Overmeyer *et al.*, "Distributed grey and white matter deficits in hyperkinetic disorder: MRI evidence for anatomical abnormality in an attentional network," *Psychol Med*, vol. 31, no. 8, pp. 1425–1435, 2001, doi: 10.1017/S0033291701004706.

[23] E. R. Sowell, P. M. Thompson, S. E. Welcome, A. L. Henkenius, A. W. Toga, and B. S. Peterson, "Cortical abnormalities in children and adolescents with attention-deficit hyperactivity disorder," *Lancet*, vol. 362, no. 9397, pp. 1699–1707, Nov. 2003, doi: 10.1016/S0140-6736(03)14842-8.

[24] C. Escofet Soteras, M. A. Fernández Fernández, C. Torrents Fenoy, F. Martín del Valle, G. Ros Cervera, and I. S. Machado Casas, "Trastorno por Déficit de Atención e Hiperactividad (TDAH)," Protoc diagn ter pediatr.

[25] J. Stiles and T. L. Jernigan, "The basics of brain development," Dec. 2010. doi: 10.1007/s11065-010-9148-4.

[26] M. J. Mas, "Neuronas en Crecimiento. Comprender el Neurodesarrollo y los Problemas Neurológicos Infantiles." Accessed: Jul. 31, 2023. [Online]. Available: https://neuropediatra.org/2015/12/16/etapas-del-neurodesarrollo/

[27] N. Halfon, E. Shulman, and M. Hochstein, "Brain Development in Early Childhood. Building Community Systemes for Young Children," Los Angeles, 2001. Accessed: Aug. 01, 2023. [Online]. Available: http://healthychild.ucla.edu

[28] J. A. Portellano Pérez, *NEUROPSICOLOGIA INFANTIL*, SINTESIS. 2007.

[29] J. A. Portellano Pérez, R. Martínez, and A. L. Zumárraga Astorqui, "MANUAL ENFEN EVALUACIÓN NEUROPSICOLÓGICA DE LAS FUNCIONES EJECUTIVAS EN NIÑOS," 2009.

[30] American Psychiatric Association, *Diagnostic and Statistical Manual of Mental Disorders*, 5th ed. American Psychiatric Association, 2013. doi: 10.1176/appi.books.9780890425596.

[31] A. Parker and P. Corkum, "ADHD Diagnosis: As Simple As Administering a Questionnaire or a Complex Diagnostic Process?," *J Atten Disord*, vol. 20, no. 6, pp. 478–486, Jun. 2016, doi: 10.1177/1087054713495736.

[32] S. J. Kooij *et al.*, "European consensus statement on diagnosis and treatment of adult ADHD: The European Network Adult ADHD," 2010, Accessed: Apr. 18, 2023. [Online]. Available: http://www.biomedcentral.com/1471-244X/10/67

[33] Red TDAH, "Protocolos de actuación TDAH. Por comunidades autónomas." Accessed: Aug. 21, 2023. [Online]. Available: https://www.redtdah.org/protocolos-de-actuacion-en-tdah/

[34] E. Cardo *et al.*, "Current state of the attention deficit hyperactivity disorder approach in neuropediatrics.," *Rev Neurol*, vol. 64, no. s01, pp. S105–S109, Feb. 2017, Accessed: Apr. 24, 2023. [Online]. Available: https://europepmc.org/article/med/28256696

[35] M. M. Zamora, G. Cecilia, H. López, and L. Ángela Gómez, "Comorbilidad del trastorno por déficit de atención e hiperactividad con los trastornos específicos del aprendizaje Title: Attention-deficit Hyperactivity Disorder Comorbidity With Specific Learning Disorders," 2009.

[36] healthychildren.org, "La AAP actualiza las pautas sobre el TDAH con los más recientes estudios de investigación." Accessed: Feb. 02, 2024. [Online]. Available: https://www.healthychildren.org/Spanish/news/Paginas/Practice-Guideline-for-the-Diagnosis-Evaluation-and-Treatment-of-ADHD.aspx

[37] A. S. Bell, "A Critical Review of ADHD Diagnostic Criteria: What to Address in the DSM-V," Jul. 2010. doi: 10.1177/1087054710365982.

[38] G. Peñas, D. Carral, and J. José, "¿Existe un sobrediagnóstico del trastorno de déficit de atención e hiperactividad (TDAH)?", [Online]. Available: http://www.evidenciasenpediatria.esEsteartículoestádisponibleen:http://www.evidenciasenpediatria.es/EnlaceArticulo?ref=2012;8:51

[39] J. Valero, G. Garrido, C. Grau, R. Jordi, and G. Ferrer, "CUESTIONARIOS TDAH PARA PROFESORES. UN ANÁLISIS DESDE LOS CRITERIOS DEL DSM-IV-TR Y DSM-V ADHD QUESTIONNAIRE FOR TEACHERS. AN ANALYSIS FROM THE DSM-IV-TR AND DSM-V CRITERIA," 2014.

[40] J. A. Amador Campos, M. Á. Idiázabal Alecha, J. Sangorrín García, J. M. Espadaler Gamissans, and M. Forns i Santacana, "Utilidad de las Escalas de Conners para discriminar entre sujetos con y sin Trastorno por Déficit de Atención e Hiperactividad," *Psicothema*, vol. 14, no. 2, pp. 350–356, 2002.

[41] H. M. Geurts *et al.*, "Can the Children's Communication Checklist differentiate between children with autism, children with ADHD, and normal controls?," *Journal of Child Psychology and Psychiatry*, vol. 45, no. 8, pp. 1437–1453, Nov. 2004, doi: 10.1111/J.1469-7610.2004.00326.X.

[42] A. Ferré and J. Narbona, "Escala para la evaluación del Trastorno por Déficit de Atención con Hiperactividad," Madrid, 2011. Accessed: Aug. 22, 2023. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/http://www.pediatrasandalucia.org/ayuped

ia/wp-content/uploads/2019/06/EDAH_ESCALA_PARA_LA_EVALUACION_DEL_TRAST.pdf

[43] C. L. Hall *et al.*, "The Validity of the SNAP-IV in Children Displaying ADHD Symptoms," *https://doi.org/10.1177/1073191119842255*, vol. 27, no. 6, pp. 1258–1271, Apr. 2019, doi: 10.1177/1073191119842255.

[44] Fundación CADAH, "En qué consisten las Escalas de Conners para evaluar el TDAH." Accessed: Aug. 22, 2023. [Online]. Available: https://www.fundacioncadah.org/web/articulo/en-que-consisten-las-escalas-de-conners-para-evaluar-el-tdah.html

[45] A. T. Jebb, V. Ng, and L. Tay, "A Review of Key Likert Scale Development Advances: 1995–2019," *Front Psychol*, vol. 12, p. 637547, May 2021, doi: 10.3389/FPSYG.2021.637547/BIBTEX.

[46] M. B. Posserud, A. K. Ullebø, K. J. Plessen, K. M. Stormark, C. Gillberg, and A. J. Lundervold, "Influence of assessment instrument on ADHD diagnosis," *Eur Child Adolesc Psychiatry*, vol. 23, no. 4, pp. 197–205, Apr. 2014, doi: 10.1007/s00787-013-0442-6.

[47] M. D. Lezak, "THE PROBLEM OF ASSESSING EXECUTIVE FUNCTIONS," *International Journal of Psychology*, vol. 17, no. 1–4, pp. 281–297, Feb. 1982, doi: 10.1080/00207598208247445.

[48] S. J. Gilbert and P. W. Burgess, "Executive Functions," *Current Biology*, vol. 18, no. 3, pp. R110–R114, 2008.

[49] Neurowikia. El portal de contenidos en Neurología, "Corteza prefrontal y funciones ejecutivas." Accessed: Sep. 18, 2023. [Online]. Available: http://www.neurowikia.es/content/corteza-prefrontal-y-funciones-ejecutivas

[50] J. Tirapu-Ustárroz, P. Cordero-Andrés, P. Luna-Lario, and P. Hernáez-Goñi, "Proposed model of executive functions based on factorial analyses," Jan. 16, 2017, *Revista de Neurologia*. doi: 10.33588/rn.6402.2016227.

[51] J. Holmes, S. E. Gathercole, M. Place, T. P. Alloway, J. G. Elliott, and K. A. Hilton, "The diagnostic utility of executive function assessments in the identification of ADHD in Children," *Child Adolesc Ment Health*, vol. 15, no. 1, pp. 37–43, Feb. 2010, doi: 10.1111/j.1475-3588.2009.00536.x.

[52] K. M. Antshel, B. O. Hier, and R. A. Barkley, "Executive functioning theory and ADHD," in *Handbook of Executive Functioning*, Springer New York, 2014, pp. 107–120. doi: 10.1007/978-1-4614-8106-5_7.

[53] R. A. Barkley, “Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD,” *Psychol Bull*, vol. 121, no. 1, pp. 65–94, 1997.

[54] J. Carnicero and A. Fernández, *Manual de Salud Electrónica para Directivos de Servicios y Sistemas de Salud*. 2012. Accessed: Nov. 27, 2023. [Online]. Available: https://hdl.handle.net/11362/3023

[55] A. Honka, K. Kaipainen, H. Hietala, and N. Saranummi, “Rethinking health: ICT-enabled services to empower people to manage their health,” *IEEE Rev Biomed Eng*, vol. 4, pp. 119–139, 2011, doi: 10.1109/RBME.2011.2174217.

