TU WIEN Informatics

Analyse, Design und prototypische Implementierung einer Früherkennung von Schlaganfällen in Serious Games

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieurin

im Rahmen des Studiums

Medizinische Informatik

eingereicht von

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an der Fakultät für Informatik
der Technischen Universität Wien

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Wien, 24.03.2022

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Informatics

Analysis, design and prototypical implementation of an early recognition of strokes in serious games

MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieurin

in

Medical Informatics

by

Mihaela Frenzel
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to the Faculty of Informatics
at the Vienna University of Technology

Advisor: Ao.Univ.Prof.i.R. Dipl.-Ing. Mag.rer.nat. Dr.techn. Rudolf Freund

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Danksagung

Ich danke meiner Familie für die endlose Unterstützung. Meinen Kindern die mir stets willkommene Abwechslung waren sowie meinem Mann der mich jahrelang begleitet und prägt. Meinen Eltern, wortlos wie bedingungslos.

Ich danke meinen Betreuern für die unendliche Geduld und viel wissenschaftlichen Input.

Ich danke vielen, die mich auf meinem persönlichen und beruflichen Weg begleitet haben und deren Begegnungen mir Motivation zum Vervollständigen dieser Arbeit geliefert haben.

Kurzfassung

Ein Schlaganfall ist ein schwerwiegendes neurologisches Krankheitsbild. Die Zerstörung von Gehirnzellen resultiert in Symptomen über den gesamten Körper verteilt. Je früher ein Schlaganfall erkannt wird, desto besser die Chancen mittels Therapie langfristige Störungen zu vermeiden. Zumeist ist eine langwierige Rehabilitation notwendig. Dies ist Grund genug um Ansätze zu erforschen die eine möglichst frühe Erkennung von Schlaganfällen ermöglichen. Serious Games begleiten derzeit oft die Rehabilitation der Folgen von Schlaganfällen, ihr Einsatz in der Früherkennung ist kaum erforscht. Dabei besteht eine fundierte Grundlage für die Durchführung neurologischer Tests wie beispielsweise der National Institute of Health Stroke Scale (NIHSS) und die darin enthaltenen Testaktivitäten ähneln durchaus den Aktivitäten in der Rehabilitation.

Während einer systematischen Literaturrecherche und der Durchführung von qualitativen Interviews entstand die Idee ein Serious Game zu designen, welches mit einer Logik für die Früherkennung von Schlaganfällen ausgestattet ist. Die Idee wurde in 8 Vermutungen und 3 Forschungsfragen zusammengefasst. Mittels Prototyping wurden die Vermutungen zu Anforderungen verfeinert, eine Logik definiert und ein Spieldesign vorgeschlagen um es im Anschluss zu evaluieren. Der Prozess wurde begleitet von vier NeurologInnen und zwei BenutzerInnen.

Um Anforderungen aus den Vermutungen für ein solches Serious Game abzuleiten, wurden ExpertInnenevaluierungen von Prototypen durchgeführt. In Summe wurden zwei Prototypen für die Logik erstellt (Card Sorting, Paper Prototype), zwei für das Spielszenario (Sketches, Wireframes) und ein (Coded Prototype) für das gesamte Konzept.

Weiters wurde der NIHSS als medizinische Grundlage für die Früherkennungslogik hinterfragt. Der Einsatz des NIHSS wurde während der ExpertInnenevaluierungen verworfen. Ein neuer Score für die digitale Erkennung von Schlaganfällen in Spielen wurde entwickelt, der Early Recognition Game Stroke Scale (ERGSS), und darauf basierend die Recognition Logic for Strokes in Serious Games (RLSG).

Zuletzt wurde nach einem Spielszenario gesucht. Mit Sketches und Wireframes konnte zugunsten eines Autorennens als Spielszenario entschieden werden, die dazugehörige ExpertInnenevaluierung diente zugleich als Proof of Principle. Spielaktivitäten wurden für das Szenario gestaltet. Als Gesamtergebnis wurde ein Konzept für das Stroke Prediction Serious Game (SPSG) sowie Anforderungen ermittelt. Eine finale Benutzerevaluierung stellt das Proof of Concept dar.

Keywords: *Health Serious Game, Diagnose Serious Game, Schlaganfall, Vorhersage, Früherkennungslogik, Digitale Schlaganfalldiagnostik*

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Abstract

A stroke is a disease that affects the brain. It destroys brain cells and causes limitations in different body functions. The earlier a stroke is detected, the more likely a good recovery is, still facing a long process of therapeutical exercises. Reason enough to explore an approach for a very early recognition of stroke symptoms. While serious games are accompanying measures during stroke rehabilitation, their usage for stroke recognition was hardly researched so far. Although the neurological test for stroke diagnosis is well documented in guidelines for example the National Institute of Health Stroke Scale (NIHSS) and the test activities are similar to the training activities.

While observing the topic with systematic literature research and qualitative interviews, the idea evolved to design a serious game with an early recognition logic for strokes. The idea was outlined in eight assumptions and three research questions. In a prototyping process, the assumptions were transformed into requirements, a logic was defined and a game design was proposed and evaluated. The process was attended by four experts in the field of neurology and two users.

The first research question dealt with the requirements such a game needs to fulfill. Therefore, the assumptions were verified with expert evaluations of designed prototypes. In summary, two prototypes were designed for the logic (card sorting, paper prototype), two for the game scenario (sketches, wireframes) and one (coded prototype) for the whole concept.

Second, the NIHSS was questioned as the medical basis for the recognition logic. The evaluation revealed that a new game stroke scale was necessary. Consequently, the Early Recognition Game Stroke Scale (ERGSS) was developed and based on this, the Recognition Logic for Strokes in Games (RLSG).

Third, a proposal for a game scenario was searched for. With sketches and wireframes, a car race was identified as a suitable game scenario and the expert evaluation served as proof of principle. Game activities within the car race scenario were designed and resulted in the concept of the Stroke Prediction Serious Game (SPSG) and a set of requirements. A final user evaluation of the coded prototype was done as proof of concept.

Keywords: *Health Serious Game, Diagnose Serious Game, Stroke, Prediction, Early Recognition Logic, Digital Stroke Diagnosis*

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1 Introduction

Digital games with characterizing goals (e.g. learning or health) are named “Serious Games”. *Health Serious Games*, in the field of stroke disease, support the rehabilitation of stroke disorders as demonstrated in chapter 2.2.1. They offer an entertaining possibility for countless repetition of the same activities. This ensures persistent motivation for the brain training activity.

A Health Serious Game could help to close the gap between unrecognized subtle indications for a stroke and the occurrence itself. But, at the moment there is no translation of the diagnostic process into a gaming scenario.

Following chapters describe how the process of diagnosing a stroke disease is transformed into a digital game with an early recognition logic. This kind of diagnostic serious game for the stroke disease is an unstudied research domain so far.

1.1 Problem Statement

A stroke is a disease that affects the brain. It occurs either when a blood vessel is blocked (thrombus) or when it ruptures (brain lesion), in both cases brain cells are damaged. Depending on the area of the brain, that is affected, a body function might not work as it should. These post stroke limitations are manifested in movement disorders or speech difficulties.

There are cases when a stroke comes along with a condition named transient ischemic attack (TIA) that is known as precursor or mini stroke where the symptoms cure within 24 hours. About 10 % of the patients suffer from another stroke within 48 hours to 7 days later. A TIA itself often remains unnoticed but a medical consultation and treatment could significantly lower the risk for another stroke with serious brain damage [1]. In any case, stroke or mini stroke (TIA), the key to a successful treatment is a very early detection of symptoms. [2]

For this purpose, digital solutions such as wearables, are able to measure specific vital signs on a regular basis. The problem is that the disease pattern of a stroke is very wide-spanned and vital signs for themselves are not able to clearly isolate precursors of a stroke. Even when combining them with risk calculations based on data from health records, there are highly diagnostic symptoms of strokes that are not considered, consequently every prediction of a stroke could be more accurate considering actual symptoms.

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There are similarities between the assessment activities for the diagnosis of strokes and the training of disorders, but there is no attempt for a gamified machine support for the neurological test. Although, there might be good interpretations of the test activities within a game scenario. An example is the test of the visual field. While a neurologist is using its hands to test if the patient sees anything in the far right field of view, it would be possible to display a symbol in a game scenario, track if it is spotted and offer rewards to the player while the information is processed with respect to the persisting stroke risk.

A promising state of the art approach for stroke recognition is an mHealth application that uses the smart phone and its camera to analyze facial movements and speech disorders [3]. These symptoms are very informative but without the current vital signs they could easily indicate a mimic. As well, the application is not integrated in an every day activity of risk patients and it offers only a snapshot at a specific time. Computer games are better integrable in the every day life and already in use for the rehabilitation of stroke disorders.

Different studies illustrate how health serious games are used for the diagnosis of other neurological diseases, e.g. Parkinson [4] and Alzheimer [5]. But currently there is no literature about serious games for the diagnosis of the stroke disease [6]. Questionable is why the Alzheimer game attempt doesn't offer any up to date reports.

1.2 Motivation

A serious game with the purpose of the early recognition of strokes is a ground-breaking approach for preventing people from serious irrecoverable brain damage. The target group for such a game could almost be everyone. Depending on the scenario of the game it can focus on kids as well as on elderly people.

Reasoned by a higher occurrence of strokes for elderly people with risk factors, this work will focus on the digital natives in their high age as target group. It is expected that the translation of stroke diagnosis in a gaming scenario will require tools from the wide range of Health IoT and that there is a good acceptance of all these tools preexisting in this target group.

1.3 Aim of the Work

The aim of this work is the development and evaluation of a prototype of a serious game that recognizes strokes. Well established medical guidelines are the only existing basis for research and requirements analysis. With expert evaluations of prototypes a reasonable set of requirements and a game concept is envisioned. A user evaluation is used to proof this concept.

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Research questions to be answered are:

- RQ 1: Which requirements for a stroke recognition serious game can be defined, using qualitative interviews and prototyping evaluations with neurologists and therapists?

To answer this question it is necessary to perform a requirements analysis with research on existing serious games for strokes and the diagnosing process itself. Interviews with professionals help to understand the topic in detail, to form a potential idea by brainstorming and to define the corresponding assumptions. These assumptions are transformed into validated requirements by evaluating different prototypes. Chapter 4.1 describes the research phase while chapter 4.4.1 lists the resulting requirements in detail.

- RQ 2: Which medical guideline can serve as basis for the recognition logic?

To answer this question prototypes are designed based on the gained knowledge about medical guidelines. An evaluation with experts allows a fundamental decision about the usage of existing guidelines for a recognition logic in a game scenario. Chapters 4.2.1 – 4.2.4 answer this question.

- RQ 3: Which serious game design can cover the defined requirements?

The research about serious games offers a wide range of game scenarios that are re-usable for an early recognition of strokes. To decide about the best suitable game design it is necessary to consider the outcome of the previous questions. The game setting, the scenarios and the activities are defined in a way that all requirements are covered. More refined prototypes are used to demonstrate and evaluate the idea with experts and users. Chapters 4.2.5 – 4.2.7 illustrate this answer.

1.4 Structure of the Work

Chapter 2 is giving an overview of the necessary knowledge areas for the evaluation process of a game based early recognition of strokes. It outlines the characteristics of the stroke disease, describes serious games and details about algorithms. Internet of medical things summarizes potential data sources for health data and the prototyping process is outlined.

In chapter 3 medical scores for the stroke assessment, the NIHSS as well as prehospital scales, are described. Existing serious games that represent the idea of diagnostic games are outlined.

Chapter 4 outlines the research results in the three subchapters research, analysis & design and implementation. A subchapter for the realization of the prototypes was introduced to allow a deep dive in the details of the evaluation.

The results are followed by a discussion in chapter 5 and answers to the three research questions.

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The last chapter summarizes the findings and points out future research questions to be answered in this context.

1.5 Methodology

By nature, this topic is characterized by numerous variables and uncertainties. A carefully planned usage of methods from explorative prototyping helps to transform an idea into a well engineered system with a set of functional requirements. [7]

Figure 1 illustrates the whole process that begins with a research phase (green) for the observation of the whole topic and the idea. It is followed by the analysis & design (yellow) where different prototypes are evaluated. Their outcomes are transformed into scientific and technical results. At last, a prototypical implementation (orange) of the designed concept is used for user evaluation.

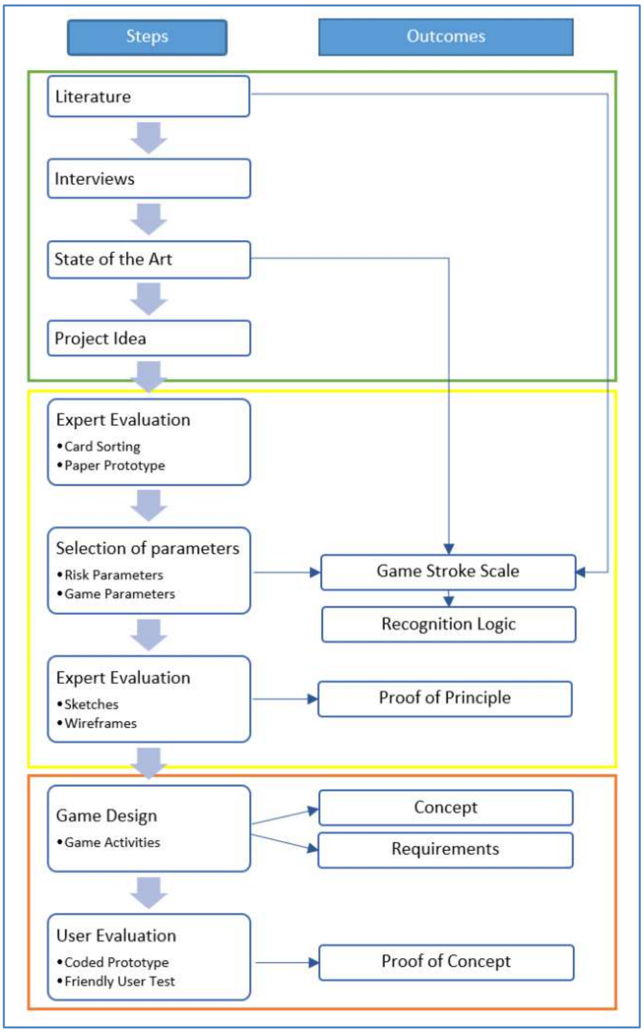

Figure 1: Introduction Methodology

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For the observation of the stroke disease it is necessary to research existing literature. Arising questions are clarified with interviews with experts in the field of neurology and therapy. The gained knowledge is aligned with state of the art attempts of serious games. All gathered information is aligned into one project idea.

The idea and designed principle is proofed with 4 prototypes. First, expert evaluations are focusing on the recognition logic, then on the game scenario. Card Sorting and a Paper Prototype are realized for the clustering of medical information and for the evaluation of an early recognition logic based on selected parameters. For the design of a game scenario Sketches and Wireframes are the best suitable techniques as well as for the proof of principle.

The evaluation of the final game concept and its requirements is done with potential users and a coded prototype that illustrates the game design and its activities.

In general, during the whole process, neurologists are asked about the applicability of the gathered medical data for their decision about a stroke risk. Users are involved from a user centered design perspective to evaluate usability and user experience [8]. In the end there is a prototype for a serious game that recognizes strokes that is verified by experts in the field of neurology and evaluated with potential users.

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2 Fundamentals

For the evaluation of a diagnostic serious game it is necessary to incorporate different knowledge areas. On the one hand basic medical knowledge in the field of neurology is required. On the other hand technical knowledge is necessary as well as an overview of existing serious games and software engineering methodologies. Therefore, subsequent chapters are about the stroke disease, serious games, algorithms, internet of medical things and prototyping.

First, the anatomy of the brain is explained, followed by a rough overview of the etiology (g. “reason”) and pathogenesis (g. “development“) of the brain disease *Stroke*. It helps to identify potential fields of body impairments that could be detected by gaming data sources.

Then, the use of *Games* in serious concerns and its evolution is illustrated in some examples. It guides through different scenarios as inspiration and points out facts that need to be considered for the development of a health serious game.

Fundamental basics of *Algorithms* are described as they are necessary to analyze and understand existing algorithms in the field of medicine. The knowledge is necessary for the development of an early recognition logic.

To extend the gaming setting from classic desktop games to a whole-body scenario that includes more data sources, the basics of *Internet of Medical Things* (IoMT) are outlined.

The methodology which is used to form a good state of the serious game is named *Prototyping*.

2.1 Strokes

For a general understanding of the stroke disease, the anatomy of the brain is explained and its functional areas are illustrated. Subsequent chapters outline the different stroke categories as well as the medical examination.