[56] H. Oh, C. A. Rizo, M. Enkin, and A. Jadad, “What is eHealth? A systematic review of published definitions,” 2005. [Online]. Available: https://www.researchgate.net/publication/7858958

[57] T. H. Van De Belt, L. J. L. P. G. Engelen, S. A. A. Berben, and L. Schoonhoven, “Definition of health 2.0 and medicine 2.0: A systematic review,” *J Med Internet Res*, vol. 12, no. 2, p. e1350, Jun. 2010, doi: 10.2196/jmir.1350.

[58] World Health Organization, “WHO. Eastern Mediterranean Region. eHealth .” Accessed: Nov. 27, 2023. [Online]. Available: https://www.emro.who.int/health-topics/ehealth/

[59] L. Otto, L. Harst, H. Schlieter, B. Wollschlaeger, P. Richter, and P. Timpel, “Towards a unified understanding of ehealth and related terms – proposal of a consolidated terminological basis,” in *HEALTHINF 2018 - 11th International Conference on Health Informatics, Proceedings; Part of 11th International Joint Conference on Biomedical Engineering Systems and Technologies, BIOSTEC 2018*, SciTePress, 2018, pp. 533–539. doi: 10.5220/0006651005330539.

[60] L. Lueiro-Astray, R. Romero, C. Sánchez-Chao, and J. C. González Moreno, “Presentación de una Plataforma Arquitectónica para Desarrollo de Soluciones de E-Health,” *Revista Ibercia de Sistemas e Tecnologías de Informacao (RISTI)*, vol. 4, pp. 1–15, 2009, Accessed: Nov. 27, 2023. [Online]. Available: https://go.gale.com/ps/i.do?p=IFME&u=anon~4d29680f&id=GALE|A277436735&v=2.1&it=r&sid=googleScholar&asid=8817d51e

[61] S. Sood *et al.*, “What Is Telemedicine? A Collection of 104 Peer-Reviewed Perspectives and Theoretical Underpinnings,” *https://home.liebertpub.com/tmj*, vol. 13, no. 5, pp. 573–590, Nov. 2007, doi: 10.1089/TMJ.2006.0073.

[62] M. Nacinovich, “Defining mHealth,” *J Commun Healthc*, vol. 4, no. 1, pp. 1–3, Apr. 2011, doi: 10.1179/175380611X12950033990296.

[63] D. Kebede and C. Zielinski, “Leveraging ehealth AHM SEE PROFILE,” 2012. [Online]. Available: https://www.researchgate.net/publication/330224310

[64] M. R. Olsen, C. Casado-Lumbreras, and R. Colomo-Palacios, "ADHD in eHealth - A Systematic Literature Review," in *Procedia Computer Science*, Elsevier B.V., 2016, pp. 207–214. doi: 10.1016/j.procs.2016.09.142.

[65] R. E. Scott and M. Mars, "Principles and framework for eHealth strategy development," 2013, *JMIR Publications Inc.* doi: 10.2196/jmir.2250.

[66] C. C. Abt, "Serious games," p. 176, 1987.

[67] B. Marcano, "Juegos serios y entrenamiento en la sociedad digital," *Education in the Knowledge Society*, vol. 9, no. 3, Jan. 2008, doi: https://doi.org/10.14201/eks.16791.

[68] P. Rego, P. Miguel Moreira, L. Paulo Reis, and R. Roberto Frias, "Serious Games for Rehabilitation A Survey and a Classification Towards a Taxonomy."

[69] Y. Khazaal *et al.*, "'Michael's Game,' a card game for the treatment of psychotic symptoms," *Patient Educ Couns*, vol. 83, no. 2, pp. 210–216, May 2011, doi: 10.1016/j.pec.2010.05.017.

[70] F. A. M. da Silva, T. S. da Silva, and E. R. Zorzal, "Use of serious games in medicine: a literature revision," *Research, Society and Development*, vol. 10, no. 16, p. e480101624208, Dec. 2021, doi: 10.33448/rsd-v10i16.24208.

[71] V. Wattanasoontorn, R. J. G. Hernández, and M. Sbert, "Serious Games for e-Health Care," 2014, pp. 127–146. doi: 10.1007/978-981-4560-32-0_9.

[72] C. Guinemer *et al.*, "Telemedicine in intensive care units: Scoping review," *J Med Internet Res*, vol. 23, no. 11, p. e32264, Nov. 2021, doi: 10.2196/32264.

[73] S. J. Sirintrapun and A. M. Lopez, "Telemedicine in Cancer Care," *American Society of Clinical Oncology Educational Book*, no. 38, pp. 540–545, May 2018, doi: 10.1200/edbk_200141.

[74] A. Asiri, S. AlBishi, W. AlMadani, A. ElMetwally, and M. Househ, "The Use of Telemedicine in Surgical Care: a Systematic Review," *Acta Informatica Medica*, vol. 26, no. 3, p. 201, 2018, doi: 10.5455/AIM.2018.26.201-206.

[75] T. Spencer, E. Noyes, and J. Biederman, "Telemedicine in the Management of ADHD: Literature Review of Telemedicine in ADHD," *J Atten Disord*, vol. 24, no. 1, pp. 3–9, Jan. 2020, doi: 10.1177/1087054719859081.

[76] Children's ADHD Telemental Health Treatment Study (CATTS), "Seattle Children's Hospital Research Foundation." Accessed: Dec. 18, 2023. [Online]. Available: https://depts.washington.edu/catts/whatis.php

[77] J. D. Neufeld, P. M. Yellowlees, D. M. Hilty, H. Cobb, and J. A. Bourgeois, "The e-Mental Health Consultation Service: Providing Enhanced Primary-Care Mental Health Services

Through Telemedicine," *Psychosomatics*, vol. 48, no. 2, pp. 135–141, Mar. 2007, doi: 10.1176/APPI.PSY.48.2.135.

[78] P. M. Yellowlees, D. M. Hilty, S. L. Marks, J. Neufeld, and J. A. Bourgeois, "A Retrospective Analysis of a Child and Adolescent eMental Health Program," *J Am Acad Child Adolesc Psychiatry*, vol. 47, no. 1, pp. 103–107, Jan. 2008, doi: 10.1097/CHI.0B013E31815A56A7.

[79] G. Reinhardt, P. E. H. Schwarz, and L. Harst, "Non-use of telemedicine: A scoping review," *Health Informatics J*, vol. 27, no. 4, Oct. 2021, doi: 10.1177/14604582211043147.

[80] M. S. Marcolino, J. A. Q. Oliveira, M. D'Agostino, A. L. Ribeiro, M. B. M. Alkmim, and D. Novillo-Ortiz, "The impact of mHealth interventions: Systematic review of systematic reviews," Jan. 01, 2018, *JMIR Publications Inc.* doi: 10.2196/mhealth.8873.

[81] A. B. Labrique, L. Vasudevan, E. Kochi, R. Fabricant, and G. Mehl, "mHealth innovations as health system strengthening tools: 12 common applications and a visual framework," *Glob Health Sci Pract*, vol. 1, no. 2, pp. 160–171, Aug. 2013, doi: 10.9745/GHSP-D-13-00031.

[82] T. A. Gurman, S. E. Rubin, and A. A. Roess, "Effectiveness of mHealth Behavior Change Communication Interventions in Developing Countries: A Systematic Review of the Literature," *J Health Commun*, vol. 17, no. SUPPL. 1, pp. 82–104, May 2012, doi: 10.1080/10810730.2011.649160.

[83] J. G. Perle and K. A. Hommel, "A Proposed Parent Management Training-Focused Smartphone App: How mHealth Can Foster Improved Inter-session Adherence and Behavioral Monitoring," *J Technol Behav Sci*, vol. 2, no. 1, pp. 49–55, Mar. 2017, doi: 10.1007/S41347-016-0007-X/METRICS.

[84] A. Raposo *et al.*, "e-CoVig: A Novel mHealth System for Remote Monitoring of Symptoms in COVID-19," *Sensors 2021, Vol. 21, Page 3397*, vol. 21, no. 10, p. 3397, May 2021, doi: 10.3390/S21103397.

[85] G. Lanzola *et al.*, "Remote Blood Glucose Monitoring in mHealth Scenarios: A Review," *Sensors 2016, Vol. 16, Page 1983*, vol. 16, no. 12, p. 1983, Nov. 2016, doi: 10.3390/S16121983.

[86] M. Schmidt, L. Babcock, B. G. Kurowski, A. Cassedy, C. Sidol, and S. L. Wade, "Usage Patterns of an mHealth Symptom Monitoring App Among Adolescents with Acute Mild Traumatic Brain Injuries," *J Head Trauma Rehabil*, vol. 37, no. 3, p. 134, May 2022, doi: 10.1097/HTR.0000000000000768.

[87] Ministry of Electronics and Information Technology Government of India, "Mother and Child Tracking System (MCTS)." Accessed: Dec. 29, 2023. [Online]. Available: https://apps.gov.in/apps/government/mother-and-child-tracking-system-mcts

[88] "Magpi." Accessed: Dec. 29, 2023. [Online]. Available: https://www.magpi.com/

[89] "Open Data Kit." Accessed: Dec. 29, 2023. [Online]. Available: https://opendatakit.org/

[90] OpenMRS Inc., "OpenMRS Medical Record System." Accessed: Dec. 29, 2023. [Online]. Available: https://openmrs.org/

[91] B. DeRenzi *et al.*, "e-IMCI: Improving pediatric health care in low-income countries," *Conference on Human Factors in Computing Systems - Proceedings*, pp. 753–762, 2008, doi: 10.1145/1357054.1357174.

[92] "REACH. Health Made Possible." Accessed: Dec. 29, 2023. [Online]. Available: https://www.reachdigitalhealth.org/

[93] S. Subramanian *et al.*, "Acceptability, Utility, and Cost of a Mobile Health Cancer Screening Education Application for Training Primary Care Physicians in India," *Oncologist*, vol. 26, no. 12, pp. e2192–e2199, Dec. 2021, doi: 10.1002/ONCO.13904.

[94] R. Littman-Quinn *et al.*, "mHealth applications for clinical education, decision making, and patient adherence in Botswana," in *2011 IST-Africa Conference Proceedings*, 2014. Accessed: Dec. 29, 2023. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/6107382

[95] S. Goel, N. Bhatnagar, D. Sharma, and A. Singh, "Bridging the Human Resource Gap in Primary Health Care Delivery Systems of Developing Countries With mHealth: Narrative Literature Review.," *JMIR Mhealth Uhealth*, vol. 1, no. 2, p. e25, Dec. 2013, doi: 10.2196/mhealth.2688.

[96] M. Chipeta and D. F. Malanga, "The Impact of mHealth on Supply Chain Management of Medical Supplies in Village Clinics: A Case of Cstock mHealth in Malawi," *https://services.igi-global.com/resolvedoi/resolve.aspx?doi=10.4018/978-1-7998-8915-1.ch006*, pp. 125–152, Jan. 1AD, doi: 10.4018/978-1-7998-8915-1.CH006.

[97] S. Chandir *et al.*, "Effect of food coupon incentives on timely completion of DTP immunization series in children from a low-income area in Karachi, Pakistan: A longitudinal intervention study," *Vaccine*, vol. 28, no. 19, pp. 3473–3478, Apr. 2010, doi: 10.1016/J.VACCINE.2010.02.061.

[98] "IRD. Interactive Research and Development." Accessed: Dec. 29, 2023. [Online]. Available: https://ird.global/

[99] V. P. Gurupur and T. T. H. Wan, "Challenges in implementing mHealth interventions: a technical perspective," *Mhealth*, vol. 3, pp. 32–32, Aug. 2017, doi: 10.21037/mhealth.2017.07.05.

[100] P. M. Kato, "Video Games in Health Care: Closing the Gap," *Review of General Psychology*, vol. 14, no. 2, pp. 113–121, 2010, doi: 10.1037/a0019441.

[101] H. G. Hoffman, D. R. Patterson, E. Seibel, M. Soltani, L. Jewett-Leahy, and S. R. Sharar, "Virtual reality pain control during burn wound debridement in the hydrotank," *Clinical Journal of Pain*, vol. 24, no. 4, pp. 299–304, May 2008, doi: 10.1097/AJP.0B013E318164D2CC.

[102] S. J. Brown, D. A. Lieberman, B. A. Gemeny, Y. C. Fan, D. M. Wilson, and D. J. Pasta, "Educational Video Game for Juvenile Diabetes: Results of a Controlled Trial," *Med. Inform.* , vol. 22, no. 1, 1997.

[103] D. A. Lieberman, "Management of Chronic Pediatric Diseases with Interactive Health Games: Theory and Research Findings," *Journal of Ambulatory Care Management*, vol. 24, no. 1, Jan. 2001.

[104] A.-M. Gabaldón-Pérez, M. Dolón-Poza, M. Eckert, N. Máximo-Bocanegra, M.-L. Martín-Ruiz, and I. Pau De La Cruz, "Serious Game for the Screening of Central Auditory Processing Disorder in School-Age Children: Development and Validation Study.," *JMIR Serious Games*, vol. 11, no. 1, p. e40284, Apr. 2023, doi: 10.2196/40284.

[105] A. Wols, A. Lichtwarck-Aschoff, E. A. Schoneveld, and I. Granic, "In-Game Play Behaviours during an Applied Video Game for Anxiety Prevention Predict Successful Intervention Outcomes," *J Psychopathol Behav Assess*, vol. 40, no. 4, pp. 655–668, Dec. 2018, doi: 10.1007/S10862-018-9684-4/TABLES/6.

[106] E. A. Schoneveld, A. Lichtwarck-Aschoff, and I. Granic, "Preventing Childhood Anxiety Disorders: Is an Applied Game as Effective as a Cognitive Behavioral Therapy-Based Program?," *Prevention Science*, vol. 19, no. 2, pp. 220–232, Feb. 2018, doi: 10.1007/S11121-017-0843-8/FIGURES/3.

[107] E. A. Schoneveld, M. Malmberg, A. Lichtwarck-Aschoff, G. P. Verheijen, R. C. M. E. Engels, and I. Granic, "A neurofeedback video game (MindLight) to prevent anxiety in children: A randomized controlled trial," *Comput Human Behav*, vol. 63, pp. 321–333, Oct. 2016, doi: 10.1016/J.CHB.2016.05.005.

[108] J. A. Anguera, F. M. Gunning, and P. A. Areán, "Improving late life depression and cognitive control through the use of therapeutic video game technology: A proof-of-concept randomized trial," *Depress Anxiety*, vol. 34, no. 6, pp. 508–517, Jun. 2017, doi: 10.1002/DA.22588.

[109] M. Semkovska and E. Ahern, "Online neurocognitive remediation therapy to improve cognition in community-living individuals with a history of depression: A pilot study," *Internet Interv*, vol. 9, pp. 7–14, Sep. 2017, doi: 10.1016/J.INVENT.2017.04.003.

[110] M. Lado-Codesido, C. M. Pérez, R. Mateos, J. M. Olivares, and A. G. Caballero, "Improving emotion recognition in schizophrenia with 'VOICES': An on-line prosodic self-training," *PLoS One*, vol. 14, no. 1, p. e0210816, Jan. 2019, doi: 10.1371/JOURNAL.PONE.0210816.

[111] K. H. Gülkesen, F. İşleyen, B. Cinemre, M. K. Samur, S. Ş. Kaya, and N. Zayim, “A web-based game for teaching facial expressions to schizophrenic patients,” *Appl Clin Inform*, vol. 8, no. 3, pp. 719–730, Jul. 2017, doi: 10.4338/ACI-2016-10-RA-0172/ID/R0172-40/BIB.

[112] Y. Zheng, R. Li, S. Li, Y. Zhang, S. Yang, and H. Ning, “A Review on Serious Games for ADHD,” Mar. 2021, [Online]. Available: http://arxiv.org/abs/2105.02970

[113] T.-Y. Chuang, I.-C. Lee, and W.-C. Chen, “Use of Digital Console Game for Children with Attention Deficit Hyperactivity Disorder.,” *Online Submission*, vol. 7, no. 11, pp. 99–105, Nov. 2010, Accessed: Jan. 08, 2024. [Online]. Available: http://www.uho.com.tw/sick.asp?aid=4500.

[114] V. Benzing and M. Schmidt, “The effect of exergaming on executive functions in children with ADHD: A randomized clinical trial,” *Scand J Med Sci Sports*, vol. 29, no. 8, pp. 1243–1253, Aug. 2019, doi: 10.1111/SMS.13446.

[115] A. Khaleghi, F. Heydari, H. Headar, M. Takhttavani, and A. Soltaninezhad, “An Approach to Diagnose Cognitive Deficits: Gamifying ADHD Children Diagnosis Questionnaire,” 2018. Accessed: Jan. 08, 2024. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.researchgate.net/profile/Hadi-Haedar/publication/327745326_An_approach_to_diagnose_cognitive_deficits_gamifying_ADHD_children_diagnosis_questionnaire/links/5ba21448a6fdccd3cb624dfc/An-approach-to-diagnose-cognitive-deficits-gamifying-ADHD-children-diagnosis-questionnaire.pdf

[116] J. C. Peijnenborgh *et al.*, “A Study on the Validity of a Computer-Based Game to Assess Cognitive Processes, Reward Mechanisms, and Time Perception in Children Aged 4-8 Years.,” *JMIR Serious Games*, vol. 4, no. 2, p. e15, Sep. 2016, doi: 10.2196/games.5997.

[117] Q. Wang, O. Sourina, and M. K. Nguyen, “Fractal dimension based neurofeedback in serious games,” *Visual Computer*, vol. 27, no. 4, pp. 299–309, Apr. 2011, doi: 10.1007/S00371-011-0551-5/METRICS.

[118] Q. Wang, O. Sourina, and M. K. Nguyen, “EEG-based ‘serious’ games design for medical applications,” *Proceedings - 2010 International Conference on Cyberworlds, CW 2010*, pp. 270–276, 2010, doi: 10.1109/CW.2010.56.

[119] Y. Ochi, T. Laksanasopin, B. Kaewkamnerdpong, and K. Thanasuan, “Neurofeedback game for attention training in adults,” *BMEiCON 2017 - 10th Biomedical Engineering International Conference*, vol. 2017-January, pp. 1–5, Dec. 2017, doi: 10.1109/BMEICON.2017.8229113.