The brain, as part of the central nervous system (CNS), controls the functions of the human body. It is, very simplified described, split into the cerebellum (lat. “little brain”) and cerebrum (lat. “brain”), besides the right and left hemisphere, as illustrated in Figure 2 and Figure 3. [9]

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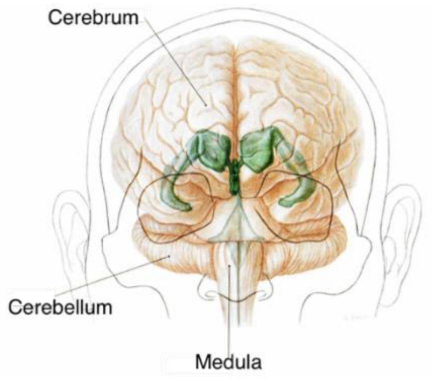

Figure 2: Central Nervous System, frontal [10]

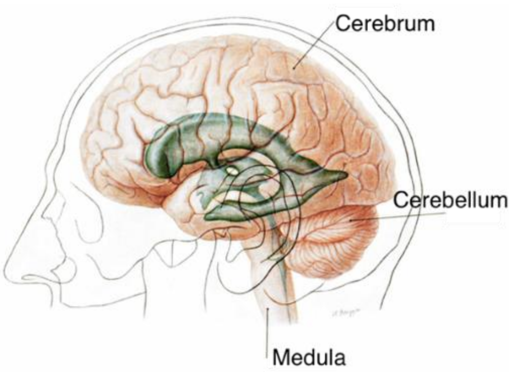

Figure 3: Central Nervous System, lateral [10]

The cerebrum is divided into five areas, each responsible for another function of the body as visible in Figure 4, Figure 5 and Figure 6. [9]

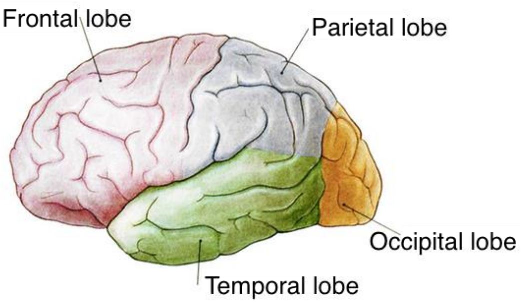

Figure 4: Cerebrum lateral [10]

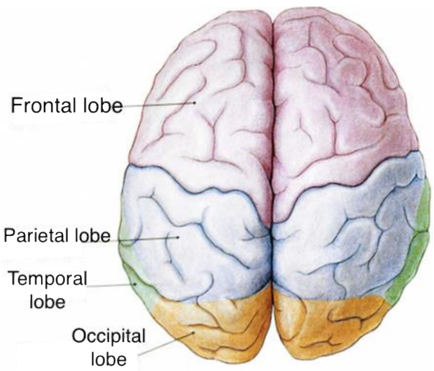

Figure 5: Cerebrum caudal [10]

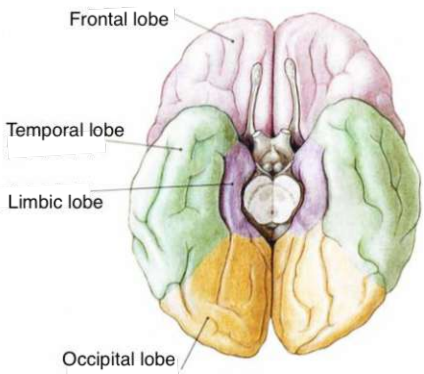

Figure 6: Cerebrum cranial [10]

The frontal lobe is mainly controlling speech and motor activity while the parietal lobe is responsible for touch and body awareness. Language is a comprehensive activity while vision is exclusively supported by the occipital lobe. Hearing and facial recognition are controlled by the temporal lobe. The limbic lobe (visible in Figure 6) is keeping memories and plays a key role in the learning ability. If it happens that a part of the brain is disturbed by some reason, it results almost

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immediately into symptoms representing the body function that is controlled by this area. [9]–[11]

2.1.1 Stroke Categories

It is possible to categorize strokes by different aspects. From the etiological point of view there are two main categories of strokes. 80 % of all strokes are ischemic, 20 % are hemorrhagic. [12]

The *ischemic stroke* is characterized by a blood vessel that is blocked by a clot, named thrombus. If the thrombus was moving from another part of the body, e.g. the heart, the condition is named embolism. If the blood vessel is too narrow to assure cerebral perfusion the condition is named stenosis. A *hemorrhagic stroke* is caused by a ruptured blood vessel. The blood compresses and destroys the surrounding brain tissue. [9]

When, because of the disturbed blood flow, the oxygen supply of brain tissue drops to less than 30 %, the patient suffers from neurological deficits. These deficits are irreparable if the oxygen supply is less than 15 % or the ischemia remains existent for too long. A complete recovery is only possible if the clot dissolves early enough and the blood supplies the brain tissue with oxygen again. How much time there is between the onset and the cell death is depending on the area and characteristics of the stroke. It varies from minutes to hours. [13]

Figure 7 and Figure 8 illustrate the ischemia with a blocked vessel and the hematoma with a ruptured vessel.

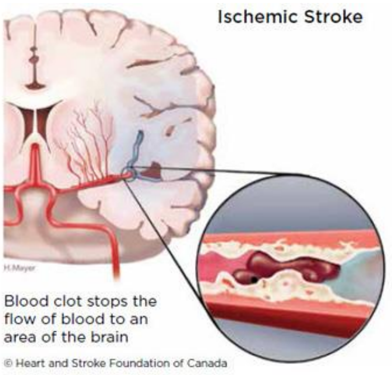

Figure 7: Ischemic stroke [14]

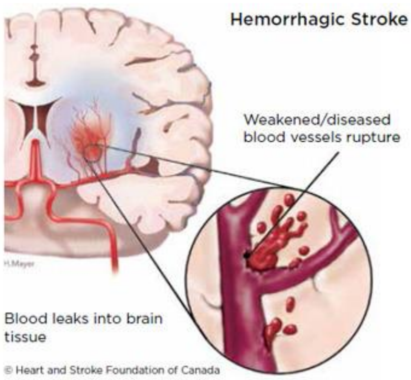

Figure 8: Hemorrhagic stroke [14]

Causes for vascular disorders that result in a cerebral (lat. "brain area") ischemia or intracranial (lat. "skull") hematoma are based upon heart diseases, hypertonia, arteriosclerosis, diabetes, and high cholesterol, to mention only the most frequent ones at present. [9]

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Unfortunately, the differentiation between ischemic and hemorrhagic stroke is only possible with neuro-imaging but gladly the stroke itself is a clinical (on-site) diagnose. It must be considered that some other disorders produce nearly the same clinical pictures as strokes, they are named *Stroke Mimics*. Neurologists can distinguish between strokes and stroke mimics by giving attention to 47 clinical factors that are scientifically proven in a study in 2006 [15].

The progression of an ischemic stroke allows a categorization as in Table 1.

#	Stage	Clinical Manifestation
I	Undefined	Asymptomatic stenosis
II	Transient ischemic attack	Complete regression of symptoms within 24 hours
III	Progressive infarct	Discontinuous increase of neurological deficits for hours, partially reversible
IV	Cerebral ischemia	Sudden appearance of irreparable neurological deficits

Table 1: Stages of strokes [9]

Giving attention to stage II, the TIA, its complete recovery makes it nearly impossible for a neurologist to identify it clinically. Even the patients themselves do not remember any disorders. In general, neural imaging is allowing the diagnosis at a later date in 50 % of all TIAs. [16]

The characteristic of a TIA is based upon the dissolving of a blood clot. As seen in Figure 9 and Figure 10, the blocked blood stream and its increased pressure can lead to a decomposition of the clot into small particles which allows the blood to flow again. [11]

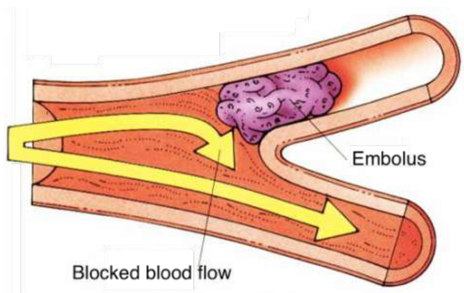

Figure 9: TIA, blocked blood flow [11]

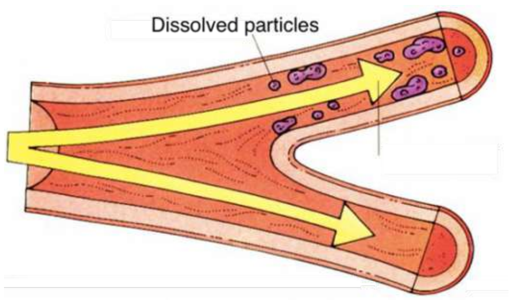

Figure 10: TIA, dissolved particles [11]

By the current state of scientific knowledge, a TIA should be medically treated similar to a cerebral ischemia even if it regresses. Per statistics, up to 10 % of the patients with a TIA suffer from another stroke with major implications within 7 days. Considering the risk factors of the ABCD-

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score described in chapter 2.3.3, it is even possible to estimate the recrudescence risk optimally adapted for a specific patient [17].

2.1.2 Medical Examination

The American Stroke Association sums up a few symptoms that should be considered as serious indication for a stroke. The most common signs are face drooping, arm weakness and speech difficulty. [18]

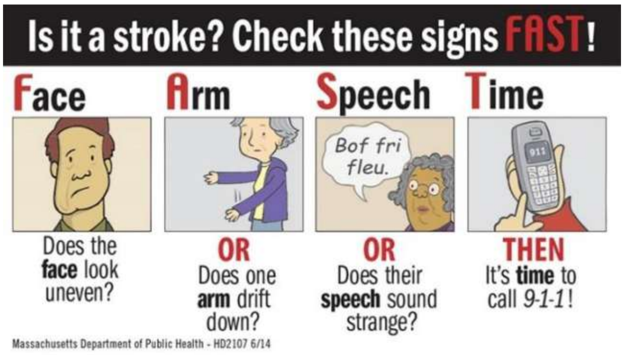

Figure 11: Face Arm Speech Time (FAST) [19]

Immediate medical treatment is of high importance because time is the factor that indicates how comprehensive the brain damage is going to be. To initiate appropriate treatment, it is necessary to assure which category of stroke the patient is suffering from. The thrombolysis, a treatment for an ischemic stroke, can have lethal effect on a patient having a hemorrhagic stroke as it intensifies the existing bleeding. [12]

2.2 Serious Games

A serious game is a digital game created with the intention to entertain and to achieve at least one additional goal (e.g., learning or health). These additional goals are named characterizing goals. [20]

Serious Games are classified within different levels. One level is the discipline which, as visible in Figure 12, might be pedagogy or psychology. Another classification is done by the used technologies and disciplines e.g. AI, HCI, sensing and graphics. For the purpose of this work the classification by application areas is considered. While the focus here is on *Health Serious Games*, there are many other domains e.g. training, education, energy (see Figure 12).

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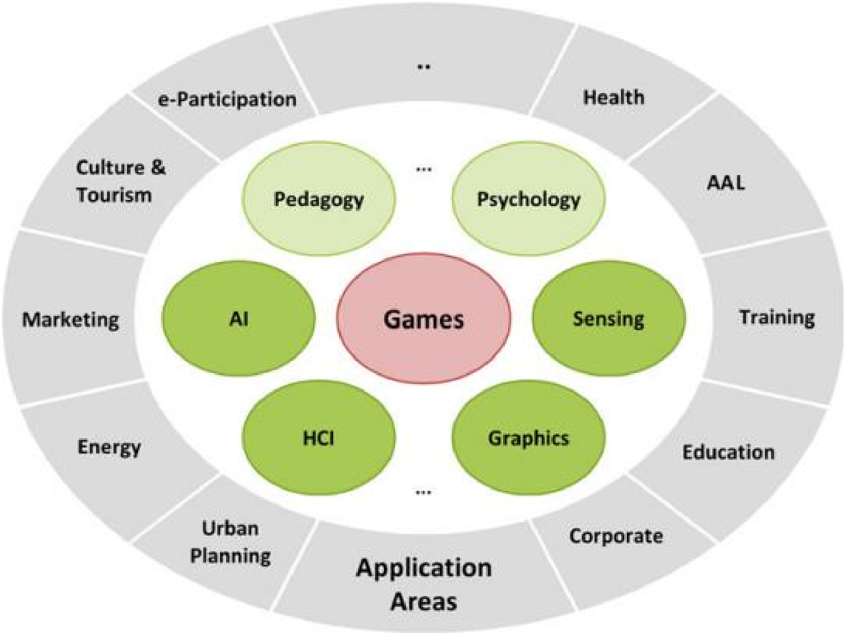

Figure 12: Serious games classification [20]

2.2.1 Serious Games for Health

Among games for training and education, serious games for health are the third most researched and developed ones. Reasoned by the global demographic changes there is a high demand for treatment of medical issues, therefore the need for digitized solutions is contemporary. The expectation is that serious games can keep the motivation in every individual high for exercising and general well-being activities so that a positive impact on the global healthcare system is achieved. [21]

Early research and development of serious games focused on the improvement on already existing health conditions which is why health serious games represent the purposes: rehabilitation, therapy and assessment (mainly within a therapy or rehabilitation process), followed by serious games for the purpose of prevention and well-being. Additionally, as the technology evolves, a new purpose developed, which is the diagnosis [21]

Other serious games that relate to the current state of the art are outlined in chapter 3. Some examples in the history of health serious games are described in the following.

Duck Duck Punch

Duck Duck Punch is one of the rehabilitation games focusing on disorders in upper extremities. It is based on a traditional carnival game. The user needs to control a virtual arm (Figure 13) to hit targets in a gallery while Microsoft Kinect motion tracking sensor is the enabling technology. [22]

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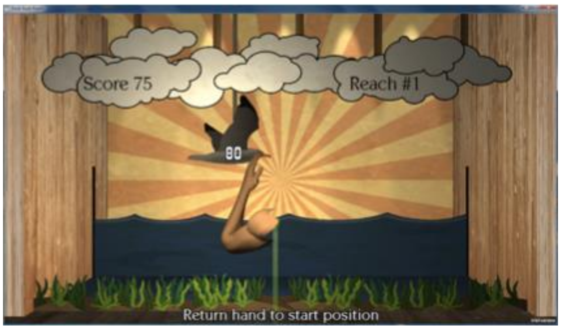

Figure 13: Duck Duck Punch [22]

Developers of this game are questioning how this game could provide the most efficient outcome for a patient. They identified some key points that are repeatedly mentioned in scientific papers dealing with games for rehabilitation. A patient would need 300-1000 repetitions of the same movement daily but according to statistics it is only possible to offer 30-50 within a therapy session accompanied by a therapist. Only a game with different levels of difficulties that are individually customizable to the capabilities of the user, could generate enough motivation to maximize movement repetitions pursuing the expected progress in rehabilitation and minimizing frustration. Furthermore, the engaged games need to be easily available at low costs [22], [23].

RehaLabyrinth

Another serious game is using the Nintendo Wii Fit Balance Board to improve balance related problems after a stroke. The Balance Board is replacing the conventional balance plate and motivation is generated with a play scheme named *RehaLabyrinth* where a ball needs to be navigated through a maze to collect stars avoiding obstacles (Figure 14 and Figure 15). Technical problems have been encountered in the connection between the Balance Board and the Bluetooth adapter when using Microsoft Windows. It could be that Apple Mac OS is the more suitable system which would support the idea of an iPad App as convenient solution within this work [24].

Figure 14: RehaLabyrinth detail [24]

Figure 15: RehaLabyrinth overview [24]

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Hungry Grizzly Bear

Speech Rehabilitation games like *Hungry Grizzly Bear* (Figure 16) or *Hanging Monkey* (Figure 17) don't give attention to post stroke patients but to children (< 2 years old) that have been treated from hearing loss with a cochlear implant. They need to develop speech abilities like post stroke patients with Aphasia do, by pronouncing specific syllables correctly [25].

Figure 16: Hungry Grizzly Bear [25]

Figure 17: Hanging Monkey [25]

Evo

Evo is a game that deals with diagnose and treatment of Alzheimer in one. People at risk of Alzheimer are identified by the amount of amyloid plaque in their brains. Current clinical trials would give an answer if there is a match between amyloid measurements via PET scan and the gameplay results. Other mental disorders e.g. ADHD, Autism, Depression, ... are planned to be covered within this game too [5].

Figure 18: Evo [5]

NeuroRacer

Researching a game that could possibly cover most of the body functions needed for stroke recognition, it is inevitable to come across Neuroscape, a neuroscience center which is part of the

University of California San Francisco with leading technologies represented in games. The already mentioned game Evo, focusing on Alzheimer and Parkinson disease, is produced by this lab. *NeuroRacer* is a car racing game from the same lab with a single and multitasking mode developed for training the brain health of elderly people. As in Figure 19 the person is constrained to perform two actions simultaneously, driving a car on a road and pressing a button when a specific sign is displayed. The response time and the accuracy of the performed actions are tracked. During an experiment it was remarkable that patients who played the game at home for one month, improved their brain activity significantly. [26]

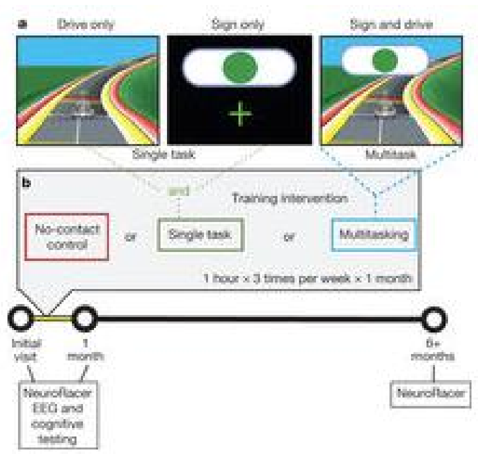

Figure 19: NeuroRacer training design [26]

Figure 20: NeuroRacer game scenario [26]

2.2.2 Serious Game Development

The development process for health serious games needs health-related competence from the very beginning. These area specialists work iteratively with game designers and game engineers in a team. Other than in entertainment games, where the game experience is the most essential success factor, in a serious game it is important that the characterizing goals are met. [20]

In case of the game PhysioVinci the goals were defined by analyzing the exercises performed in physical therapy sessions. The decision to focus on the six movements in Figure 21 based on the commonness of an impairment in this area and on the possibility to monitor the movements by image processing techniques. [27]

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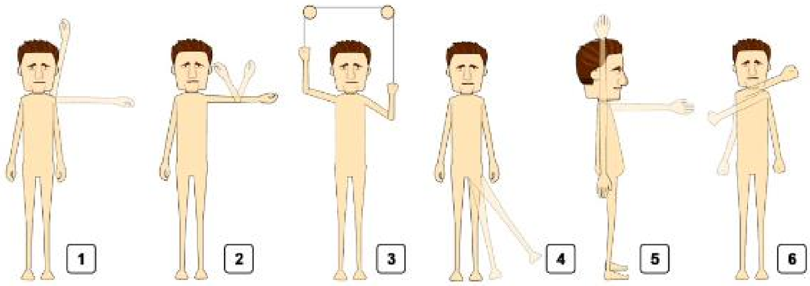

Figure 21: PhysioVinci exercises [27]

Game designers mainly need to fulfil two tasks. The first is to maintain the challenge for the player during the game at the right level. The second is to motivate players to continue playing. Storyboards and other prototyping methods (see chapter 2.5.1) are used to iteratively create better results to these requirements. [20]

Figure 22 represents the storyboard for one level of PhysioVinci. At the beginning the words "waiting for player" are displayed while a stabilized flight needs to be followed by the player. As soon as the player holds its arm in the right position, the flight is taken over and navigation continues by the movements of one arm. In this exercise the second arm is mirrored as the physical impairment exists only in one arm. If the position of the arm is wrong the flight is destabilized and the flyer starts to fall. [27]

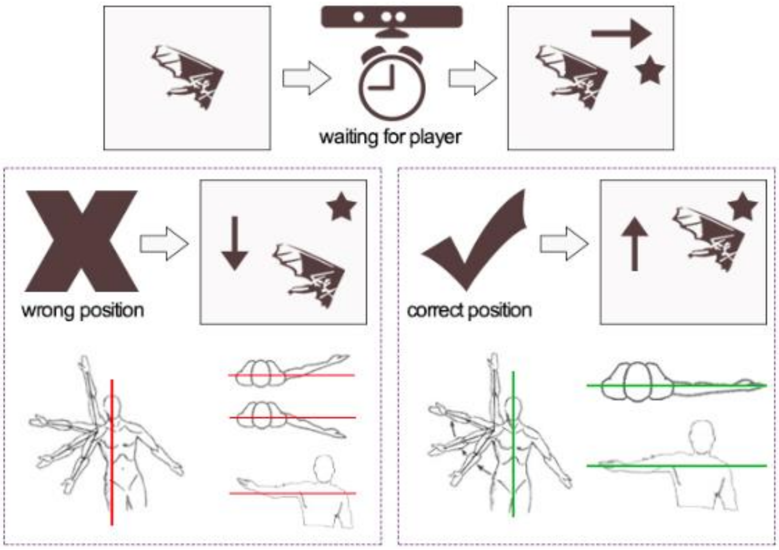

Figure 22: PhysioVinci storyboard [27]

The translation from a serious game on a conceptual design level to an implemented software is done by game engineers. Reasoned by the complexity of this task, the software design paradigm "Divide et impera" (cf. "Divide and Conquer") is used to break down the system into many subsystems and steadily deal with smaller problems. [20]

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The architecture of a game, as in Figure 23, illustrates the interaction of components to form the entire digital game. The Game Runtime Environment operates between the User Interface and the Operating System. It is based on a Platform Independence Layer and contains a Main Loop which deals with all the data that needs to be updated regularly during a game session. The asset data is handled by the Resource Manager, and the game data by the Game Data Manager. An Input Handler and an Output Generator serve the purpose of exchanging information with the user via its User Interface. Multiplayer Management is mostly realized on a separate server. [20]

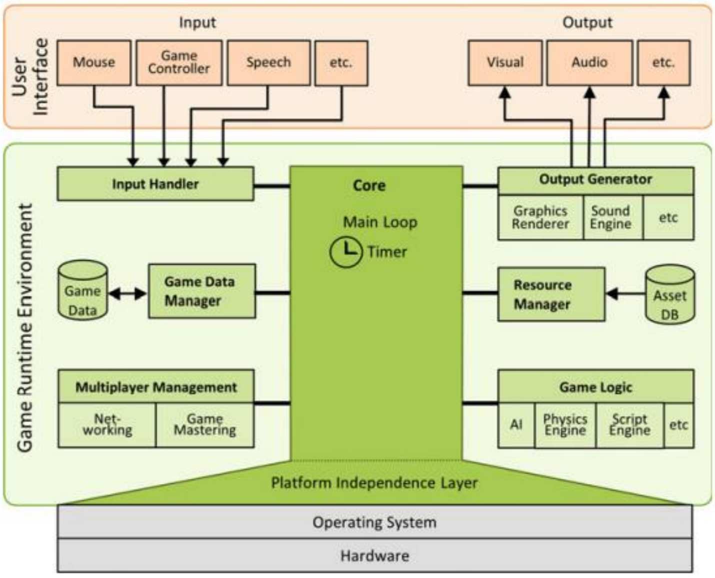

Figure 23: Game architecture at runtime [20]

Figure 24 is another illustration of a serious game for training the every day activity "Preparing Coffee". Here there is GlovePIE between the Operating System and WiiMotion, which is responsible for the interpretation of the data of the Wiimote. GlovePIE is connecting the Wiimote's controls with those of the PC mouse thus forwards data from the OS to WiiMotion. [27]

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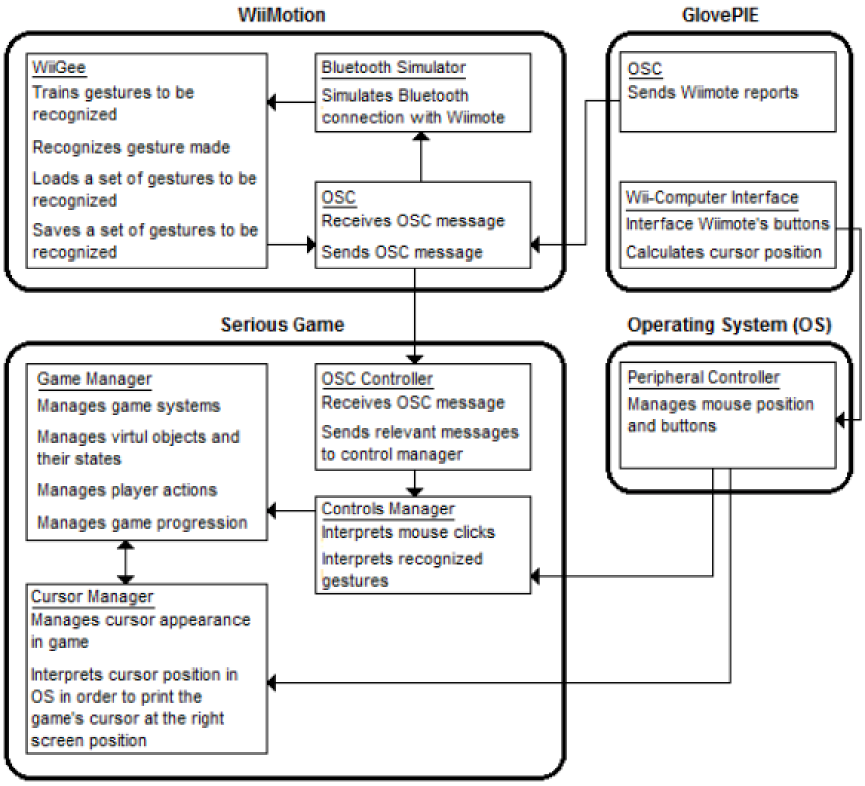

Figure 24: Serious game with gesture recognition system [27]

When choosing input devices within a serious game it is absolutely essential to examine their usability appropriateness. As visible in Figure 25, touchpads and eye mice are not suitable at all for the use with players with cognitive impairments. [28]

Device \ Disability	*Motor*	*Cognit*
Trackball	*	*
Touchpad	*	
Joystick	*	*
Head mouse	*	*
Eye mouse	*	
Touch screen	*	*
Actigraph	*	*
Gesture remote	*	*

Figure 25: Input devices suitability [28]

2.2.3 Serious Game Devices

Serious games require, depending on the purpose, smart input devices that enable the collection of supportive data that is processed within the game. The NeuroRacer game, mentioned in chapter 2.2.1, is a good example for an extended setup within the game.

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Smart wheels and pedals, as well as a multi-monitor setup, can offer a lot more information about the player then the regular joystick and laptop screen.

Smart Steering Wheel

In the automotive industry there is a big interest in automated driving and automotive safety. This is the reason that steering wheels are continuously researched and enhanced. In [29] a wheel is presented that is equipped with sensors for the detection of the hand position. Figure 26 visualizes green LEDs (A1 – A6) that cover the area where a human hand can be detected. This technology helps to identify if the hands of the driver are on or off the wheel, which would lead to safety conclusions in the drive mode. [29]

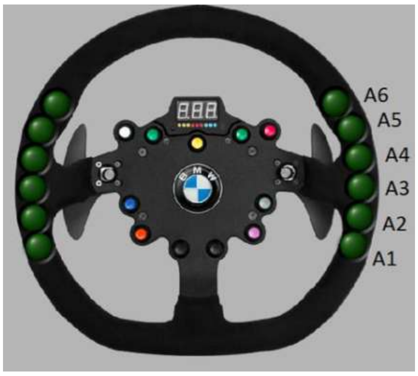

Figure 26: Smart steering wheel with sensors for hands on/off detection [29]

Another approach is the direct monitoring of cardiovascular health parameters (ECG, PPG, oximetry) and driver behavior with a smart wheel visible in Figure 27. Aim here is the detection of fatigue. [30]

Figure 27: Smart steering wheel for unobtrusive health monitoring

Smart Pedal

A pedal, see Figure 28, comes often in a set with the steering wheel. It would be necessary to extend it with technologies for measuring differences in the muscle power.

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Figure 28: Car race pedal exemplary [31]

Unfortunately, when it comes to measuring pedal muscle activities, the current focus is on the use of foot-wearables as they offer the possibility to track body vital signs e.g. heart rate [32] in addition.

Multi-Monitor Setup

A multi-monitor setup, as visible in Figure 29, extends the visual field of the player and is a popular gaming setting to visualize real life simulations. Therefore a set of monitors, preferably curved for the car racing scenario, are connected and the display configuration extended.

Figure 29: Multi-Monitor setup in a private apartment

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2.3 Algorithms

Solving problems with algorithms has been done long before digital devices existed. Euclid's algorithm for finding the greatest common divisor of two numbers is an often-cited example and is more than two thousand years old [33], [34].

Starting with the characteristics of algorithms and Euclid's algorithm in different languages, the subsequent chapters point out the design factors for algorithms. The most frequent algorithms are outlined and a medical algorithm is explained.

An algorithm is a step-by-step instruction in traditional spoken or written language or in computer language to solve a well-defined problem. It has some basic characteristics: [35]

- Finite
- Deterministic
- Effective

Euclid's algorithm in natural language [34]**:**
Compute the greatest common divisor of two nonnegative integers p and q as follows:
If q is 0, the answer is p. If not, divide p by q and take the remainder r. The answer is the greatest common divisor of q and r.

Euclid's algorithm as Java-language description [34]**:**

Code01

```
public static int gcd(int p, int q)
{
      if (q == 0) return p;
      int r = p % q;
      return gcd(q,r);
}
```

Both descriptions of Euclid's algorithm are defined as recursions. While a recursion is a method that (re-) calls itself, an iterative algorithm does specific steps as long as a condition is reached. Euclid's algorithm is defined as iteration as follows:

Euclid's algorithm as iterative pseudocode:

Code02

```
Divide m by n, remainder is r
If r = 0 > End
Else m = n, n = r >REPEAT
Continue until r = 0
```

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2.3.1 Design of Algorithms

To be able to decide about the best suitable algorithm for a specific aim, there are some variables that need to be considered: [35], [36]

- Data Structure (linear, hierarchical, other)
- Design (recursive, greedy, divide & conquer, …)
- Purpose (sorting, searching, …)

Data structure

Algorithms are strongly connected to data structures. Each algorithm is performed on a set of data, it depends on the organization of the data which types of algorithms lead to best results. As well, algorithms could be used to (re-) organize the data itself and generate an optimized data set for the use of an algorithm for a specific purpose in a next step. [35]

Existing data structures are: [35]

- Linear (List, Stack, Queue, Array)
- Hierarchical (Tree, Heap, Trie)
- Other (Hash Map, Graph, Matrix)

Design of Algorithms

Taking an unorganized and random example, there might be a box with balls each having a different number from 0 – 100 on it. Searching for the ball with the number 42, it would be possible to find the ball by simply taking one out of the box, checking the number on it and repeating. These steps formally described would define a "Brute Force Algorithm". An algorithm that "forces" the execution of some steps without learning effects or simplification of the given search area. In most cases this approach is not enough which is why many algorithms for specific reasons exist. [33]

Well-known design methods are: [36]

- Recursive
- Greedy
- Divide & Conquer
- Dynamic Programming
- Branch & Bound with Backtracking
- Brut Force

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Purpose of Algorithms

The purpose of an algorithm is given as: [36]

- Sorting (Merge, Quick Sort, …)
- Searching (Linear, Binary, …)

Further examples, but not as important as those two, are: Insert, Update, Delete [34]

Analysis of Algorithms

An iterative algorithm differs from a recursive in the use of resources. When defining new, analyzing or choosing suitable existing algorithms the necessary resources always need to be considered. While both expressions would lead to a result, the recursion would mostly be more time consuming. Therefore, any algorithm needs to be analyzed considering time and memory usage. The analysis can be done as

- Worst Case
- Average Case
- Best Case

Typically, the worst case is measured to be on the sure side and the average case to declare an expected consumption. [33], [35], [36]

2.3.2 Frequent Algorithms

A frequently used sorting algorithm is Quicksort. It utilizes the divide & conquer method where a big problem is divided in many subproblems and solved in sub steps. [36]

QuickSort

Figure 30 illustrates the algorithm that expects an array of items to be sorted. [36]

Code03

```
QuickSort(item a[i..j])
  item x; index l, r; boolean loop ← true
  if i < j
    then x ← a[j], l ← i, r ← j − 1
         while loop do
               while a[l] < x do l ← l + 1
               while a[r] > x do r ← r − 1
               if l < r
                  then exchange a[l] and a[r]
                       l = l + 1, r = r − 1
                  else  loop ← false
         exchange a[l] and a[j]
         QuickSort(a[i..l − 1])
         QuickSort(a[l + 1..j])
```

Figure 30: Quick Sort [36]

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In a loop it sorts two items of a subset by exchanging their positions if necessary. It selects the item at the last position as pivot element, sorts all smaller items on its left and all bigger items on its right side. The left is a subset where again the last position is defined as pivot element. This is continued until no further items exist, in the end all the items are assembled.

Binary Search

Another algorithm that uses the divide and conquer strategy is the Binary Search. It expects a set of items and the item to search for. Figure 31 illustrates the algorithm. [36]

Code04

```
index BinSearch(item a[0..n − 1], x)
index l, r, i
l ← 0, r ← n   1
repeat
    i ← (l + r) div 2
    if a[i] < x
      then l ← i + 1
      else  r ← i − 1
until a[i] = x or l > r
if a[i] = x
  then return i
  else  return  − 1
```

Figure 31: Binary Search [36]

The searched item is compared to the item in the middle of the (sub-) set of items as long as the item is found.

2.3.3 Medical Algorithms

Clinical scores and scales are representations of medical algorithms. They exist for different fields of healthcare treatment, including diagnostic, therapeutic and care activities. They are the result of one-time or constant evaluation of the patient’s condition [37].

The *Barthel Index* is an example for evaluating the patient’s need of care helpers. It consists of items that represent everyday activities e.g. Eating, Showering, … . The higher the score a patient reaches, the higher the level of independency. The level and type of assistance is depending on the reached score. [38]

The most important score for neurologists is described in chapter 3.1 as well as others in the following.