[120] A. Ali and S. Puthusserypady, “A 3D learning playground for potential attention training in ADHD: A brain computer interface approach,” *Proceedings of the Annual International*

Conference of the IEEE Engineering in Medicine and Biology Society, EMBS, vol. 2015-November, pp. 67–70, Nov. 2015, doi: 10.1109/EMBC.2015.7318302.

[121] J. E. Munoz, D. S. Lopez, J. F. Lopez, and A. Lopez, “Design and creation of a BCI videogame to train sustained attention in children with ADHD,” *2015 10th Colombian Computing Conference, 10CCC 2015*, pp. 194–199, Nov. 2015, doi: 10.1109/COLUMBIANCC.2015.7333431.

[122] D. Z. Blandon, J. E. Munoz, D. S. Lopez, and O. H. Gallo, “Influence of a BCI neurofeedback videogame in children with ADHD. Quantifying the brain activity through an EEG signal processing dedicated toolbox,” *2016 IEEE 11th Colombian Computing Conference, CCC 2016 - Conference Proceedings*, Nov. 2016, doi: 10.1109/COLUMBIANCC.2016.7750788.

[123] N. Hocine, “Personalized Serious Games for Self-regulated Attention Training,” *ACM UMAP 2019 Adjunct - Adjunct Publication of the 27th Conference on User Modeling, Adaptation and Personalization*, pp. 251–255, Jun. 2019, doi: 10.1145/3314183.3323458.

[124] A. Dewhirst, R. Laugharne, and R. Shankar, “Therapeutic use of serious games in mental health: scoping review,” *BJPsych Open*, vol. 8, no. 2, Mar. 2022, doi: 10.1192/bjo.2022.4.

[125] P. García-Redondo, T. García, D. Areces, J. C. Núñez, and C. Rodríguez, “Serious Games and Their Effect Improving Attention in Students with Learning Disabilities,” *International Journal of Environmental Research and Public Health 2019, Vol. 16, Page 2480*, vol. 16, no. 14, p. 2480, Jul. 2019, doi: 10.3390/IJERPH16142480.

[126] N. Wrońska, B. Garcia-Zapirain, and A. Mendez-Zorrilla, “An iPad-Based Tool for Improving the Skills of Children with Attention Deficit Disorder,” *International Journal of Environmental Research and Public Health 2015, Vol. 12, Pages 6261-6280*, vol. 12, no. 6, pp. 6261–6280, Jun. 2015, doi: 10.3390/IJERPH120606261.

[127] E. Hakimirad, L. Kashani-Vahid, M. S. Hosseini, A. Irani, and H. Moradi, “Effectiveness of EmoGalaxy Video Game on Social Skills of Children with ADHD,” *Proceedings of the 2019 International Serious Games Symposium, ISGS 2019*, pp. 7–12, Dec. 2019, doi: 10.1109/ISGS49501.2019.9046992.

[128] H. M. Lau, J. H. Smit, T. M. Fleming, and H. Riper, “Serious games for mental health: Are they accessible, feasible, and effective? A systematic review and meta-analysis,” Jan. 18, 2017, *Frontiers Media S.A.* doi: 10.3389/fpsyt.2016.00209.

[129] M. Graafland *et al.*, “How to systematically assess serious games applied to health care,” Jul. 01, 2014, *JMIR Publications Inc.* doi: 10.2196/games.3825.

[130] “SCORM. SCORM Explained Internet.” Accessed: Jan. 11, 2024. [Online]. Available: https://scorm.com/scorm-explained/

[131] S. Carlier, V. Naessens, F. De Backere, and F. De Turck, "A Software Engineering Framework for Reusable Design of Personalized Serious Games for Health: Development Study," *JMIR Serious Games*, vol. 11, 2023, doi: 10.2196/40054.

[132] S. Verschueren, C. Buffel, and G. Vander Stichele, "Developing theory-driven, evidence-based serious games for health: Framework based on research community insights," Apr. 01, 2019, *JMIR Publications Inc.* doi: 10.2196/11565.

[133] B. Spyridon and R. Ioannis, "An Adaptation and Personalisation Methodology for Serious Games Design," in *Proceedings of the 12th European Conference on Game Based Learning*, Odense, Denmark: ACPI, Oct. 2019, p. 119. doi: 10.34190/GBL.19.122.

[134] N. Peiffer-Smadja *et al.*, "Challenges and issues about organizing a hospital to respond to the COVID-19 outbreak: experience from a French reference centre," *Clinical Microbiology and Infection*, vol. 26, no. 6, pp. 669–672, Jun. 2020, doi: 10.1016/J.CMI.2020.04.002.

[135] R. S. Mans, W. M. P. van der Aalst, and R. J. B. Vanwersch, "Process Mining in Healthcare," 2015, doi: 10.1007/978-3-319-16071-9.

[136] W. van der Aalst, "Data Science in Action," *Process Mining*, pp. 3–23, 2016, doi: 10.1007/978-3-662-49851-4_1.

[137] C. Alvarez *et al.*, "Discovering role interaction models in the Emergency Room using Process Mining," *J Biomed Inform*, vol. 78, pp. 60–77, Feb. 2018, doi: 10.1016/J.JBI.2017.12.015.

[138] M. Song and W. M. P. van der Aalst, "Towards comprehensive support for organizational mining," *Decis Support Syst*, vol. 46, no. 1, pp. 300–317, Dec. 2008, doi: 10.1016/J.DSS.2008.07.002.

[139] W. M. P. Van Der Aalst, H. A. Reijers, and M. Song, "Discovering social networks from event logs," *Computer Supported Cooperative Work*, vol. 14, no. 6, pp. 549–593, Oct. 2005, doi: 10.1007/S10606-005-9005-9/METRICS.

[140] A. Syamsiyah, B. F. van Dongen, and W. M. P. van der Aalst, "Discovering social networks instantly: Moving process mining computations to the database and data entry time," *Lecture Notes in Business Information Processing*, vol. 287, pp. 51–67, 2017, doi: 10.1007/978-3-319-59466-8_4/COVER.

[141] S. Suriadi, M. T. Wynn, J. Xu, W. M. P. van der Aalst, and A. H. M. ter Hofstede, "Discovering work prioritisation patterns from event logs," *Decis Support Syst*, vol. 100, pp. 77–92, Aug. 2017, doi: 10.1016/J.DSS.2017.02.002.

[142] Z. Huang, W. Dong, L. Ji, L. Yin, and H. Duan, "On local anomaly detection and analysis for clinical pathways," *Artif Intell Med*, vol. 65, no. 3, pp. 167–177, Nov. 2015, doi: 10.1016/J.ARTMED.2015.09.001.

[143] M. Rovani, F. M. Maggi, M. De Leoni, and W. M. P. Van Der Aalst, "Declarative process mining in healthcare," *Expert Syst Appl*, vol. 42, no. 23, pp. 9236–9251, Dec. 2015, doi: 10.1016/J.ESWA.2015.07.040.

[144] C. Combi, F. Galetto, H. C. Nakawala, G. Pozzi, and F. Zerbato, "Enriching surgical process models by BPMN extensions for temporal durations," *Proceedings of the ACM Symposium on Applied Computing*, pp. 586–593, Mar. 2021, doi: 10.1145/3412841.3441939.

[145] S. Aguirre, C. Parra, and M. Sepúlveda, "Methodological proposal for process mining projects," *International Journal of Business Process Integration and Management*, vol. 8, no. 2, pp. 102–113, 2017, doi: 10.1504/IJBPIM.2017.083793.

[146] M. L. Van Eck, X. Lu, S. J. J. Leemans, and W. M. P. Van Der Aalst, "PM2: A process mining project methodology," *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 9097, pp. 297–313, 2015, doi: 10.1007/978-3-319-19069-3_19/COVER.

[147] S. J. J. Leemans, E. Poppe, and M. T. Wynn, "Directly follows-based process mining: Exploration & a case study," *Proceedings - 2019 International Conference on Process Mining, ICPM 2019*, pp. 25–32, Jun. 2019, doi: 10.1109/ICPM.2019.00015.

[148] N. Martin *et al.*, "Recommendations for enhancing the usability and understandability of process mining in healthcare," *Artif Intell Med*, vol. 109, 2020.

[149] W. M. P. van der Aalst, M. Bichler, and A. Heinzl, "Responsible Data Science," *Business and Information Systems Engineering*, vol. 59, no. 5, pp. 311–313, Oct. 2017, doi: 10.1007/S12599-017-0487-Z/METRICS.

[150] W. Van Der Aalst *et al.*, "Process mining manifesto," *Lecture Notes in Business Information Processing*, vol. 99 LNBIP, no. PART 1, pp. 169–194, 2012, doi: 10.1007/978-3-642-28108-2_19/COVER.

[151] A. Pika, M. T. Wynn, S. Budiono, A. H. M. T. Hofstede, W. M. P. van der Aalst, and H. A. Reijers, "Privacy-Preserving Process Mining in Healthcare," *International Journal of Environmental Research and Public Health 2020, Vol. 17, Page 1612*, vol. 17, no. 5, p. 1612, Mar. 2020, doi: 10.3390/IJERPH17051612.

[152] M. Dumas, J. Recker, and M. Weske, "Management and engineering of process-aware information systems: Introduction to the special issue," *Inf Syst*, vol. 37, no. 2, pp. 77–79, Apr. 2012, doi: 10.1016/J.IS.2011.09.003.