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2.4 Internet of Medical Things (IoMT)

Medical data is produced in various areas of our lives. Some applications collect and offer data of medical equipment while others are dealing with data of individuals. Figure 32 divides the IoMT applications in body and object centric applications that come into use in- or outdoors. As well as the Medical Equipment Tracking and Maintenance, the Electronic Health Record is categorized as an object centric application indoor. In contrast to body centric applications, that monitor or support the data interaction with body signals, the EHR collects data about the patient seen as the object of the EHR. [39]

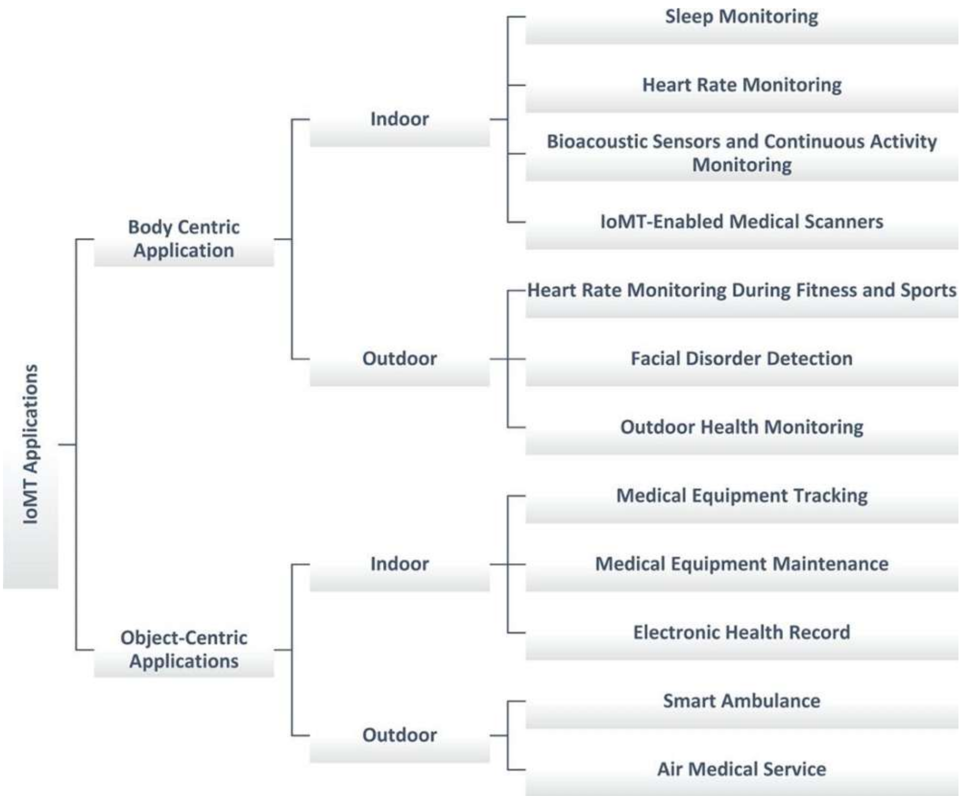

Figure 32: IoMT applications [39]

2.4.1 Patient Record

Around the world there are different approaches for the realization of an Electronic Health Record (abb. “Patient Record”, “PR” or “EHR”). It is a virtual medical record that offers insight about the patients health state, time and location-independent, to authorized persons. In Austria the realization was named ELGA (**EL**ektronische **G**esundheits**A**kte) and started with pre-projects in 1980 [40].

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By now, year 2021, the health record is implemented in the whole country offering functionalities e.g. patients discharge letter, e-medication and electronic reports from laboratory and radiology. Further discussions about the integration of data from smart devices are ongoing.

For the purpose of this work it is considered that the patient record offers [40]:

- Demographic data of the patient (e.g. age)
- The medical history (e.g. diabetes, cardiovascular diseases)
- The medication (e.g. blood glucose regulator)

2.4.2 Wearables

An important role in early recognition goes to wearables or even smart clothes. They come into operation in two different ways in the health system. First, they offer data for continuous tracking. Second, they can supply immediate information about the current state of health parameters.

In particular, two noninvasive monitoring technologies for cardiovascular functions are in use; the ECG (electrocardiography) and the PPG (photoplethysmography), each with several measurement sites for the corresponding devices, as visible in Figure 33. [41]

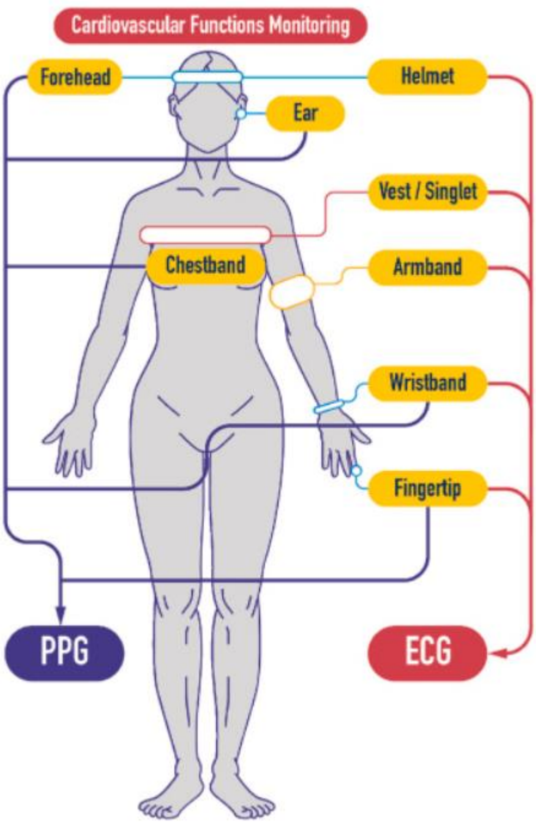

Figure 33: Measurement sites for wearable devices [41]

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A smart watch with PPG monitoring is considered as the best approach in this paper for the reason that it offers values for more than one health parameter with one device. Photoplethysmography is a low cost method for measuring the pulse wave of blood vessels. It works on the principle of a pulse oximeter. [42]

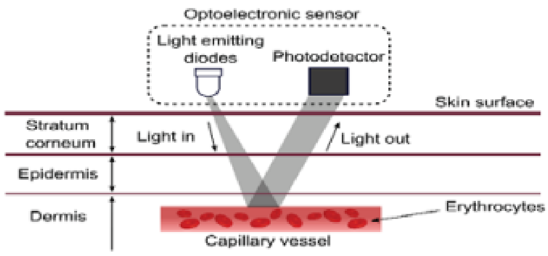

Figure 34: Principle of PPG [42]

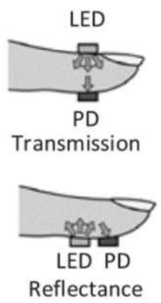

Figure 35: Transmission, reflection-type PPG [43]

As visible in Figure 34 and Figure 35, a sensor emits light to the skin and measures the intensity of the light which is reflected back (reflection-type PPG, rPPG) or transmitted through the skin (transmission-type PPG). [43]

For wearable devices, reflection-type PPG is commonly used, it measures the health parameters [42]

- Heart Rate
- Blood Oxygen
- Blood Pressure
- Blood Glucose

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2.5 Prototyping

Prototyping is a method to transform assumptions and ideas into software products by keeping efforts precisely adapted to the expected outcome. Not knowing if the concept is working properly or the imagined design is accepted by the user, it would cause unnecessary costs to introduce a coded, highly detailed version of the product to a stakeholder from the early beginning. [44]

It is recommended to start with a low fidelity prototype that offers enough information to validate requirements and assumptions. Continuing into as many iterations as necessary should help to move to the right level of higher fidelity. [45]

2.5.1 Prototyping Methods

There are different methods of prototyping, each better or less compatible with a specific level of fidelity. [46]

- Card sorting

  Terms are written on index cards and users are supposed to group these terms as it makes sense for them.

- Wireframe prototyping

  A drawn sketch is used to illustrate design ideas mostly within a concrete scenario.

- Storyboard prototyping

  A storyboard articulates requirements in form of a usage scenario or story where it is described how users need to take actions to perform specific tasks.

- Paper prototyping

  In contrast to the wireframe, a paper prototype is characterized by its interactivity. The paper mockup represents functionality of the user interface which is executed by the test person using manual or voice input.

- Digital prototyping

  A digital version of the paper prototype created by a non-technical person without coding skills and simple office productivity tools instead.

- Blank model prototyping

  Blank model prototyping is mostly used during early stages of product design within an internal design team. The prototype is produced using arts and crafts materials and intends to create a shared understanding of the form and operation of a design artifact.

- Video prototyping

  Video prototyping offers a good start in the software design process. It allows to produce a

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conceptual idea of the product by analyzing user roles and interactions creating a video of the system and its functions.

- Wizard-of-Oz prototyping

A human "wizard" is mimicking the interaction with a system so that the test person believes she is working with a working system.

- Coded prototyping

A coded prototype is usually used in a later phase of the software design process. It is developed in the targeted programming language and represents the outcome of earlier applied prototyping methods with lower fidelity.

2.5.2 Prototyping Process

The main goal of a prototyping process in general is to convert assumptions into formal correct requirements. To achieve this, a few iterations of prototypes are necessary, starting with a set of assumptions and ending with a large collection of firm requirements as basis for a high fidelity coded prototype. [47]

Figure 36 visualizes the progress. In step 1 there is the idea with assumptions of different categories. A quick wireframe helps to extract business requirements and a second, refined wireframe allows to create a vague impression of the business and functional requirements.

A storyboard helps to firm end user requirements by reviews with internal and external stakeholders while a coded prototype enables the validation of requirements that can be used for the high-fidelity software development.

The background color of each field represents the level of its validity, transforming from invalidated to validated.

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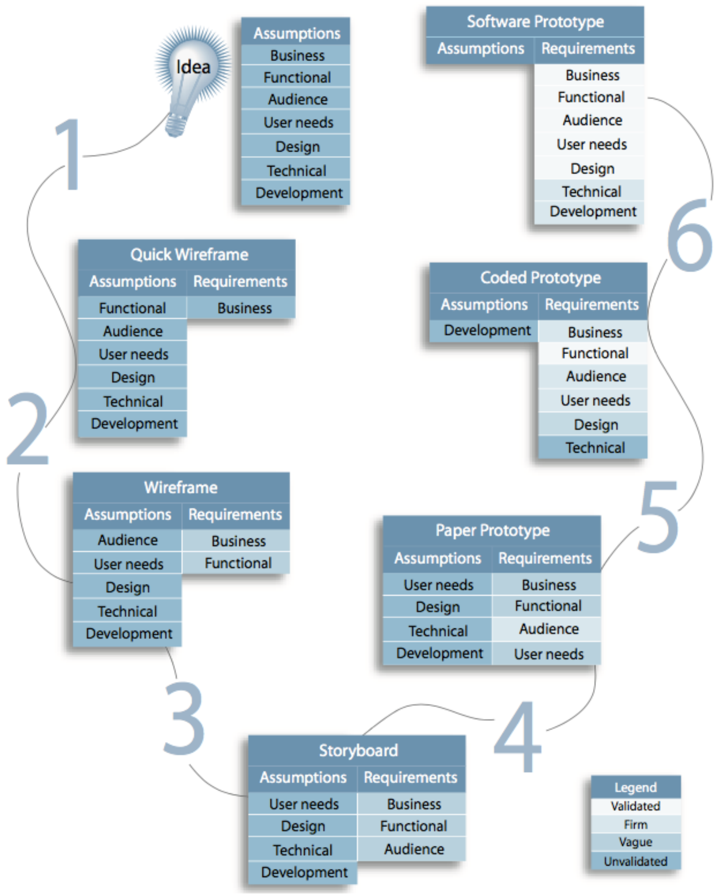

Figure 36: Transforming assumptions into requirements via prototyping [47]

2.5.3 Prototyping Model in Software Engineering

Creating a prototype is done in different steps, visible in Figure 37. After an initial requirements gathering an iteration of prototyping is started with a quick design before building the prototype that is evaluated with customers or experts and afterwards refined. The final engineering of the system is done as soon as the feedback of all iterations was formed to a clear concept. [48]

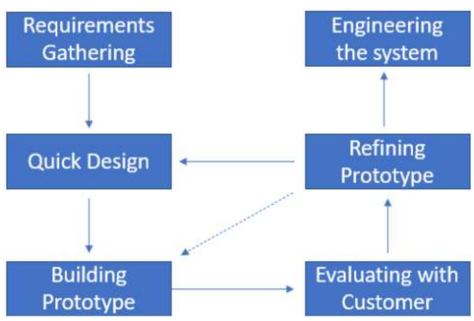

Figure 37: Prototyping design and evaluation [48]

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3 State of the Art

A diagnostic serious game for strokes is a hardly studied research domain. An essential role for doing research in this field has the state of the art of medical assessment guidelines as well as of serious games that represent the idea of symptom detection. Therefore, following chapters include the acute stroke assessment scale NIHSS and prehospital scales. Further, serious games are listed that exist in the field of stroke or for the diagnosis of other diseases.

Health Serious Games in general, can follow different purposes [4], [49]–[58]:

- Treatment (rehabilitation, therapy)
- Monitoring
- Prevention (behaviour change towards a healthier lifestyle)
- Diagnostic

In chapter 2.2.1 some serious games developed in the early history were already mentioned. The state of the art around stroke disorders shows a persistent strong focus on games for the rehabilitation of post stroke limitations. Table 2 and following chapters offer an insight into health serious games and other digital attempts in the field of stroke or with the idea of symptom detection. All items are outlined referring to the aspects: (technical) discipline, purpose and disease.

Title	Discipline	Purpose	Disease
NeuroWorld [52]	Serious Game	Therapy	Stroke
Reha@Stroke [56]	Serious Game	Rehabilitation	Stroke
NAO Robot [55]	Robotics	Diagnosis	Autism
WarCAT [54]	Serious Game MachineLearning	Diagnosis	MCI (Mild Cognitive Impairment)
LEA Vision Test [51]	Serious Game	Diagnosis	Vision
mHealth App [3]	Machine Learning	Diagnosis	Stroke

Table 2: Examples of Health Serious Games

Besides this, the medical state of the art, which is represented by stroke scales, needs to be considered. There is a lack in comparison of stroke scales and gaming scenarios but exactly this should allow the definition of an early recognition logic and furthermore establish future fields of

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application of serious games. This work is dealing with the diagnosis of strokes in contrast to the existing games or the diagnosis of other brain disease. The NIHSS is considered as a possible medical basis.

3.1 National Institutes of Health Stroke Scale (NIHSS)

The NIHSS is an *Acute Stroke Assessment Scale*. Besides the European Stroke Scale, the Glasgow Coma Scale, the Scandinavian Stroke Scale and a few others, it is the most used one by neurologists worldwide [59]. Other scales, such as the Cincinnati Stroke Scale, the Los Angeles Prehospital Stroke Scale and the ABCD Score, are defined as *Prehospital Stroke Assessment Scales.* They serve as guidelines for identifying strokes in an early phase, where neurologists are mostly not present.

The NIHSS is a clinical assessment scale for a systematical observation of the neurological status of a patient. 15 items, outlined in Table 3, are covering essential functions of the body that are controlled by all areas of the brain. Based on the types of limitations that are present, a trained expert can identify which area of the brain (see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**) is affected.

Performing the exploration, a numerical value is assigned to each item based on the correctness of the fulfillment of the exercise. 0 stands for a normal execution. Other values up to value 5 are specifically adjusted to variations of the execution of the exercise. The sum of all values is between 0 and 42. The higher the value, the more serious the impairment is and the bigger the affected brain volume.

The NIH Stroke Severity Range [60] is defined as follows:

- 0: no stroke symptoms
- 1 – 4 : minor stroke
- 5 – 15: moderate stroke
- 16 – 20: moderate to severe stroke
- 21 – 42: severe stroke

An NIHSS form with the complete description of each item and its scale definition is in the appendix, a summary is described in Table 3.

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NIHSS#	Limitation	Medical Examination
1 a – c	Consciousness	The level of responsiveness (a) of the patient is in focus while asking questions (b) and commands (c) to be executed.
2	Best Gaze	The horizontal eye movement in one or both eyes is reviewed.
3	Visual	Visual loss is tested using finger moving from the right and left end of the normal visual field.
4	Facial Palsy	Paralysis is tested encouraging the patient to show teeth or raise eyebrows.
5 a, b	Motor Arm	Motoric impairment in the left (a) or right (b) arm is tested by placing it in a certain position and reviewing if there is drift or movement at all.
6 a, b	Motor Leg	Motoric impairment in the left (a) or right (b) leg is tested by placing it in a certain position and reviewing if there is drift or movement at all.
7	Limb Ataxia	The finger-nose-finger test is performed to rate the coordination and fine-tuning of movement.
8	Sensory	Different body areas are tested to specifically check for sensory loss on one side of the body.
9	Best Language	The comprehension of spoken language is tested.
10	Dysarthria	The patient's speech is obtained by reading or repeating words.
11	Extinction and Inattention	It is tested if the patient shows perception of each side of its body.

Table 3: NIH stroke scale description [61]

Back in 2002 there was an attempt to shorten the NIHSS (sNIHSS) to the most significant items [62]. In 2009 a study meant to reprove the use of a modified NIHSS (mNIHSS) that contains 11 items [63]. Both versions are outlined in the following chapters.

3.1.1 Shortened NIHSS (sNIHSS)

A prehospital scale is brief and easily administered in the field. These aspects are not compatible with the full assessment of the NIHSS. A shortened subset of the NIHSS-15 is meant to close the gap of easily measuring stroke severity and still retaining the predictive performance.