[153] M. Reichert and B. Weber, "Enabling flexibility in process-aware information systems: Challenges, methods, technologies," *Enabling Flexibility in Process-Aware Information Systems: Challenges, Methods, Technologies*, pp. 1–515, Jan. 2012, doi: 10.1007/978-3-642-30409-5/COVER.

[154] A. Burattin, "Streaming Process Discovery and Conformance Checking," *Encyclopedia of Big Data Technologies*, pp. 1–8, 2018, doi: 10.1007/978-3-319-63962-8_103-1.

[155] H. K. Brittain, R. Scott, and E. Thomas, "The rise of the genome and personalised medicine," *Clinical Medicine*, vol. 17, no. 6, pp. 545–551, Dec. 2017, doi: 10.7861/CLINMEDICINE.17-6-545.

[156] I. R. König, O. Fuchs, G. Hansen, E. von Mutius, and M. V. Kopp, "What is precision medicine?," *European Respiratory Journal*, vol. 50, no. 4, p. 1700391, Oct. 2017, doi: 10.1183/13993003.00391-2017.

[157] Z. Valero-Ramon, C. Fernandez-Llatas, B. Valdivieso, and V. Traver, "Dynamic Models Supporting Personalised Chronic Disease Management through Healthcare Sensors with Interactive Process Mining," *Sensors 2020, Vol. 20, Page 5330*, vol. 20, no. 18, p. 5330, Sep. 2020, doi: 10.3390/S20185330.

[158] Universidad Politécnica de Madrid, "Lineas de Investigación. Programa Doc. Ing. Sistemas y Servicios para la Soc. Inf. (DISSSI))." Accessed: Nov. 20, 2023. [Online]. Available: https://www.etsist.upm.es/estudios-ingenieria-sistemas-telecomunicaciones-madrid/masters-ingenieria-madrid/doctorado/pdisssi/lininvest

[159] F. K. Y. Chan and J. Y. L. Thong, "Acceptance of agile methodologies: A critical review and conceptual framework," *Decis Support Syst*, vol. 46, no. 4, pp. 803–814, Mar. 2009, doi: 10.1016/J.DSS.2008.11.009.

[160] A. Srivastava, S. Bhardwaj, and S. Saraswat, "SCRUM model for agile methodology," *Proceeding - IEEE International Conference on Computing, Communication and Automation, ICCCA 2017*, vol. 2017-January, pp. 864–869, Dec. 2017, doi: 10.1109/CCAA.2017.8229928.

[161] Y. Bassil, "A Simulation Model for the Waterfall Software Development Life Cycle," *Int J Eng Technol*, vol. 2, no. 5, pp. 2049–3444, May 2012, Accessed: Mar. 05, 2024. [Online]. Available: https://arxiv.org/abs/1205.6904v1

[162] SCRIBD, "ENFEN. Cuadernillo de Anotación PDF." Accessed: Mar. 19, 2024. [Online]. Available: https://www.scribd.com/document/366075163/ENFEN-Cuadernillo-de-anotacion-pdf

[163] S. Álava Sordo, "Relación entre Diagnóstico de TDAH y los Procesos Intelectuales y Atencionales en Muestra Clínica: Comparación entre TDAH y Trastorno de Aprendizaje," Universidad Autónoma de Madrid, Madrid, 2018. Accessed: Apr. 01, 2024. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://repositorio.uam.es/bitstream/handle/10486/685757/alava_sordo_silvia.pdf

[164] A. M. Gabaldón-Pérez, M. L. Martín-Ruiz, F. Díez-Muñoz, M. Dolón-Poza, N. Máximo-Bocanegra, and I. Pau de la Cruz, "The Potential of Digital Screening Tools for Childhood ADHD in School Environments: A Preliminary Study," *Healthcare (Switzerland)*, vol. 11, no. 20, Oct. 2023, doi: 10.3390/healthcare11202795.

[165] Massachusetts Institute of Technology (MIT), "KODULAR." Accessed: Mar. 20, 2024. [Online]. Available: https://www.kodular.io/

[166] Google, "Firebase Realtime Database." Accessed: Mar. 21, 2024. [Online]. Available: https://firebase.google.com/docs/database

[167] L. M. Sullivan, "Repeated measures," *Circulation*, vol. 117, no. 9, pp. 1238–1243, Mar. 2008, doi: 10.1161/CIRCULATIONAHA.107.654350/ASSET/BBA79396-FDF7-4446-B95C-1F02124C485E/ASSETS/GRAPHIC/25FF3.JPEG.

[168] R. F. Woolson, "Wilcoxon Signed-Rank Test," *Wiley Encyclopedia of Clinical Trials*, pp. 1–3, Sep. 2008, doi: 10.1002/9780471462422.EOCT979.

[169] "A Review on Conformance Checking Technique for the Evaluation of Process Mining Algorithms," *TEM Journal*, vol. 8, no. 4, pp. 1232–1241, 2019.

[170] C. Putnam, M. Puthenmadom, M. A. Cuerdo, W. Wang, and N. Paul, "Adaptation of the system usability scale for user testing with children," in *Conference on Human Factors in Computing Systems - Proceedings*, Association for Computing Machinery, Apr. 2020. doi: 10.1145/3334480.3382840.

[171] Center-TBI, "Trail Making Test (TMT)-Spanish Version." Accessed: Oct. 30, 2023. [Online]. Available: https://www.google.com/search?q=trail+making+test&sca_esv=577734576&sxsrf=AM9HkKnxvJeZW597KsnS8y7K0qE_ou0ziA%3A1698654376516&ei=qGg_ZdOIH82vkdUPztSesAo&oq=trail+ma&gs_lp=Egxnd3Mtd2l6LXNlcnAiCHRyYWlsIG1hKgIIADIHECMYigUYJzIFEAAYgAQyBRAAGIAEMgoQABiABBgUGIcCMgUQABiABDIFEAAYgAQyBRAAGIAEMgUQABiABDIFEAAYgAQyBRAAGIAESJENUABY3QZwAHgBkAEAmAGcAaABpgeqAQMyLja4AQPIAQD4AQHCAg0QABiKBRixAxiDARhDwgIHEAAYigUYQ8ICCxAAGIAEGLEDGIMBwgIREC4YgAQYsQMYgwEYxwEY0QPCAgsQABiKBRixAxiDAcICCxAuGIAEGLEDGIMBwgIIEAAYgAQYsQPCAgsQLhiKBRixAxiDAcICBRAuGIAE4gMEGAAgQYgGAQ&sclient=gws-wiz-serp

[172] N. cognitiva y temas afines. Neurobase. Neuropsicología, "Un repaso al paradigma de tarea dual desde la neuropsicología (1ª parte)." Accessed: Oct. 30, 2023. [Online]. Available: https://neurobase.wordpress.com/2020/03/20/un-repaso-al-paradigma-de-tarea-dual-desde-la-neuropsicologia-1a-parte/

[173] Fundación CADAH, “Conners’ Continuous Performance Test II.” Accessed: Oct. 30, 2023. [Online]. Available: https://www.fundacioncadah.org/web/printPDF.php?idweb=1&account=j289eghfd7511986&contenido=cpt-ii-instrumento-de-evaluacion-de-la-atencion-y-concentracion

[174] PsicoActiva, “Entrenamiento online con la prueba N-Back para mejorar la memoria de trabajo a corto plazo,” 2023, Accessed: Oct. 30, 2023. [Online]. Available: https://www.psicoactiva.com/juegos-inteligencia/entrenamiento-nback-potenciar-memoria-corto-plazo/

[175] C. Alfonso and F. Chavarro, “MANUAL DE APLICACIÓN PROTOCOLO DE PRUEBAS DE TAMIZACIÓN Y DE EVALUACIÓN NEUROPSICOLÓGICA .” Accessed: Oct. 30, 2023. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://repositorio.unal.edu.co/bitstream/handle/unal/78228/MANUAL%20DE%20APLICACIO%CC%81N%20PROTOCOLO%20DE%20PRUEBAS_Anexo%20B.pdf?sequence=2&isAllowed=y

[176] T. Castelain and B. Marín Picado, *Cuadernos Metodológicos. Psicología Experimental: Experimentales para el Estudio de Procesos Cognitivos*. 2014.

[177] C. J. Golden, B. Ruiz-Fernandez, T. Luque, and F. Sánchez Sánchez, *Stroop. Test de Colores y Palabras*. TEA, 2020.

[178] Ó. Castillero Mimenza, “Juego de Azar de Iowa ('Iowa Gambling Task’): qué es y cómo se usa.” Accessed: Oct. 30, 2023. [Online]. Available: https://psicologiaymente.com/clinica/juego-azar-iowa

[179] J. León Carrión and J. M. Barroso Martín, “La Torre de Hanoi/Sevilla: una prueba para evaluar las funciones ejecutivas, la capacidad para resolver problemas y los recursos cognitivos.,” *Revista Española de Neuropsicología*, vol. 4, no. 3, pp. 63–72, 2021.

[180] Á. Rebuge and D. R. Ferreira, “Business process analysis in healthcare environments: A methodology based on process mining,” *Inf Syst*, vol. 37, no. 2, pp. 99–116, Apr. 2012, doi: 10.1016/J.IS.2011.01.003.

[181] M. Robin DiMatteo, P. J. Giordani, H. S. Lepper, and T. W. Groghan, “Patient adherence and medical treatment outcomes: a meta-analysis,” *Mecial Care*, vol. 40, no. 9, 2002.

[182] D. Wang *et al.*, “Representation primitives, process models and patient data in computer-interpretable clinical practice guidelines:: A literature review of guideline representation models,” *Int J Med Inform*, vol. 68, no. 1–3, pp. 59–70, Dec. 2002, doi: 10.1016/S1386-5056(02)00065-5.

[183] A. Ten Teije *et al.*, “Improving medical protocols by formal methods,” *Artif Intell Med*, vol. 36, no. 3, pp. 193–209, Mar. 2006, doi: 10.1016/J.ARTMED.2005.10.006.

[184] R. Gatta *et al.*, "What role can process mining play in recurrent clinical guidelines issues? A positon paper," *Int J Environ Res Public Health*, vol. 17, no. 18, 2020.

[185] R. Gatta *et al.*, "Clinical Guidelines: A Crossroad of Many Research Areas. Challenges and Opportunities in Process Mining for Healthcare," *Lecture Notes in Business Information Processing*, vol. 362 LNBIP, pp. 545–556, 2019, doi: 10.1007/978-3-030-37453-2_44/COVER.

[186] S. Timmermans and M. Berg, "Standardization in Action: Achieving Local Universality through Medical Protocols," *http://dx.doi.org/10.1177/030631297027002003*, vol. 27, no. 2, pp. 273–305, Apr. 1997, doi: 10.1177/030631297027002003.

[187] D. Roulin, M. Muradbegovic, V. Addor, C. Blanc, N. Demartines, and M. Hübner, "Enhanced Recovery after Elective Colorectal Surgery - Reasons for Non-Compliance with the Protocol," *Dig Surg*, vol. 34, no. 3, pp. 220–226, Apr. 2017, doi: 10.1159/000450685.

[188] L. O. Karlsson, S. Nilsson, M. Bång, L. Nilsson, E. Charitakis, and M. Janzon, "A clinical decision support tool for improving adherence to guidelines on anticoagulant therapy in patients with atrial fibrillation at risk of stroke: A cluster-randomized trial in a Swedish primary care setting (the CDS-AF study)," *PLoS Med*, vol. 15, no. 3, p. e1002528, Mar. 2018, doi: 10.1371/JOURNAL.PMED.1002528.

[189] M. Peleg, "Computer-interpretable clinical guidelines: A methodological review," *J Biomed Inform*, vol. 46, no. 4, pp. 744–763, Aug. 2013, doi: 10.1016/J.JBI.2013.06.009.

[190] H. B. Klasky and O. Ozmen, "Process mining in healthcare - a case study for the corporate data warehouse of the veterans affairs office," 2019. doi: https://doi.org/10.2172/1649520.

[191] R. Lenz, M. Peleg, and M. Reicheret, "Healthcare process suport: achievements, challenges, current research," *International Journal of Knowledge-Based Organizations*, vol. 2, no. 4, 2012.

[192] S. J. van Zelst, F. Mannhardt, M. de Leoni, and A. Koschmider, "Event abstraction in process mining: literature review and taxonomy," *Granular Computing*, vol. 6, no. 3, pp. 719–736, Jul. 2021, doi: 10.1007/S41066-020-00226-2/TABLES/3.

[193] T. Conca *et al.*, "Multidisciplinary collaboration in the treatment of patients with type 2 diabetes in primary care: Analysis using process mining," *J Med Internet Res*, vol. 20, no. 4, p. e8884, Apr. 2018, doi: 10.2196/jmir.8884.

[194] L. Cao, "Data Science," *ACM Computing Surveys (CSUR)*, vol. 50, no. 3, Jun. 2017, doi: 10.1145/3076253.

[195] N. Martin and J. Bergs, "Patient flow data registration: A key barrier to the data-driven and proactive management of an emergency department.," *Int Emerg Nurs*, vol. 53, pp. 100932–100932, Oct. 2020, doi: 10.1016/J.IENJ.2020.100932.

[196] P. Dimitri, "The evolution of evidence based clinical medicine," *Practical Pediatric Urology: An Evidence-Based Approach*, pp. 1–15, Dec. 2020, doi: 10.1007/978-3-030-54020-3_1/COVER.

[197] B. Djulbegovic and G. H. Guyatt, "Progress in evidence-based medicine: a quarter century on," *The Lancet*, vol. 390, no. 10092, pp. 415–423, Jul. 2017, doi: 10.1016/S0140-6736(16)31592-6.

8 Annexes

Annex A. Principal Symptoms of ADHD According to Predominant Subtype (Classification According to the DSM-V)

At least six of the following symptoms must be present, or at least five for individuals over sixteen years of age, with persistence for at least six months to a degree that is inconsistent with the developmental level and negatively impacts social and academic/occupational activities.

Inattention
1. Fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities.
2. Has difficulty sustaining attention in tasks or play activities.
3. Does not seem to listen when spoken to directly.
4. Does not follow through on instructions and fails to finish shcoolwokrs or chores.
5. Has difficulty organising tasks and activities.
6. Avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort.
7. Often loses items necessary for tasks or activities.
8. Is easily distracted by extraneous or irrelevant stimuli.
9. Is forgetful in daily activities.

Hyperactivity and impulsivity
1. Fidgets with hands, taps feet, or squirms in seat; cannot sit still.
2. Leaves seat in situations where remaining seated is expected.
3. Runs, jumps, or climbs excessively in inappropriate situations.
4. Is unable to engage in quiet activities or play.
5. Appears to be constantly on the go, as if driven by a motor.
6. Talks excessively: disrupts peers, monopolises conversations, etc.
7. Answers before a question is completed, blurting out responses.
8. Has difficulty waiting for their turn.
9. Interrupts or intrudes on other’s conversations or activities.

Annex B. Neuropsychological Tests Recommended by the CNC for the Assessment of EFs in School-aged Children Suspected of ADHD

Test name	Description
Trail Making Test (TMT)	Commonly used in clinical settings for the detection of cognitive disabilities, this test allows for the assessment of cognitive and executive functions, particularly in the domains of attention, mental flexibility, and visuomotor efficiency. There are two subcategories: • *TMT-A*. In this test, numbers 1 to 25 are randomly distributed on a sheet of paper. The task involves connecting the numbers in ascending order using lines. The time taken to complete the test and the number of errors are recorded. • *TMT-B*. The individual is presented with a paper containing a combination of numbers (1 to 13) and letters (A to L). The challenge is to alternate between numbers and letters (1-A-2-B-3-C...). Again, time taken and errors are recorded. The longer the completion time and the greater the number of errors, the greater the cognitive disability associated with the assessed functions [171].

Dual Task	These tests measure the individual's ability to maintain attention on a primary task while simultaneously performing a secondary task. Typically, this involves combining emotional, cognitive, and motor tasks, with cognitive-motor combinations being the most common [172]. Depending on the cognitive functions to be assessed, the specialist designs the primary and secondary tasks for the individual under suspicion of ADHD.
Conners Continuous Performance Test (CPT)	In the clinical context, the CPT evaluates sustained and selective attention, as well as working memory, motor control, and inhibitory function. Over 15 minutes, a series of letters are presented on screen (one every two seconds). The individual must press the space bar as quickly as possible whenever the letter on screen is not 'X'. Performance is measured by the number of hits, errors, omissions, and reaction times. Variations in these parameters can indicate attention dysfunction, impulsivity, and lack of motor control or inhibition [173].
N Back Test	Designed to assess and train working memory, this test is useful for evaluating executive function in individuals suspected of ADHD. Participants must recall a sequence of stimuli (visual or auditory) presented at regular intervals and determine if the current stimulus matches the one presented n positions back in the sequence. The difficulty varies based on n, the type of stimulus, and the interval between presentations[174].
Corsi Block-Tapping Test	Developed by Pietro Corsi in the 1970s, this test assesses visuospatial memory and working memory. The examiner shows the patient a sequence of numbered blocks, tapping or highlighting each one. The individual must repeat the

	sequence in the specified order. The difficulty increases with longer sequences, and the score depends on the maximum sequence length successfully replicated [175].
Go/NoGo Task	Participants must execute a motor response to a *Go* signal and inhibit this response when presented with a *NoGo* signal. The speed and accuracy of the responses are measured, commonly used to assess executive function and selective attention. This test provides insights into inhibitory control and selective attention [176].
Stroop Test	A psychological test linked to neuropsychology that measures interference from automatisms during task performance. It assesses selective attention, inhibitory control, and processing speed. The test consists of three phases: • Word reading. The subject reads colour names written in black ink. • Colour identification. The subject identifies the colour of ink used for meaningless symbols. • Interference task. The subject is shown colour names in mismatched coloured inks and must name the ink colour, ignoring the written word. This test evaluates interference and the ability to resist it [177].
Iowa Gambling Task (IGT)	A psychological, behavioural test used to evaluate decision-making processes. The participant is presented with four decks of cards, two of which are advantageous (long-term gains, smaller losses) and two disadvantageous (short-term gains, larger long-term losses). The task is to learn which decks are beneficial based on experience. The IGT assesses the ability to learn from feedback and make decisions aligned with variable realities [178].