Based on NIHSS-15 (the original NIHSS with 15 elements), the sNIHSS-8, sNIHSS-5 and sNIHSS-1 were derived in a first phase and validated in a second phase. Figure 38 lists, among

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others, the items *Level of consciousness*, *Gaze*, *Visual field*, *Facial paresis*, *Motor-leg-right*, *Motor-leg-left*, *Language* and *Dysarthria* that were most predictive of good outcome and consolidated within the sNIHSS-8. Eliminating *Level of consciousness*, *Facial paresis* and *Dysarthria*, there was no significant difference in the predictive performance, which is why the sNIHSS-5 turned out to best fit during prehospital validations. [62]

TABLE 2. NIHSS-15 Items, Their Inclusion in Shortened Scales, Mean Scores, and Nonparametric Correlations With NIHSS-15

NIHSS-15 Item*		sNIHSS-8	sNIHSS-5	sNIHSS-1
1a. Level of consciousness	(0–3)	X		
1b. Orientation	(0–2)			
1c. Commands	(0–2)			
2. Gaze	(0–2)	X	X	
3. Visual fields	(0–3)	X	X	
4. Facial paresis	(0–3)	X		
5a. Motor–arm–right	(0–4)			
5b. Motor–arm–left	(0–4)			
6a. Motor–leg–right	(0–4)	X	X	X (weaker leg)
6b. Motor–leg–left	(0–4)	X	X	
7. Limb ataxia	(0–2)			
8. Sensory	(0–2)			
9. Language	(0–3)	X	X	
10. Dysarthria	(0–2)	X		
11. Extinction	(0–2)			
Possible scores	0–42	0–24	0–16	0–4
Derivation phase (mean, SD)		7.4 (3.9)	4.7 (3.0)	2.2 (1.2)
Validation phase (mean, SD)		6.2 (3.4)	3.7 (2.6)	1.7 (1.3)
Correlation with NIHSS-15 score (Spearman's ρ)				
Derivation phase		0.96	0.93	0.70
Validation phase		0.93	0.88	0.59

*Numbers in parentheses next to NIHSS-15 items indicate the possible score.

Figure 38: Shortening NIHSS-15 to sNIHSS-8, sNIHSS-5 and sNIHSS-1 [62]

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The data of the derivation phase, visualized in Figure 39, even allowed to conclude that the motoric activity of the more severely affected leg has the greatest informative value (82,6% - 93.6%). This outcome is recorded by introducing the sNIHSS-1. [62]

TABLE 3. Relative Predictive Importance of sNIHSS-8 Items, as Estimated by Percentage of Bootstrap Iterations Where *P*<0.10 (Derivation Phase Data)

sNIHSS-8 Item	Models Where *P*<0.10
1a. Level of consciousness	17.4%
2. Gaze	29.0%
3. Visual fields	26.0%
4. Facial paresis	14.2%
6a. Motor–leg–right	93.6%
6b. Motor–legleft	82.6%
9. Language	20.8%
10. Dysarthria	7.6%

Figure 39: Predictive importance of sNIHSS-8 items [62]

The sNIHSS was not designed to identify stroke patients, therefore seems to be less suitable within a stroke prediction game, while other scales like the LAPSS and the CPSS (chapters 3.2.1 and 3.2.2) are designed for this aim. Nevertheless, there is an overlap between sNIHSS items and those in LAPSS and CPSS which is represented by motoric asymmetry.

3.1.2 Modified NIHSS (mNIHSS)

The mNIHSS was derived to eliminate redundancy, complexity and items of the NIHSS with poor reliability. As well as multiple other published variations, it eliminates the items *Level of Consciousness, Facial Palsy, Limb Ataxia* and *Dysarthria*. These items turn out to contribute to difficulties in practitioner communication and might lead to incorrect decisions for the treatment. [63]

Table 4 illustrates the items of sNIHSS-8 and sNIHSS-5 and their matchings with the mNIHSS.

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NIHSS#	Limitation	#mNIHSS	sNIHSS-8	sNIHSS-5	m&8	m&5
1a	Level of Consciousness	-	X	-		X
1b	LOC Questions	X	-	-		
1c	LOC Commands	X	-	-		
2	Gaze	X	X	X	X	X
3	Visual Fields	X	X	X	X	X
4	Facial Palsy	-	X	-		X
5a	Left Motor Arm	X	-	-		
5b	Right Motor Arm	X	-	-		
6a	Left Motor Leg	X	X	X	X	X
6b	Right Motor Leg	X	X	X	X	X
7	Limb Ataxia	-	-	-	X	X
8	Sensory	X	-	-		
9	Best Language	X	X	X	X	X
10	Dysarthria	-	X	-		X
11	Extinction & Inattention	X	-	-		
				Matches to mNIHSS	6	9

Table 4: Items of mNIHSS opposed to sNIHSS-8 and sNIHSS-5

There is a higher correspondence of mNIHSS and sNIHSS-5 (column "m&5") as the same items are included or eliminated. While the sNIHSS eliminates *Level of Consciousness*, *Motor Arm*, *Sensory* and *Extinction*, these items are still available in the mNIHSS.

3.2 Prehospital Stroke Assessment Scales

As far as the NIHSS and its derivations are meant to identify in detail what condition the patient is in, it is not meant to identify stroke patients in an early phase. Therefore, it is necessary to oppose stroke scales with this specific aim. The systematic review of published stroke identification instruments in [64], [65] allows a list of following scales for further observation:

- Face, Arm and Speech Test (FAST)
- Recognition of Stroke in the Emergency Room (ROSIER)
- Los Angeles Prehospital Stroke Scale (LAPSS)

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- Melbourne Ambulance Stroke Scale (MASS)
- Ontario Prehospital Stroke Scale (OPSS)
- Medic Prehospital Assessment for Code Stroke (MedPACS)
- Cincinnati Prehospital Stroke Scale (CPSS)

In cases where a patient already suffered from a TIA once, there are further scales:

- ABCD Score (Age, Blood, Clinics, Duration)
- ABCD2 Score (Age, Blood, Clinics, Duration, Diabetes)

The use of CPSS and LAPSS can have significant impact on the treat of ischemic strokes [66] and they are both listed as prehospital stroke assessment scales [67]. FAST is a very rough scale that focusses on the most valuable identification items only. It is not supposed to deliver reliable outcome within a gaming scenario [68], [69]. ROSIER ([70]–[72]), MASS ([73], [74]), OPSS ([75]) and MedPACS ([64], [65]) are neither listed from *The Internet Stroke Center* nor do they offer additional, utilizable items or information, which is why these scales, as well as FAST, are not considered for further investigation.

The validity of LAPSS and CPSS is outlined in statistical measures. [76] [77]

a) *Sensitivity* (true positives / (true positives + false negatives))
Probability of being test positive when disease is present.

b) *Specificity* (true negatives / (true negatives + false positives))
Probability of being test negative when disease is absent.

c) *Positive Predictive Value* (true positives / (true positives + false positives))
Probability (having disease when test is positive).

Mentioned scales are attached in all detail in the appendix.

3.2.1 Los Angeles Prehospital Stroke Screen (LAPSS)

The LAPSS is more complex than the CPSS. A positive LAPSS value is only possible if every screening criterion listed in Table 5 is rated with Yes (or unknown).

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Screening Criteria	Yes	No
Age over 45 years		
No prior history of seizure disorder		
New onset of neurological deficits in the last 24 hours		
Patient was ambulatory at baseline (prior event)		
Blood glucose between 60 and 400		
Based on exam, patient has only unilateral (not bilateral) weakness		

Table 5: LAPSS screening [67]

The LAPSS has a sensitivity of 91 % and a specificity of 97 % [78]. The LAPSS is considered as option to replace the NIHSS as basis for the early recognition game. A detailed mapping of all scales, their informative value and the technological coverage in a gaming scenario in chapter 4.3.3 will help to underline or disprove this assumption.

3.2.2 Cincinnati Prehospital Stroke Scale (CPSS)

The CPSS is a simplification of the NIHSS and based on three items: face, arm and speech. They were determined as the most predictive ones [79]. If one examination item shows abnormal results, the indication for a stroke is present.

Medical knowledge is not necessary to assess a neurological deficit with the exam as follows:

Examination Item	Normal	Abnormal
Facial Droop	Both sides of the face move equally	One side of the face does not move at all
Arm Drift	Both arms move equally or not at all	One arm drifts compared to the other
Speech	Patient uses correct words with no slurring	Slurred or inappropriate words or mute

Table 6: CPSS examination [67]

The CPSS has a good sensitivity of 83 % and a specificity of 69 %. [80]

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3.2.3 ABCD and ABCD2-Score

The ABCD- and the ABCD^2-Score (ABCD extended by the factor “diabetes”), can help neurologists to estimate the risk of having another stroke within a short time after a TIA (see Table 7). A calculated value up to 3 represents low risk, values 4 and 5 represent medium risk and 6 to 7 points represent high risk. [81]

Risk Factor	Characteristics	Value
Age	≥ 60 years	+ 1
Blood Pressure	≥ 140/90 mmHg (either SBP ≥ 140 or DBP ≥ 90)	+ 1
Clinical Features of TIA	Unilateral Weakness	+ 2
	Speech Disturbance without Weakness	+ 1
	Other Symptoms	+ 0
Duration of Symptoms	≤ 10 minutes	+ 0
	10 – 59 minutes	+ 1
	≥ 60 minutes	+ 2
Diabetes	Existing	+ 1

Table 7: ABCD^2 risk factors [67]

Despite some studies with a differing conclusion, the predictive value of the ABCD- and ABCD2-Score is good [82].

3.3 Diagnostic Serious Games

Following serious games, robots, tests and an app were taken into consideration within this work because they represent the idea of a recognition of disease patterns or are stroke oriented with a newly introduced approach. NeuroWorld [52] is tracking the progress of post stroke rehabilitation while Reha@Stroke is a mobile stroke rehabilitation game. NAO Robot diagnoses autism and WarCAT detects cognitive impairments. LEA is a vision test. The mHealth App is not integrated in a game scenario yet but considered as the most promising attempt for the purpose of this work.

3.3.1 NeuroWorld

In NeuroWorld, six cognitive rehabilitation games (see Figure 40) are used within a game-based therapy program for chronic stroke patients.

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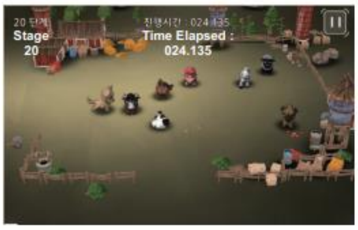
(a) Game #1: Animals come into the screen and an animal leaves the screen in one of the four directions (up, down, left, right). The subject is asked to remember and choose the correct direction that the animal left.

(b) Game #2: Animals come into the screen one by one and a subset of them leaves the screen one by one. The subject is asked to remember all the animals which left the screen and choose them in the presented candidates.



(c) Game #3: Animals come into the screen in a specific order. The subject is asked to choose the correct order that the animals entered the screen.

(d) Game #4: A set of animals are displayed on the screen. The subject is asked to count the number of animals that have the same visual characteristics, that is described in a separate image.

(e) Game #5: A set of animals are presented on the screen. The subject is asked to find the same animal that is presented in a separate image among the presented animals.

(f) Game #6: A sequence of shapes is presented on the screen in a certain pattern. The subject is asked to choose the correct shape that should come after the displayed sequence among the candidates.

Figure 40: NeuroWorld [52]

With a machine-learning approach it is possible to predict the outcome of the therapy program with information available at baseline. Therefore an initial assessment is done with an MMSE (Mini Mental Status Examination) and combined with the game specific performance at baseline. 14 patients received the therapy twice for 12 weeks and a follow-up assessment was done. The prediction of the follow-up assessment was remarkable with a good accuracy. This finding can be used to assist neurologists when prescribing the game-based therapy and reduce trials that won't lead to cognitive improvements. Far more individual therapeutic programs would be the result. [52]

3.3.2 Reha@Stroke

Reha@Stroke is a serious game for the rehabilitation of motoric impairments as post-stroke disease. It is available on mobile devices without any further sensors than the integrated ones (gyroscope and touch screen). The game offers three categories: movement, touch and gesture. As in Figure 41 it is necessary to rotate the phone to empty the water from the bottle into the glass. Motoric impairments in the wrist are trained as the user needs to stay within a limited range of rotation. In a second level the wrist needs to be pronated and supinated to move a needle through buttons in a path. Further exercises present symbols on the screen that need an interaction from the user with its fingers in order to train the sense of touch and gesture. [56]

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Figure 41: Reha@Stroke [56]

3.3.3 NAO Robot

NAO is a programmable, interactive, humanoid robot. For the purpose of diagnosing autism in children it was supplemented with two games "Dance with me" and "Touch me". As autistic children show difficulties in social interaction, NAO is used to track their activities within the games. First results show a clear behavioral pattern from autistic children, the upcoming challenge is the differentiation of autism from other similar disorders. [55]

Figure 42: NAO Robot

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3.3.4 WarCAT

Another serious game that is designed for mobile devices is named WarCAT (War Cognitive Assessment Tool). Aim of the game is to detect Mild Cognitive Impairments (MCI) capturing the processes of strategy recognition, learning and memory. The game reproduces the familiar card game WAR where each player turns up a card and the player with the higher card takes both cards. Machine Learning is used for synthetic data generation and for data classification to emulate various stages of MCI. [54]

Fig. 1 An instance of play during WarCAT

Figure 43: WarCAT

3.3.5 LEA Vision Test

The optometric vision test LEA is transformed into a 2D-3D game to pre-diagnose vision problems of children. The underlying recognition of symbols in this test is implemented in a scenario where an assistant is presenting a symbol and the patient needs to hit the corresponding pictogram in a line at the top of the screen. Kinect 2.0 serves as sensor device. Each level the pictograms appear smaller which represents a higher distance between patient and test symbols. [51], [57].

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Figure 44: LEA vision test

3.3.6 mHealth App

In 2020 [3] an attempt was started to create a smartphone app that identifies stroke patients. Therefore 84 patients from an emergency room, that were suspected to have a stroke, were asked to perform two tasks:

1. repeat the sentence: “it is nice to see people from my hometown”
2. describe a “cookie theft” picture

While performing the tasks, the patients were filmed with a smartphone camera. In addition, physicians were asked for an initial judgement if the patient has a stroke and an MRI was performed to ground a definite diagnose.

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Figure 45: mHealth App1 [3]

Figure 46: mHealth App2 [3]

Based on this dataset a multimodal deep learning framework was introduced that is deployable on smartphones, hence highly accessible. The performance of the framework was outlined with a 93,12 % sensitivity and a 79,27 % accuracy compared to clinical impressions by physicians. Figure 45 and Figure 46 show a female patient participating in the smartphone screening test.

The proposed fusion mechanism is illustrated in Figure 47. In a first step audio files are transcribed while videos are sent to the spatiotemporal proposal module to perform face detection, tracking, cropping, and stabilization. The pre-processed data is then loaded into separate audio and video modules.

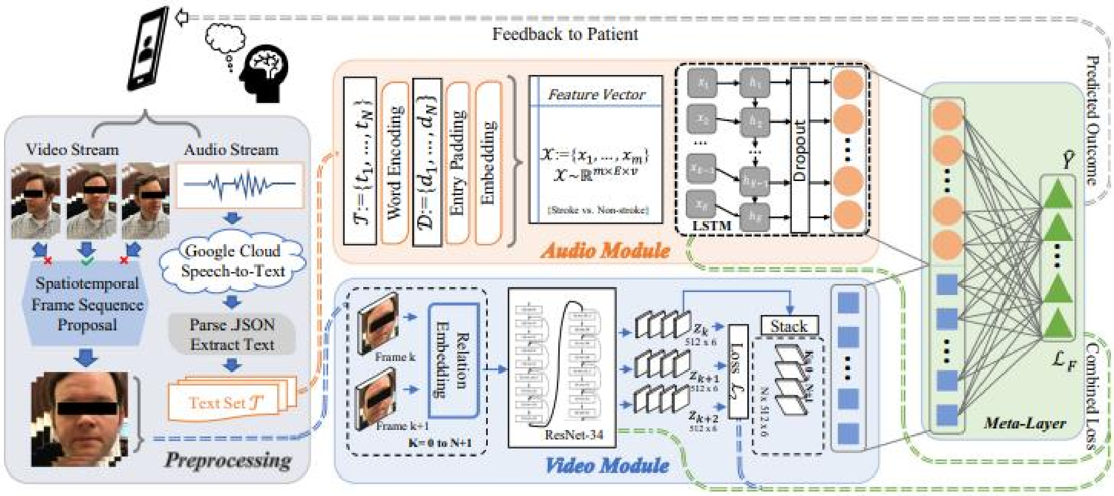

Figure 47: Two stream network fusion process [3]

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In the audio module, the words ($t_{1..n}$) are encoded and a basic bidirectional long short-term memory (LSTM) model is used for text classification. The video classification is done with a ResNet-34 model. A novelty is that feature differences between consecutive frames are used for classification instead of directly the frame features. A Meta-Layer combines the outputs of the two modules and predicts the outcome. [3]

3.3.7 Summary and Differentiation

Table 8 visualizes the difference of the serious game that is prototyped in this work and already existing serious games. Despite the limitation to the outlined set of serious games, this is a representative subset of the existing serious games for health in research. It is visible that all items are serious games except the NAOrobot, that is a robot equipped with a game, and the mHealth App which is a diagnostic mobile app. Other items in Table 8 that fulfill the diagnostic criteria are not focusing on the stroke disease except NeuroWorld. But, NeuroWorld does not have the aim to diagnose a stroke, it only fulfills the idea of recognizing an impairment by continuous monitoring of cognitive abilities. Still, it focusses only on the cognitive ability, as well as all other items that mainly chose one impairment as focus. The mHealth App is the only item that considers more than one body function, more precisely face, arm and speech as defined in the CPSS. There was no attempt to focus on a set of informative and technically easily traceable impairments so far reasoned by the focus on the rehabilitation of one impairment at a time. When it comes to the recognition of strokes, there is more than one body function to be considered as symptom and it is inevitable to find a suitable medical basis for the collection of body symptoms.