Torre de Hanoi	This test involves a platform with three rods on which various-sized disks are placed. The user begins with the disks arranged by size on the left rod and must replicate a target configuration on the right rod. The test evaluates planning ability and sustained attention, as the goal is to replicate the configuration in the shortest time and with the fewest moves [179].

Annex C. Characteristics of the Clinical Care Domain and Associated Challenges for Implementing PM4H

Characteristic	Description	Application challenges
D1: Exhibit substantial variability	**Processes in the healthcare domain are often characterised by complexity, partly due to the notable presence of variability** [180]. Several factors contribute to this inherent variability, including the wide range of activities typically performed, the possibility of simultaneously executing multiple subprocesses, and the influence of differing preferences and characteristics of patients, doctors, and other healthcare professionals. This combination of factors leads to considerable diversity across cases, each being significantly different.	C1, C2, and C10
D2: Value the infrequent behaviour	In general contexts, infrequent behaviour may be perceived as noise, **but in healthcare, such atypical behaviour can be a valuable source of information**. Healthcare is characterised by the tendency to adopt improvised solutions, implying deliberate deviations from established practices. As a result, infrequent behaviour often requires consideration in the context of PM4H. For example, an improvised solution might reveal how different paths through a process lead to the same outcome, providing relevant insights into variations in the treatment of a specific disease [181].	C1, C4, and C9

D3: Use guidelines and protocols	The paradigm of evidence-based medicine has been accompanied by a significant increase in the availability of clinical guidelines and protocols [182], [183]. **The presence of both offers extensive opportunities for process mining in healthcare,** compared to other sectors where reference processes are less prominent [184]. First, guidelines and protocols can facilitate process mining. For example, available guidelines may serve as prescriptive models with which to compare actual process execution using conformance-checking algorithms [185]. Second, process mining can provide evidence to improve guidelines and protocols by evaluating their effectiveness and efficiency. This evidence can also be used to adapt global standardisation efforts to local contexts affordably and effectively [186].	C1, C2, C3, and C10
D4: Break the glass	Despite the clear objective of guidelines and protocols to establish high-level structures for healthcare processes, day-to-day situations may arise where doctors and other healthcare professionals need to *break the glass* and deviate from established protocols. Such situations may occur at two levels: • *Patient level.* Alternative courses of action may be required due to previously unknown comorbidities, unexpected complications, patient preferences, or combinations of comorbidities not covered by existing guidelines [187], [188]. • *System level*. Emergencies may arise from an influx of patients or a sudden reduction in staff availability [189]. Thus, **healthcare processes encounter unplanned situations due to unforeseen emergencies or the need to optimise limited resources.**	C1, C3, and C9

D5: Consider data at multiple abstraction levels	A common misconception about PM4H is that it only uses medical treatment data and, therefore, is synonymous with medical treatment analysis. Although medical treatment analysis is a significant use case, healthcare involves a wide variety of data types linked to both clinical and organisational/administrative processes [166]-[168]. A key distinction is made between: • *Low-level data*. Highly detailed information recorded by medical equipment or sensors in healthcare facilities. Aggregation is often required to extract meaningful patterns from extensive volumes of detailed data [192]. • *High-level data*. More general data that tends to facilitate the identification of meaningful patterns during analysis without requiring aggregation. This data, typically recorded in hospital information systems or administrative records, may be suitable for comparisons between organisations. Given the multitude of high- and low-level data sources in healthcare entities, researchers are likely to encounter various data types.	C1, C2, C4, and C9
D6: Involve a multidisciplinary team	Healthcare processes are increasingly multidisciplinary [193]. Similarly, data science, by nature, is multidisciplinary [194], and PM is no exception [136]. In addition to the possible involvement of experts from the aforementioned informatics fields, PM4H researchers and practitioners must always acknowledge the multidisciplinary nature of healthcare processes. To ensure the relevance of PM4H techniques, **it is essential to involve doctors, nurses, and other healthcare professionals from all relevant departments**.	C1 and C5

	Practically, a multidisciplinary team should be formed and closely engaged in all stages: data collection, data analysis, and data interpretation	
D7: Focus on the patient	A typical healthcare process involves multiple actors—patients, family members, doctors, nurses, etc. However, **it is crucial to recognise that the patient is at the centre of all healthcare processes**. Therefore, PM4H researchers must always ensure that processes are analysed from the patient's perspective, even if the patient is not explicitly represented in the team described in D6. Thus, the patient's perspective should receive explicit attention when developing methods, tools, and frameworks	C1, C8, and C10
D8: Think about white-box approaches	In day-to-day practice, doctors face tricky situations and must make complex decisions. Despite their extensive training, decisions regarding the necessary diagnoses and treatments for a patient depend on a risk-benefit evaluation by the doctor, which is context-dependent. Advances in artificial intelligence and machine learning have fostered new decision support systems that provide accurate information to assist doctors in making clinical decisions. However, one of the greatest challenges is that doctors are reluctant to trust and adopt recommendations from a system they do not fully understand. To enable data-driven improvements in healthcare processes, transparent approaches are required to allow healthcare professionals to understand the origin of particular observations. **PM techniques are perceived as white-boxes, as their ultimate goal is to offer healthcare professionals techniques to better understand what happens in their processes. The strength of process mining lies in its focus on comprehensibility.**	C1 and C5

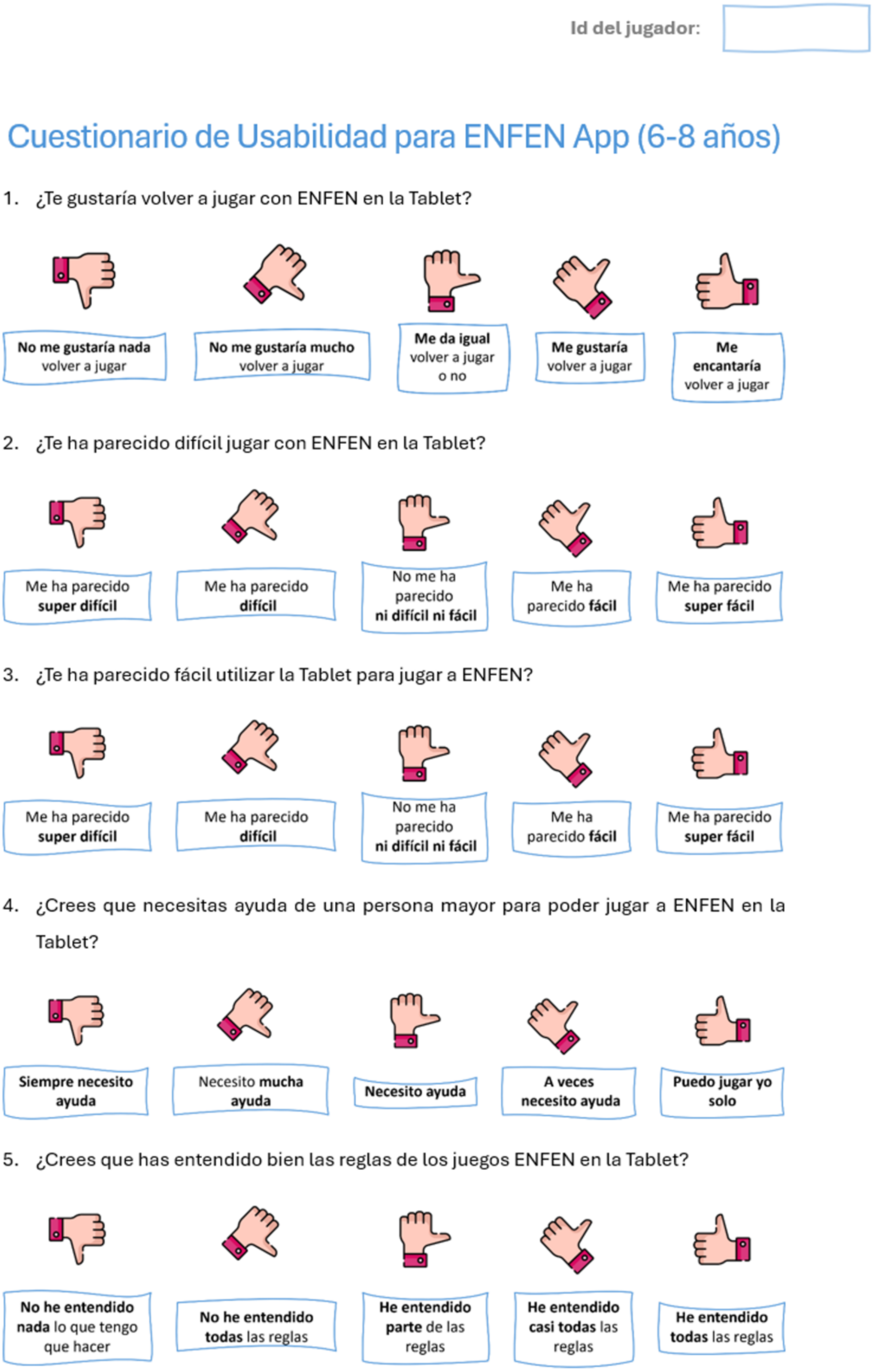
D9: Generate sensitive and low-quality data	When applying process mining in healthcare, it is necessary to consider data sensitivity. Healthcare event logs, **containing information such as patient medical conditions, must be handled carefully**. Due to their confidentiality, the use, storage, and transfer of these logs are strictly regulated by institutions, countries, and even international treaties [151]. In addition to data privacy, low-quality data is also a significant issue in healthcare. In many countries, healthcare processes still rely on paper records, which present challenges for accurately timestamping activities. **While integrated Health Information Systems are becoming more widespread, existing research shows that healthcare processes tend to be characterised by low-quality data** [195]. This issue is partly attributable to the fact that event recording often still requires manual action by doctors or administrative staff.	C1, C4, C6, and C7
D10: Handle rapid evolutions and new paradigms	**Healthcare is a domain that undergoes rapid and continuous evolution, which also has implications for healthcare processes.** High-quality research findings are integrated into clinical practice, which may introduce changes in diagnostic or treatment processes [196], [197]. Similarly, the rapid evolution of technologies also affects processes in this domain. Evolution in healthcare is driven not only by new clinical knowledge or technological advancements but also by the emergence of new paradigms, such as the patient-centred care paradigm. To provide valuable contributions to healthcare, the PM4H community must be capable of handling rapid evolutions and new paradigms.	C10

Annex D. Subfunctions Evaluated by the ENFEN Test Battery

Characteristic	Description
Cognitive Flexibility	The mental ability to shift thinking or approach to a problem based on new situations, information, or perspectives. **It refers to the capacity to adapt and adjust thinking or behaviour in response to changing demands or circumstances.**
Processing Speed	Refers to the speed at which a person can **process and understand information from their environment, as well as the pace at which they can perform cognitive tasks and solve problems.**
Working Memory	The **human capacity to actively hold and manipulate relevant information in mind for a brief period to perform complex cognitive tasks**. It involves the temporary storage of information in short-term memory and its effective use for mental activities such as reasoning, problem-solving, language comprehension, and decision-making.
Inhibition Control	A cognitive function that **involves the ability to actively suppress or control impulses, thoughts, emotions, or automatic or irrelevant behaviours** in a given situation. It is essential for executive functioning and plays a crucial role in regulating behaviour, making decisions, and solving problems.

Prospective Memory	A type of memory involving the recall of an intended action in the future, either at a specific time or in response to a particular stimulus. It refers to **remembering and executing a planned action at the appropriate time in the future.**
Selective Attention	A cognitive process that **involves focusing attention on a specific stimulus or set of stimuli while ignoring other stimuli that may be equally perceptible but irrelevant at the moment**. It entails directing attention to certain aspects of the environment or information while filtering out or disregarding others
Visuospatial Ability	The capacity to perceive, analyse, and manipulate visual information concerning space and the spatial relationships between objects. It **involves the ability to understand and visually represent three-dimensional space and to perceive and manipulate objects within that space**.
Graphomotor Skill	The ability to coordinate fine movements of the hand and fingers with vision to perform tasks requiring precision, control, and fluidity. **It involves the integration of visual and motor processes to execute precise and coordinated movements.**
Planning	A cognitive function that involves **the ability to set goals, develop strategies to achieve those goals, and organise the actions** necessary to effectively carry out those strategies

Annex E. UX Questionnaire for the Evaluation of ENFEN App (Children Aged 6 to 8 Years)



Id del jugador:

Cuestionario de Usabilidad para ENFEN App (6-8 años)

1. ¿Te gustaría volver a jugar con ENFEN en la Tablet?

No me gustaría nada volver a jugar	**No me gustaría mucho** volver a jugar	**Me da igual** volver a jugar o no	**Me gustaría** volver a jugar	**Me encantaría** volver a jugar

2. ¿Te ha parecido difícil jugar con ENFEN en la Tablet?

Me ha parecido **super difícil**	Me ha parecido **difícil**	No me ha parecido **ni difícil ni fácil**	Me ha parecido **fácil**	Me ha parecido **super fácil**

3. ¿Te ha parecido fácil utilizar la Tablet para jugar a ENFEN?

Me ha parecido **super difícil**	Me ha parecido **difícil**	No me ha parecido **ni difícil ni fácil**	Me ha parecido **fácil**	Me ha parecido **super fácil**

4. ¿Crees que necesitas ayuda de una persona mayor para poder jugar a ENFEN en la Tablet?

Siempre necesito ayuda	Necesito **mucha ayuda**	**Necesito ayuda**	**A veces necesito ayuda**	**Puedo jugar yo solo**

5. ¿Crees que has entendido bien las reglas de los juegos ENFEN en la Tablet?

No he entendido nada lo que tengo que hacer	**No he entendido todas** las reglas	**He entendido parte** de las reglas	**He entendido casi todas** las reglas	**He entendido todas** las reglas

Id del jugador:

6. ¿Crees que hay cosas sin sentido en los juegos de ENFEN en Tablet?

Si, **hay muchas cosas sin sentido**	Si, **hay algunas cosas sin sentido**	**No estoy seguro**	**La mayoría de cosas tienen sentido**	**Todo tiene sentido**

7. ¿Crees tus amigos podrían aprender a jugar a ENFEN en Tablet fácilmente?

Creo que **les sería muy difícil**	Creo que **les sería difícil**	**No estoy seguro**	Creo que **les sería fácil**	Creo que **les sería muy fácil**

8. ¿Te ha resultado raro algo mientras jugabas con ENFEN en la Tablet?

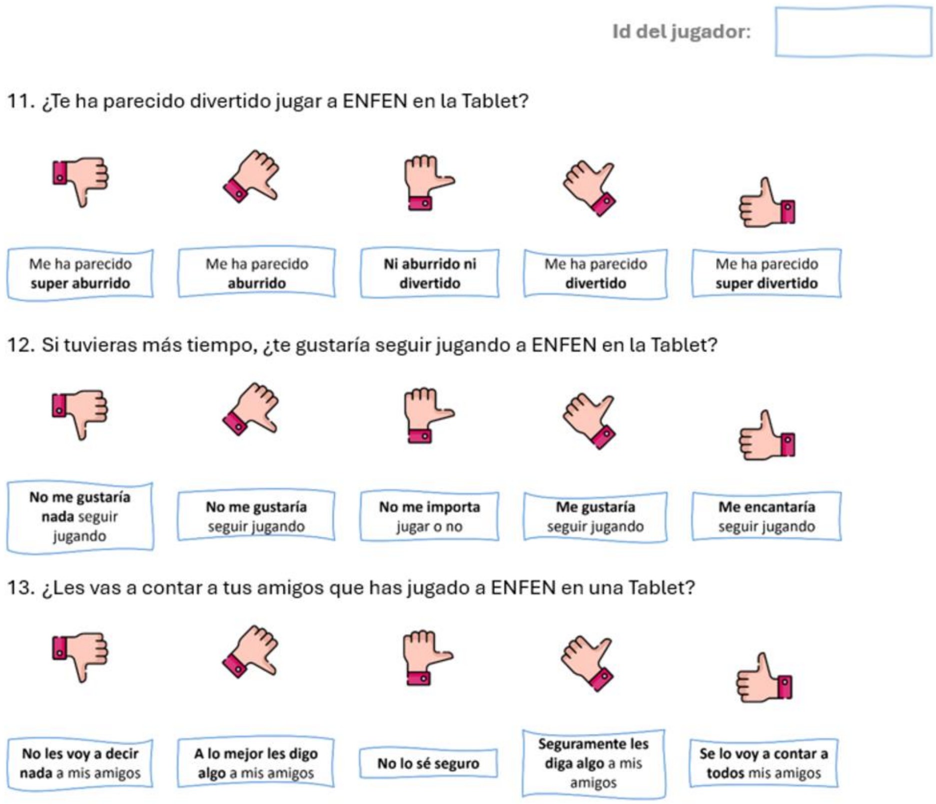
Si, **he hecho muchas cosas raras**	Si, **he hecho algunas cosas raras**	**No estoy seguro**	**No he hecho casi ninguna cosa raras**	**No he hecho ninguna cosa rara**

9. ¿Te sientes contento contigo mismo por cómo has jugado a ENFEN en la Tablet?

No estoy nada contento con como he jugado	**No estoy contento** con como he jugado	**No estoy ni contento ni no contento**	**Estoy contento** con como he jugado	**Estoy super contento** con como he jugado

10. ¿Crees que tienes que aprender muchas cosas antes de jugar a ENFEN en la Tablet?

Creo que **tengo que saber bastantes cosas** para poder jugar	Creo que **tengo que saber muchas cosas** para poder jugar	Creo que **tengo que saber algunas cosas** para poder jugar	Creo que **no tengo que saber muchas cosas** para poder jugar	Creo que **no tengo que saber nada** para poder jugar



Id del jugador:

11. ¿Te ha parecido divertido jugar a ENFEN en la Tablet?

Me ha parecido **super aburrido**	Me ha parecido **aburrido**	**Ni aburrido ni divertido**	Me ha parecido **divertido**	Me ha parecido **super divertido**

12. Si tuvieras más tiempo, ¿te gustaría seguir jugando a ENFEN en la Tablet?

No me gustaría nada seguir jugando	**No me gustaría** seguir jugando	**No me importa** jugar o no	**Me gustaría** seguir jugando	**Me encantaría** seguir jugando

13. ¿Les vas a contar a tus amigos que has jugado a ENFEN en una Tablet?

No les voy a decir nada a mis amigos	**A lo mejor les digo algo** a mis amigos	**No lo sé seguro**	**Seguramente les diga algo** a mis amigos	**Se lo voy a contar a todos** mis amigos