Accordingly, it is visible that there is no other serious game fulfilling the criteria:

- Serious game
- Diagnosis
- Stroke disease

In special, no other serious game evaluates the perfectly suitable combination of body elements of a score to reach the best possible and technologically coverable prediction results. In this work this is done by deriving a very specific stroke recognition scale for the gaming scenario.

Hence, serious games for stroke patients focus on the rehabilitation of existing symptoms and one symptom at a time, while other serious games already assist in the diagnosis of specific diseases. This work will find a serious game serving the purpose of diagnosing strokes in an early stage.

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Name	Serious Game	Diagno-sis	Stroke Disease	Body Im-pairment
DuckDuck Punch (chapter 2.2.1)	x		x	Arm
RehaLabyrinth (chapter 2.2.1)	x		x	Balance
Hungry Grizzly Bear (chapter 2.2.1)	x			Speech
Evo (chapter 2.2.1)	x	x		Cognitive
NeuroRacer (chapter 2.2.1)	x		x	Cognitive
NeuroWorld (chapter 3.3)	x	"x"	x	Cognitive
Reha@Stroke (chapter 3.3.2)	x		x	Hand
NAO Robot (chapter 3.3.3)	"x"	x		Autism
WarCAT (chapter 3.3.4)	x	x		Cognitive
LEA Vision Test (chapter 3.3.5)	x	x		Vision
mHealth App (chapter 3.3.6)		x	x	CPSS
Stroke Prediction Serious Game	**x**	**x**	**x**	**ERGSS**

Table 8: Serious games for the diagnosis of a stroke disease

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4 Results

The prototyping process in chapter 2.5.2 and the prototyping model in software engineering in 2.5.3 show how to get from assumptions and ideas to the point of structured knowledge as basis for the design and development of well-engineered systems. Figure 37 models an initial phase of requirements gathering that is followed by an iterative process of prototyping before it ends with the engineering of the system.

In this work it was necessary to realize this model in a more enhanced way. As visible in Figure 48 the realization was done in three different phases: Research, Analysis & Design, Implementation. The phases were introduced in chapter 1.5 and illustrated in Figure 1 out of a step by step perspective with corresponding outcomes. Each phase itself was performed in numerous steps and iterations. The research phase built on idea generation and requirements gathering. Analysis and design was done for the logic and the game in separate iterations of prototypes. The interim results were united in the implementation phase where the coded prototype was developed. The coded prototype, as final result of this work, is a car racing game enhanced with use cases for stroke recognition.

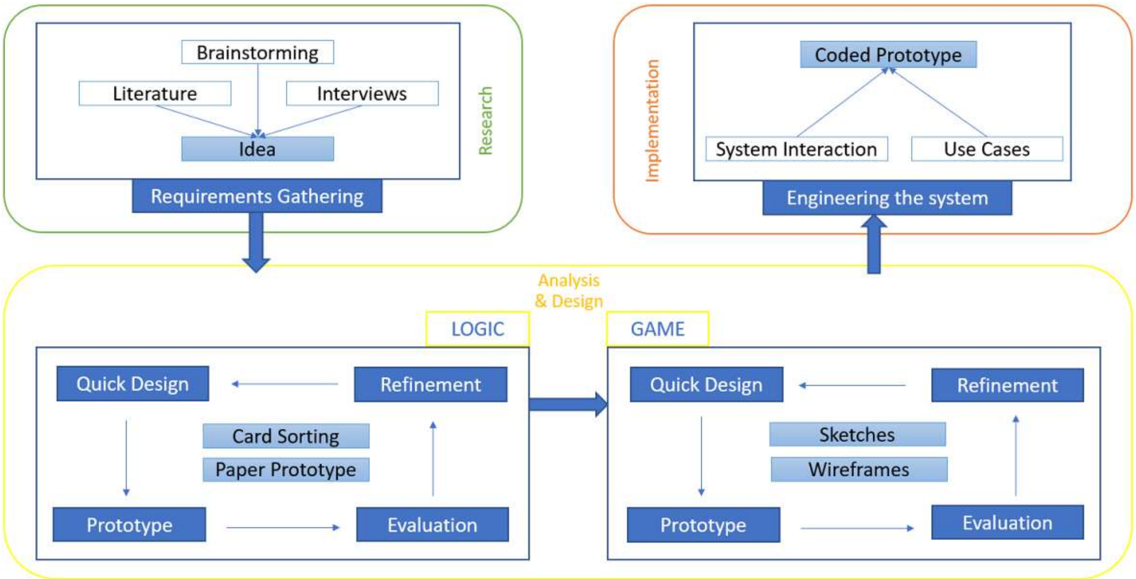

Figure 48: Implemented prototyping process

The colors in Figure 48 refer to the maturity level of each phase as far as the whole topic is concerned. It means that there are steps during the analysis and design that need to be researched

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and evaluated far beyond this thesis. The green color symbolizes a very good level of completion, the yellow color a good level and the orange level means there are a lot more iterations expected until the final system evolves. Open questions from this point are outlined in the chapter Summary and Future Work.

As visible in the columns of Table 9, each phase was realized with different methods to fulfill specific purposes and deliver results.

The research phase is the first phase in the prototyping model and characterized by three steps [R0] literature research, [R1] interviews and [R2] brainstorming. It offered all invalidated assumptions that were analyzed in the next phase.

Analysis & design is the second phase and characterized by two iterations of prototypes [AD1.i1] card sorting and [AD2.i2] paper prototype, as well as two interim results [AD3.ir1] and [AD4.ir2], for the logic. Another two iterations [AD5.i3] sketches and [AD7.i4] wireframes and one related interim result [AD6.ir3] were created for the game.

The implementation phase is the third and final phase. It is summarizing all requirements [I0], illustrating the system interaction [I1] and the use cases [I2] for the development of a coded prototype [I3] and its evaluation by users [I4].

Chapter 4.1, 4.2 and 4.4 describe each phase with their (interim) results and findings. Additionally, chapter 4.3 is offering an extended deep dive into the realization process of the prototypes summarized in chapter 4.2 beforehand.

Table 9 lists all performed iterations in advance. The colors refer to the phases in Figure 48. The mentioned IDs follow a specific pattern,
e.g. AD4.ir2:

- AD = **A**nalysis & **D**esign
- 4 = step **4** of the phase
- ir2 = **i**nterim **r**esult **2**

e.g. AD7.i4

- AD = **A**nalysis & **D**esign
- 7 = step **7** of the phase
- i4 = **i**teration **4** of prototype(s)

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Phase	Realization	ID	Purpose	Results	Assumptions	Participants
Research	Literature Research	R0	Knowledge acquisition	Research Questions	Invalidated	
Research	Interviews	R1	Requirements Gathering	Research Questions	Invalidated	P01, P02
Research	Brainstorming	R2	Idea Generation	Idea	Invalidated	
Analysis & Design	Iteration 1: Card Sorting	AD1.i1	Verification NIH Cluster	Pseudo Algorithm	A03,A04,A05,A07	P01, P03
Analysis & Design	Iteration 2: Paper Prototype	AD2.i2	Verification Pseudo Algorithm	Verification FAILED	A03,A04,A05,A07	P01,P03,P04,P05
Analysis & Design	Interim Result 1	AD3.ir1	NIH Alternative	Game Stroke Scale	A03,A04,A05,A07	
Analysis & Design	Interim Result 2	AD4.ir2	Update Pseudo Algorithm	Recognition Logic	A02	
Analysis & Design	Iteration 3: Sketches	AD5.i3	Decision Game Scenario	Car Race Scenario	A08	P01
Analysis & Design	Interim Result 3	AD6.ir3	Design Game Activities	Stroke Prediction Game	A08	
Analysis & Design	Iteration 4: Wireframes	AD7.i4	Expert Evaluation	Verified Game Activities	A01	P01, P03
Implementation	Requirements	I0	Assumptions to Requirements	Validated Requirements		
Implementation	System Interaction Diagram	I1	Visualize interactive behavior	High Level System Design	A06	
Implementation	Use Cases	I2	Identify functions and roles	Use Case Diagrams	A06	
Implementation	Coded Prototype	I3	Early User Feedback	Serious Game Prototype		
Implementation	Evaluation Coded Prototype	I4	User Verification	Verified Game Scenario	Validated	P06, P07

Table 9: Implemented iterations

Each phase was accompanied by different participants. The research and the analysis phase required experts in the field of neurology while the implementation phase required users that could give early feedback on the game scenario. Table 10 lists the participants.

#	Initials	Qualification	Gender	Age
P01	FF	General practitioner, Resident physician neurology	M	< 40
P02	AK	Occupational therapist	F	< 30
P03	CW	Resident physician neurology	M	< 40
P04	EP	Resident physician neurology	F	< 40
P05	WK	Neurologist	M	< 40
P06	MM	Individual bus driver, risk patient	M	>= 60
P07	MM	Assembly woman, potential risk patient	F	< 60

Table 10: Participants

Users were selected for this purpose within the close domestic area of the author as well as the general practitioner P01. P02 – P05 were colleagues working in the same hospital and ward as P01.

4.1 Research

The first phase for research had three steps [R0 – 2]. It started with systematic literature research that offered an insight in serious games and their usage for the stroke disease. Then, to find out what kind of impairment could be supported with newly developed serious games, it was necessary to understand the disease pattern itself. Therefore, research continued on the collected information. As well, an interview with neurologist P01 helped to gain more insights in the disease. Another interview with the occupational therapist P02 helped to gain knowledge about traditional therapeutic treatments. All collected information was brainstormed in the matter of finding a new purpose for a stroke serious game.

Research Findings

The information from the interviews with P01 and P02 was interpreted as in Table 11.

P	Information	Interpretation	Assump-tions
P01	A stroke is manifested with symptoms in different parts of the body (see chapter 2.1). There is a score named NIHSS	The NIHSS is a step by step instruction to fulfill specific activities and a	A02, A03, A04

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	(see chapter 3.1) that helps neurologists to examine impairments like this.	simple mathematical addition of reached “points”.	
P01	The NIHSS offers good insights into the body functions that are affected when a stroke occurs.	The NIHSS allows a cross-check if a technical interpretation of symptoms is possible.	A01, A07
P01	It happens that the symptoms imply a stroke when another disorder e.g. drunkenness is present. This condition is named mimic.	The recognition of strokes implies an exclusion of other diseases.	A05, A06
P02	Stroke patients often receive occupational rather than physio-therapy. Target there is, to help patients strengthen the performance of every day life activities, e.g. using a coffee machine, in their personal environment.	Stroke patients need solutions that are available in their personal environment.	A08

Table 11: Interviews findings

In a brain storming session all research findings were visualized in a MindMap (see Figure 49). This helped to identify the idea to use the NIHSS for diagnosing the stroke in a gaming scenario rather than building another stroke rehabilitation game. Research confirmed that there is no stroke serious game with the aim of diagnosing a stroke.

Each assumption concerning this idea was listed in Table 12.

Figure 49: Brainstorming MindMap

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#	Invalidated Assumption
A01	It is possible to fetch each symptom of the NIHSS technically.
A02	It is possible to calculate a numerical positive value that indicates the necessity of a neurological consultation.
A03	It is possible to determine a combination of symptoms and conditions that always asks for a neurological consultation.
A04	It is possible to identify other health conditions that help estimating the probability of a stroke.
A05	It is possible to clearly separate symptoms that mimic a stroke and symptoms that represent another disease.
A06	It is possible to isolate accidently faked symptoms with intended actions.
A07	It is possible to verify if a symptom is alarming or only alarming in combination with other symptoms or health conditions.
A08	An already existing serious game for the therapy of post stroke impairments could be reused for the diagnosis.

Table 12: Invalidated assumptions

None of the assumptions was confirmed at this stage, therefore their level of validity is "invalidated". At this point the next phase, analysis and design, began and through the iterations of prototyping the assumptions were transformed into requirements of different validities (see chapter 4.4.1).

4.2 Analysis & Design

In the previous research phase an idea evolved and was put down in assumptions. Then, the second phase of analysis & design started for the purpose of transforming the initially gathered assumptions into validated requirements. Therefore, four iterations of prototypes were designed, evaluated and analyzed, each with a specific aim and of emerging fidelity. Two prototypes were designed for the logic [AD1.i1], [AD2.i2] and two for the game [AD5.i3], [AD7.i4].

As listed in Table 9, in the first iteration for the logic, card sorting was verifying NIH cluster to define a pseudo algorithm. Second, a paper prototype was built to verify the pseudo algorithm. Interim results [AD3.ir1] and [AD4.ir2] were defined as it turned out that the NIHSS was not the suitable score for the prediction logic. For the game, a third iteration with sketches was done, they were created to unite the results so far and help to decide about a game scenario. After that, another interim result [AD6.ir3] specified the game activities, translating neurological assessment

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items into matching game activities. In iteration 4 wireframes were designed to evaluate the game activities with the neurologists P01 and P03.

4.2.1 Iteration 1: Card Sorting

The very first prototype [AD1.i1] (= analysis & design, step 1, iteration 1) was done to get a step closer to a potential stroke prediction logic and to validated the assumptions A03, A04, A05 and A07 (see Table 12).

During the interview with P01 in the research phase [R1], it was suspected that some examination items of the NIHSS are diagnostically more or less conclusive than others. The expectation was that the items were classifiable into five categories that resulted from the interview.

Card Sorting was chosen to verify if it is possible to assign every examination item of the NIHSS to one of the categories. Each examination item was represented by a card that needed to be classified. This classification helped to assign the symptoms to specific reference points in an algorithm e.g. a symptom that is classified as "not a stroke" would lead to a decrease of risk in a calculation.

A detailed description of the realization of the card sorting is done in chapter 4.3.1. With the findings during this iteration, it was possible to design a first draft of an algorithm as follows.

Card Sorting Findings

It is possible to categorize the symptoms in correlation with the relevance for a stroke but it is not clear if the historical and general health conditions in combination can help to increase or decrease the probability for a stroke.

It is assumed that the NIHSS might not be the correct basis for the logic. It consists of items that involve functions of the whole body. This could be challenging for any game to cover and that again makes it necessary to detect and focus on the best specific items (symptoms, general or historical conditions and similar).

Another assumption is that the level of consciousness could have major impact on the probability of a stroke, but it might be the trickiest symptom to discover without contacting the player directly per video. General and historical conditions (existing illnesses, current medication, ...) would, from the technical point of view, enable unnoticed fetching of symptoms and would be easier to implement.

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The achieved knowledge allowed the high level definition of a first pseudo code draft for the algorithm:

```
Code05
1. Fetch symptoms that are questionable in most cases.                    +1
2. Check medical history
   a. Cognitive impairment → STACK AND PAUSE                              -1
   b. Heart or vascular disease → PROCEED TO 3                            +1
3. Check blood pressure
   a. app. 120/80 → STACK AND PAUSE                                       -1
   b. sys > 140 mmHg or dias >= 90 mmHg → PROCEED TO 4                    +1
4. Check consciousness and other symptoms. OR
5. Transmit warning.
```

In words it means that the algorithm collects questionable symptoms and increases the corresponding counter for stroke risk. It checks the medical history if there have been previous cognitive impairments and decreases the counter if so, because it would mean that there is some impairment already existing for longer. If there are risk factors like vascular disease the counter is increased. If the blood pressure is ok there might be a mimic present but if the blood pressure is high (systolic > 140 mmHg or diastolic >= 90 mmHg according to ABCD score) the chances are high that a stroke is occurring. Therefore, the consciousness should be checked and eventual other symptoms. When a threshold is reached a warning is transmitted.

All questions that arose within this step were taken over to the paper prototype design. Especially a clear statement about significant symptoms was necessary.

4.2.2 Iteration 2: Paper Prototype

A *Paper Prototype* [AD2.i2] was created to verify if the proposed algorithm [AD1.i1] of the previous iteration is valuable. Therefore, some differently shaped and colored bricks were used to present a game sequence.

Four questions needed an answer:

1. Which symptoms cause a check for former illnesses in the medical history?
2. Which symptoms cause a check of general health conditions?
3. When is it necessary to directly contact the player?
4. When does the neurologist want to see the player?

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Figure 50 was created to illustrate step 1 of the algorithm in detail. It was assumed that the combination of actions and symptoms could be summed up until a specific value is reached. In a next step the consolidation with other factors, e.g. the medical history, would be performed.

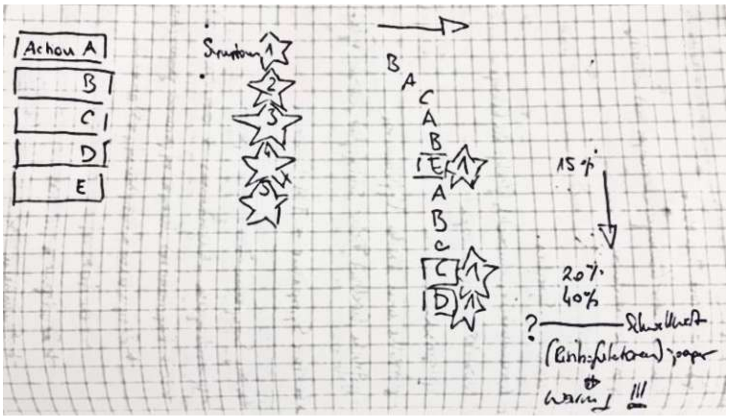

Figure 50: Paper draft of objects and activities in the algorithm

The paper draft was transferred to an adapted paper prototype enhancing it with symbolic objects like bricks. This helped to visualize the activities better for the test persons. (see more details about the realization of the paper prototype in chapter 4.3.2)

Paper Prototype Findings

Basically, the first two underlying questions could be easily answered but did not help verifying the algorithm because each participant was crosschecking the former illnesses and general examination every single time before estimating the risk for a stroke. Participants reasoned that with experienced situations, where it happened that a senior physician was called just to detect a hypoglycemia which could have been easily treated by the assistant himself prescribing a glucose infusion. These mainly embarrassing situations cause a focus on always making sure that the most common differential diagnoses are excluded.

The video contact to the player was only used once hence it is suspected not to be too relevant. If an examination item resulted in "1 of 2 actions performed correctly", it did not result in a concrete input for the risk estimation.

Unfortunately, the elevation was not continued after having a look at the intermediate results of 4 participants, each performing 4 turns of the game. The expectation couldn't be met because the results were highly variable so that it was not expectable to derive a clear conclusion with a few more participants and turns. It was not possible to even guess a pattern that based on explicit symptoms. The combinatorics behind the risk estimation was not as expected and question 4 couldn't be answered in any case.

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The unsatisfying findings of this setting and the assumption that hundreds of participants would be needed to eventually determine a pattern, caused a move back to literature research. This step provided a deeper insight into many more different existing scales in the field of strokes (see chapter 3.1.1, 3.1.2 and 3.2).

After the extended research, a first interim result [AD3.ir1] was developed (see chapter 4.2.3). It is a new digital stroke scale derived from the most informative items of the existing scales. These items were taken to update the pseudo algorithm [AD1.i1] and create the second interim result [AD4.ir2].

4.2.3 Interim Result 1: Early Recognition Game Stroke Scale (ERGSS)

After the first two iterations of prototyping for the logic [AD1.i1] and [AD2.i2], the findings were not as expected and the literature research was extended. Prehospital scales were determined, their use seemed to be better corresponding to the idea of a computer-based early recognition. Therefore, in this chapter a new score was derived [AD3.ir1] as first interim result.

All common scales were analyzed in detail in chapters 3.1.1, 3.1.2 and 3.2. It became transparent that the NIHSS is not the correct scale for the aim of an early recognition.

While the examination with an NIHSS focusses on observing the potential brain damage and its location in detail, this process of in- or excluding specific diagnoses is not necessary in an early recognition. It rather is the information that “something might be wrong” than the explanation of “what exactly is wrong” that needs to be collected.

Prehospital scales are reference points for nursing staff and paramedics. Some of them could even be used by every nonmedical person. On the other hand, their informative value is limited because of very roughly defined investigation objects. Transposing one of these scales into a digital algorithm would not efficiently apply the benefits of the entire technological possibilities. Furthermore, as far as none of the existing scales was meant to be used in a digitalized setting, it is not simple to find one satisfactory gaming scenario for covering all items of a scale ensuring the best possible predictive value.

According to this complex of problems it was found as necessary to accumulate all information from the existing scales, create a categorized mapping and derive a new scale which is applicable as early recognition.

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The resulting scale is named “Early Recognition Game Stroke Scale – ERGSS”, focusing on 15 items as a combination of the most valuable items of the NIHSS and the items that can easily be tracked with existing technologies.

The items are categorized in different types, as visible in Table 13:

- Risk Factors (for stroke risk prediction)
- Symptoms (for stroke recognition)
- Health Condition (for stroke exclusion)

Column „Origin“ shows in which scales this item is existing, e.g. NIHSS#2 stands for the 2nd item of the original NIHSS with 15 items (N-15), N-8 is the shortened NIHSS to 8 items, and so on.

The derivation process is described in chapter 4.3.3. The ERGSS as first interim result [AD3.ir1] was afterwards transformed into a prediction logic in [AD4.ir2]. These two interim results for the logic served as basis for the next two iterations of prototypes focusing on the game scenario and game activities.

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ERGSS#	Examination Item	Risk Increase Characteristics	Origin	Type
1	LOC Questions	Person doesn't answer both questions correctly: - Which month is it? - What is your age?	NIHSS#2 of N-15, mN	Symptom
2	LOC Commands	Person is not able to perform both tasks correctly: a) Open and close eyes. b) Grip and release (non-paretic) hand.	NIHSS#3 of N-15, mN	Symptom
3	Visual Fields	Visual fields (upper and lower quadrants) are tested by confrontation, using finger counting or visual threat, as appropriate. Patients may be encouraged, but if they look at the side of the moving fingers appropriately, this can be scored as normal.	NIHSS#5 of N-15, N-8, N-5, mN	Symptom
4	Facial Movement	There is an asymmetry in grimace when the person shows teeth or raises eyebrows and closes eyes.	NIHSS#6 of N-15, N-8, LAPSS, CPSS, ABCD, ABCD2	Symptom
5, 6	Motor Arm (L+R)	The person is not able to hold the arm for 10 sec. without a drift.	NIHSS#7,#8 of N-15, mN, LAPSS, CPSS, ABCD, ABCD2	Symptom
7, 8	Motor Leg (L+R)	The person is not able to hold the leg for 5 sec. without a drift.	NIHSS#9,#10 of N-15, N-8, N-5, N-1, mN, ABCD, ABCD2	Symptom
9	Speech	Aphasia (reduction of speech and/or comprehension) or dysarthria (clarity of articulation reduced).	NIHSS#13 of N-15, N-8, N-5, mN, CPSS, ABCD, ABCD2	Symptom
10	Age	min. 45 years	LAPSS, ABCD, ABCD2	Risk Factor

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11	History	The patient has no prior history of seizure.	LAPSS	Risk Factor
12	Time	There was an anomaly in the last 24h.	LAPSS, ABCD, ABCD2	Risk Factor
13	Ambulatory at Baseline	Patient was ambulatory at baseline (prior event).	LAPSS	Risk Factor
14	Blood Glucose	The glucose level is not between 60 – 400 mg/dl.	LAPSS, ABCD2	Health Condition
15	Blood Pressure	The blood pressure is ≥ 140/90 mmHg (either SBP ≥ 140 or DBP ≥ 90).	ABCD, ABCD2	Health Condition

Table 13: Early Recognition Game Stroke Scale (ERGSS)

4.2.4 Interim Result 2: Recognition Logic for Strokes in Games (RLSG)

In this chapter the newly developed digital scale ERGSS [AD3.ir1] is transformed into a prediction logic named Recognition Logic for Strokes in Games (RLSG) [AD4.ir2]. It's based on the conclusion that there are separate sections in the logic that need to be considered. This is reasoned by the types of items the ERGSS consists of.

1. Stroke Risk Prediction (referring to risk factors from ERGSS)
2. Stroke Recognition (referring to symptoms from ERGSS)
3. Stroke Exclusion (referring to health condition from ERGSS)
4. Stroke Warning

The pseudo logic [AD1.i1] is adapted as follows:

CODE 06

1. Calculate risk based on patient record	+1
2. Check game history for anomalies in 24 hours	+1
3. Fetch symptoms from ERGSS	+1
4. Check blood pressure	
a. app. 120/80 → STACK AND PAUSE	-1
b. sys > 140 mmHg or dias >= 90 mmHg → PROCEED TO 5	+1
5. Check blood glucose	
a. 60 – 250 mg/dl → STACK AND PAUSE	-1
b. The glucose level is not between 60 – 250 mg/dl	+1
6. Check threshold	
7. Transmit warning	

In words it means that the algorithm calculates an initial stroke risk based on existing data from the patient record and an eventually existing game history. During the game it collects questionable symptoms and increases the corresponding counter for stroke risk. It checks the blood pressure, if it is ok there might be a mimic present but if the blood pressure is high (systolic > 140 mmHg or diastolic >= 90 mmHg according to ABCD score) the chances are high that a stroke is occurring. The blood glucose is checked, if it is under 60 mg/dl the mimic hypoglycemia might be present, hyperglycemia if over 250 mg/dl. When a threshold is reached a warning is transmitted. The threshold is definable according to stroke severity range (see chapter 3.1).

The blue framed blocks of CODE 06 refer to the 4 sections of the logic.

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An exemplary iteration was performed as a trial in Figure 51.

- The medical history is loaded for an initial calculation of a pre-existing stroke risk and the game activity started.
- The risk is compared to a threshold when the game activity is performed.
- A question is asked during the race, if wrong the risk increases.
- The player is asked to perform commands, if wrong the risk increases again.
- Other activities continue as long as the risk value reaches the threshold.
- If the threshold is reached the smart watch is activated, blood pressure and blood glucose checked.
- An alarm is only released if the blood pressure is not ok or the blood glucose is ok.
- If the blood pressure is ok or the blood glucose is not ok, there might be a mimic occurring, the risk value is decreased and the logic continues with the analysis of the game activities.

	A	B	C	D	E	F	G
1	#	input	condition	process	output	command	ERGSS
2	1	medical history		calculate stroke prediction value	initial stroke risk	CONTINUE	11
3	2	game activity	risk < threshold	ask questions during race, if wrong ..	risk value ++	CONTINUE	1
4			risk < threshold	ask commands during race, if wrong ..	risk value ++	CONTINUE	2
5			risk < threshold	place symbols in scenario, if not caught ..	risk value ++	CONTINUE	3
6			risk = threshold +/-1	check facial movement, if anomaly detectable ..	risk value ++	BREAK	4
7			risk = threshold +/-1	instruct to hold smart wheel with a specific grip and angle	risk value ++	BREAK	5, 6
8			risk = threshold +/-1	instruct to push smart pedal to reach specific speed	risk value ++	BREAK	7, 8
9			risk = threshold +/-1	instruct to hold smart wheel with a specific grip and angle	risk value ++	BREAK	5, 6
10			risk = threshold +/-1	ask player to repeat words, if wrong	risk value ++	BREAK	9
11	3	smart watch	risk > threshold	check blood pressure, if ok ..	risk value --	CONTINUE	15
12			risk > threshold	check blood glucose, if not ok ..	risk value --	CONTINUE	14
13			risk > threshold	check blood pressure, if not ok ..	alarm	STOP	15
14			risk > threshold	check blood glucose, if ok ..	alarm	STOP	14

Figure 51: RLSG iteration example

4.2.5 Iteration 3: Sketches

After the interim results [AD3.ir1], [AD4.ir2] finalized the prediction logic within the scope of this work, a third prototype [AD5.i3] (= analysis & design, step 5, iteration 3) was done to deal with assumption A08. This prototype is for the purpose of finding a suitable game scenario.

With reference to the RLSG [AD4.ir2], stroke risk prediction, stroke recognition and stroke exclusion need to be considered before a warning is released. Prediction and exclusion are handled with IoMT (see chapter 2.4). To find out how stroke recognition could be handled, sketches were designed. Therefore, a detailed look at the examination methods for the body functions of the ERGSS elements was necessary.

ERGSS#1 and ERGSS#9 are examined with the speech of the patient while ERGSS#2a, ERGSS#3 and ERGSS#4 are in the area of the face and eyes. ERGSS#2b as well as ERGSS#5,#6 and ERGSS#7,#8 are about the muscle power in arms and legs.

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This lead to the conclusion that four different technical examination methods are necessary for stroke recognition in a game: The analysis of

- speech
- facial expression
- visual field
- muscle power

With this knowledge, the author of this work thought through all the game scenarios that appeared during research as well as the games that were known from the private context. With regards to the muscle power in arms and legs, the first game scenario that was identified to offer activities in combination with the other methods was a dancing game. It seemed to cover all required body functions but had major deficits as listed in Table 14.

The second game scenario was a car racing game which was taken as option because of the existing stroke rehabilitation game NeuroRacer [26] (see chapter 2.2.1).

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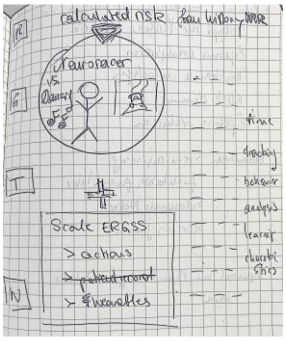
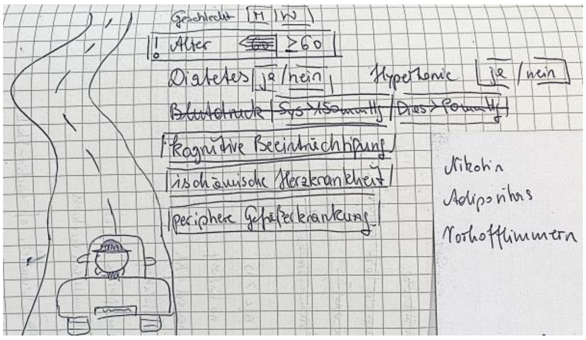
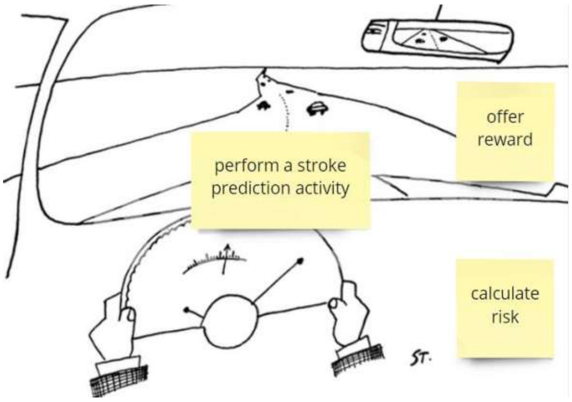
Item	Scenario 1: Dancing	Scenario 2: Car Race
Draft		
Sketch		
Facial Expression	Facial expression difficult, the player might be too far from the camera because of the whole body scenario.	Facial expression possible, player sits directly in front of the camera.
Speech	Speech analysis is possible.	Speech analysis is possible.
Motor Arm Motor Leg	Arm and leg movement is possible but no detection of muscle power.	Arm and leg movement is limited, detection of muscle power possible.
Visual Field	Visual field is difficult because of the whole body scenario.	Visual field is possible and improvable with the hardware setting (screen).

Table 14: Sketches

Sketches Findings

A car race is the most suitable scenario for stroke detection in a game, considering the items in the ERGSS. There were more advantages compared to a dancing game scenario. In general, the technical possibilities to detect symptoms are more accurate.

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4.2.6 Interim Result 3: Stroke Prediction Serious Game (SPSG) Scenario

Now that the prediction logic was defined [AD4.ir2] and an appropriate game scenario was chosen [AD5.i3], the definition of appropriate game activities is done. Brainstorming helped to find activities in a car racing game that could cover the neurological examination methods described for each symptom. This formed the Stroke Prediction Serious Game (SPSG) [AD6.ir3].

Table 15 is an extension of the ERGSS [AD3.ir1]. Two additional columns describe suitable game activities and corresponding data sources for the elevation of each item. Smart game devices (see chapter 2.2.3), as well as the state of the art approach for stroke detection mHealth App (see chapter 3.3.6), are needed for items of the type symptom. Risk factors are available from the patient record (see chapter 2.4.1) and the game history, while health condition parameters are expected from a smart watch (see chapter 2.4.2).

The transcribed activities were afterwards illustrated in wireframes [AD7.i4] to verify the ideas with P01 and P03.

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ERGSS#	Examination Item	Risk Increase Characteristics	Game Activity	Data Source
1	LOC Questions	Person doesn't answer both questions correctly: - Which month is it? - What is your age?	Display questions during race and offer boost when answered. (not only when correctly answered, an answer is more valuable than a correct answer)	mHealth App
2	LOC Commands	Person is not able to perform both tasks correctly: a) Open and close eyes. b) Grip and release (non-paretic) hand.	a) Display command during race and analyze facial expression. b) Display command during race and analyze joystick usage.	mHealth App, Smart Wheel,
3	Visual Fields	Visual fields (upper and lower quadrants) are tested by confrontation, using finger counting or visual threat, as appropriate. Patients may be encouraged, but if they look at the side of the moving fingers appropriately, this can be scored as normal.	Display a symbol in an area that is outside the standard visual field and ask to interact with it.	Multi-Monitor Setup
4	Facial Movement	There is an asymmetry in grimace when the person shows teeth or raises eyebrows and closes eyes.	Display commands and analyze facial expression.	mHealth App
5, 6	Motor Arm (L+R)	The person is not able to hold the arm for 10 sec. without a drift.	Ask player to hold the wheel in a specific position on the screen and analyze the movement.	Smart Wheel
7, 8	Motor Leg (L+R)	The person is not able to hold the leg for 5 sec. without a drift.	Ask player to push the gas pedal and analyze the movement.	Smart Pedal
9	Speech	Aphasia (reduction of speech and/or comprehension) or dysarthria (clarity of articulation reduced).	Ask player to repeat a few words and analyze speech.	mHealth App
10	Age	min. 45 years	Fetch data from patient record.	Patient Record

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11	History	The patient has no prior history of seizure.	Check the medical history of this person	Patient Record
12	Time	There was an anomaly in the last 24h.	Check the game history of this person.	Game History
13	Ambulatory at Baseline	Patient was ambulatory at baseline (prior event).	Check the medical history of this person.	Patient Record
14	Blood Glucose	The glucose level is not between 60 – 250 mg/dl.	Activate the wearable and compare values.	Smart Watch
15	Blood Pressure	The blood pressure is ≥ 140/90 mmHg (either SBP ≥ 140 or DBP ≥ 90)	Activate the wearable and compare values.	Smart Watch

Table 15: ERGSS in game scenarios

4.2.7 Iteration 4: Wireframes

The fourth prototype was done to deal with assumption A01. After deciding about the game scenario with sketches [AD5.i3], the ERGSS was translated into activities in a car racing game and transcribed in the SPSG [AD6.ir3]. Finally, wireframes [AD7.i4] were designed to visualize the SPSG activities and use them for another evaluation with medical experts.

The designed wireframes are illustrated as follows:

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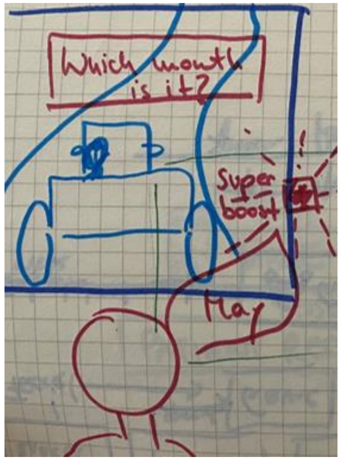
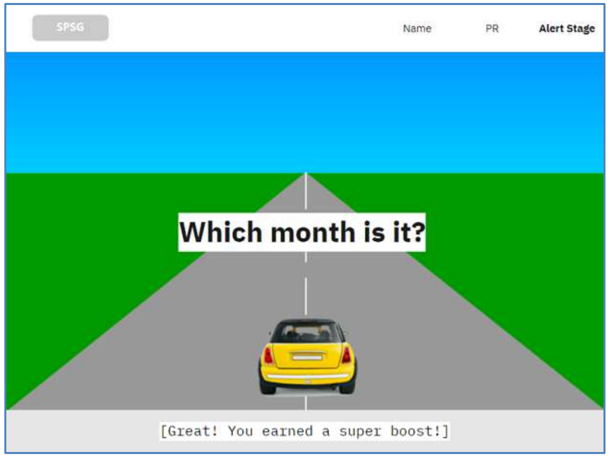
ERGSS	Serious Game Activity	Technology
LOC Questions (ERGSS#1) Speech (ERGSS#9)	  In this activity questions need to be answered. They could be displayed at any time during the game. The player needs to speak the answer loudly and then continue with the game while receiving a reward e.g. super boost. With this activity two items of the ERGSS could be assessed. ERGSS#1 examines the level of consciousness by interpreting the meaning of answers to two very simple questions. ERGSS#9 expects answers from the patient as well, but the assessment is done based on the speech clarity, articulation and / or comprehension. Both manifestations are traceable with a speech analysis software and a microphone (see chapter 3.3.6).	Analysis of Speech Microphone

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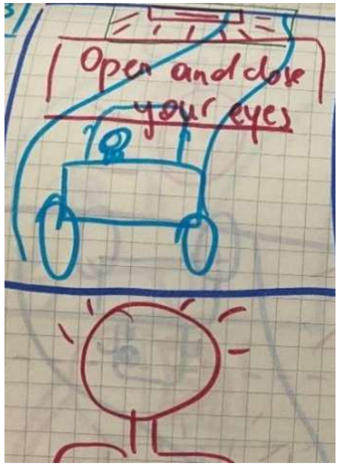
<table>
<tr><th>ERGSS</th><th colspan="2">Serious Game Activity</th><th>Technology</th></tr>
<tr><td rowspan="2">LOC Commands (ERGSS#2a)

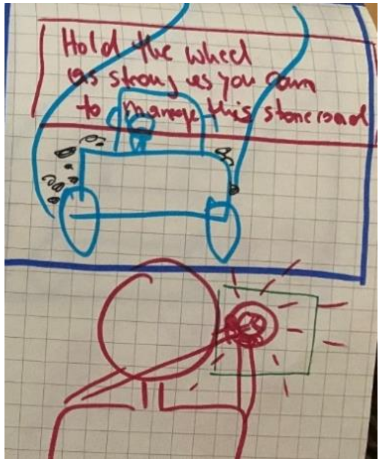
Facial Movement (ERGSS#4)</td><td>
</td><td>
</td><td rowspan="2">Analysis of Facial Expression

Webcam</td></tr>
<tr><td colspan="2">In this activity a command needs to be executed. Depending on the character of the command an appropriate data source is necessary.

In ERGSS#2a the player is asked to perform an activity in the area of the face which is why the activity is defined as combination with ERGSS#4.
In ERGSS#4 the player is asked to perform a grimace for the detection of asymmetries.

Both manifestations are traceable with a face analysis software and a video camera (see chapter 3.3.6).</td></tr>
</table>

<table>
<tr><th>ERGSS</th><th colspan="2">Serious Game Activity</th><th>Technology</th></tr>
<tr><td rowspan="2">LOC Commands (ERGSS#2b)

Motor Arm L+R (ERGSS#5, #6)</td><td>
</td><td>
</td><td rowspan="2">Analysis of Muscle Power in the Arm

Smart Wheel</td></tr>
<tr><td colspan="2">In this activity a command needs to be executed. Depending on the character of the command an appropriate data source is necessary.

In ERGSS#2b the player is asked to perform an activity with arm muscle power which is why the activity is defined as combination with ERGSS#5,6.
In ERGSS#5,6 the player is asked to hold the arm for a specific time.

Both manifestations are traceable with a smart steering wheel that measures the muscle power and locates the position (see chapter 2.2.3).</td></tr>
</table>

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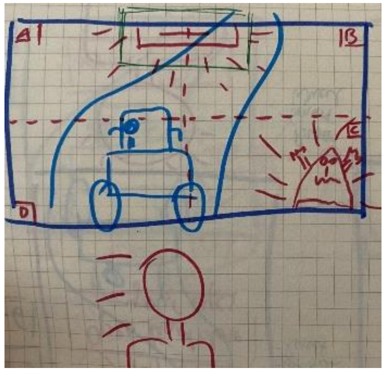
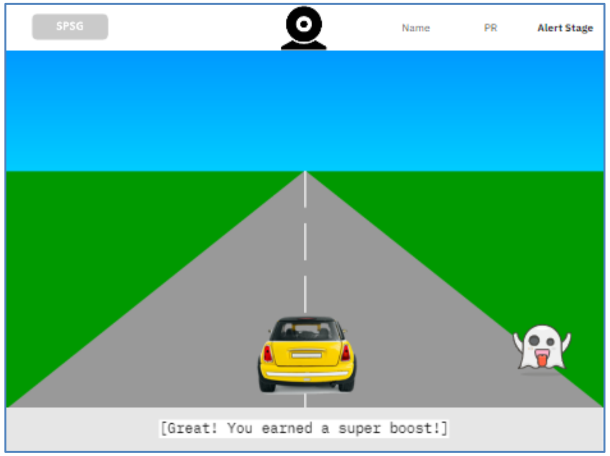
ERGSS	Serious Game Activity	Technology
Visual Field (ERGSS#3)	  In this activity the player is triggered to see objects that are placed deep in the corners of the sight quadrants. In ERGSS#3 the visual field is examined with a stimulus in the quadrants. This manifestation is traceable with a multi-monitor setup (see chapter 2.2.3).	Analysis of the Visual Field Multi-Monitor Setup

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ERGSS	Serious Game Activity		Technology
Motor Arm L+R (ERGSS#5, #6)			Analysis of Muscle Power in the Arm Smart Steering Wheel
	In this activity the player is asked to hold the wheel in a specific position for 10 seconds. In ERGSS#5,#6 the arm function is assessed by detecting if there is a drift of the arm during the defined time range. This manifestation is traceable with a smart steering wheel that locates the position of the wheel (see chapter 2.2.3).		

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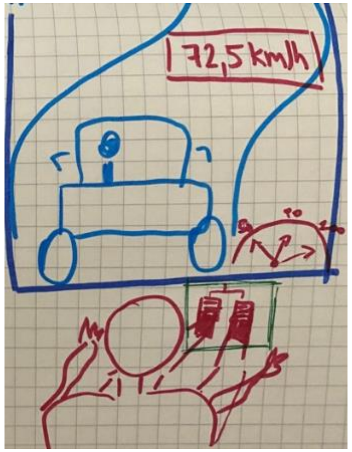
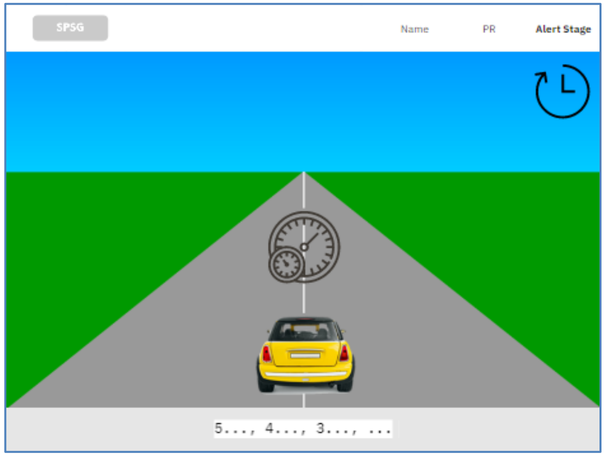
ERGSS	Serious Game Activity	Technology
Motor Leg L+R (ERGSS#7, #8)	  In this activity the player is asked to press the pedal so that a defined speed is held for 5 seconds. In ERGSS#7,#8 the leg function is assessed by detecting if there is a drift of the leg during the defined time range. This manifestation is traceable with a smart gas pedal that allows the analysis of the motoric power in the leg (see chapter 2.2.3).	Analysis of Muscle Power in the Leg Smart Pedal

Table 16: Wireframes

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The evaluation of the wireframes was prepared as semi structured interview with open questions. This enabled an open, creative and critical discussion about the suggested game activities. The interviews were done with P01 and P03 separate. Both participants were already involved in the card sorting and paper prototype iterations and they share the passion of computer gaming.

Main question was to verify if the game activities would lead to a valid interpretation about a stroke manifestation.

Wireframes Findings

LOC Questions: (ERGSS#1)	A combination with ERGSS#9 is valid but implies that the person answers more than one word.
LOC Commands: (ERGSS#2a)	It is only relevant if any command is performed as requested. It would be an option to use different methods for the request of commands e.g. audio requests or the activity is displayed per video and needs to be copied. This way the cognitive comprehension is decoupled from facial paralysis and other impairments.
LOC Commands: (ERGSS#2b)	It is only relevant if any command is performed as requested. This activity is good for the assessment of ERGSS#5,6 in combination.
Visual Field: (ERGSS#3)	It would be better if the symbol moves from one side of the scenario to the other, at least to the middle. It needs to be reproducible app. 5 times from each visual quadrant. It would be an idea to display a train that appears from any side of the scenario as this is a regular examination method that resembles the everyday life. This idea could be reused for the assessment of NIHSS#11 which is not part of the ERGSS. If the player recognizes a train that comes from the left and afterwards one that comes from the right but nothing if two trains come from both sides, it implies that there might be a stroke occurring.
Facial Movement: (ERGSS#4)	An activity that involves the activation of mouth corners e.g. showing teeth facilitates the detection of facial paralysis.
Motor Arm: (ERGSS#5,6)	It is necessary to ensure that one hand doesn't compensate the other. A severe paralysis would be detectable.
Motor Leg: (ERGSS#7,8)	The use of a pedal activates muscles that are easily controllable consequently only severe paralysis would be detectable.
	The activities for ERGSS#5,6 and ERGSS#7,8 are not explicitly needed. It is only relevant if there is any loss of muscle power. Using a smart wheel

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and smart pedal that track the muscle power during the regular game activities might be enough.

Speech: (ERGSS#9) A few sentences spoken by the patient are necessary to detect speech disorders.

4.3 Realization Prototypes

Before continuing with the description of the third and last phase in the whole process, following chapters offer in-depth descriptions of the realization of the card sorting [AD1.i1], the paper prototype [AD2.i2] and the detailed derivation process of the ERGSS [AD3.ir1]. All information refer to the previously summarized prototypes in chapter 4.2. In general, an insight into the transformation of the NIHSS to the ERGSS follows.

4.3.1 Realization Card Sorting

As anticipated in 4.2.1, card sorting was done to classify the examination items of the NIHSS and conclude about the diagnostical relevance of the symptom in a prediction logic. The setting for this purpose was chosen as described in the following chapter.

Card Sorting Setting

Each symptom from NIHSS was written on a card in its possible characteristics and manifestation. These cards needed to be classified within five categories:

a) Possibly a differential diagnose
b) Decreases the probability of a stroke
c) Increases the probability of a stroke
d) Indicates a stroke
e) Eliminates a stroke (predicts a mimic)

Participant P01 was asked to assign each symptom card to a category.

Card Sorting Realization

The first attempt was in a rather casual setting where the neurologist was asked a question as follows:

Which symptoms would you consider as mostly relevant for a stroke? Please assign each card to one of the categories.

The card sorting was difficult to handle. It seemed that the neurologist analyzes each symptom in detail to find a specific diagnose, which lead to more and more aspects that needed to be

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considered. This approach made it nearly impossible to assign any card to a category because each symptom could lead to many different diagnoses.

In the end, the result of the first sorting basically represented the numerical categorization of the NIHSS. Symptoms that are represented by value 0 were mostly decreasing the probability of a stroke while symptoms with value 2 or higher were increasing the probability of a stroke. A few of the symptoms were identified as potential differential diagnose but still the question of relevance of a symptom for a stroke was not answered clear enough, or only answered the same it was known from the NIHSS already.

Figure 52 illustrates the result in detail. The first column represents symptoms that “indicate a differential diagnose” (a), the second column all symptoms that “decrease the probability of a stroke” (b) and the third column all symptoms that “increase the probability of a stroke” (c). An assignment to the remaining two columns, “indicates a stroke” (d) and “eliminates a stroke” (e) was not performed as there was not enough information for such a clear definition, according to the neurologist.

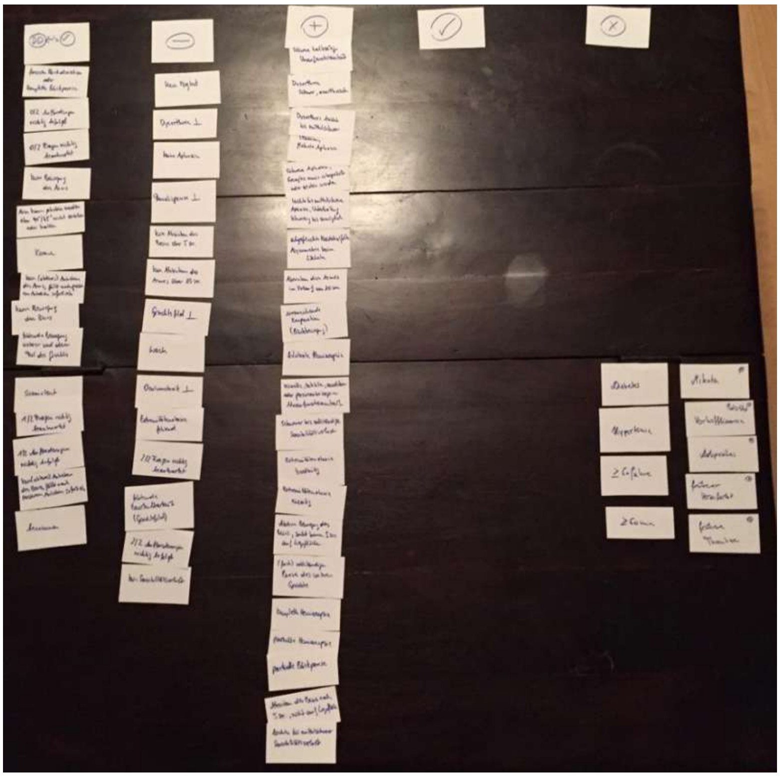

Figure 52: Card Sorting 1st attempt

The set of health conditions and risk factors on the right side of the image intended to offer “more information” but only helped to identify a few items for the first column and again did not lead to any assignment to (d) or (e). The information consisted of: diabetes, hypertonia, age > 60 years,

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duration of symptoms > 60 min., nicotine, atrial fibrillation, obesity, earlier cardiac infarction or thrombosis. Some of the items were taken from the $ABCD^2$-Score, others were added by the neurologist.

Nevertheless, it was recognizable that the neurologist was trying to derive a diagnosis, which differed from the intention of the card sorting and lead to a more complex progress. In fact, the intended logic should allow that a neurologist sees patients that *could* have a stroke, not only the ones that are *definitely* suffering from one. Therefore, the second attempt was accompanied by a question that better describes the intention and reuses a situation every neurologist knows very well:

Imagine you are on duty during the night shift and there is a patient with known risk factors for a stroke. The nursing staff wakes you up in the middle of the night. Which would be the symptoms that make you angry (e), because it's not that urgent to see the patient now, and which would be the symptoms you couldn't continue your sleep with anyways (d)?

In this attempt, the approach of the card sorting changed completely and the outcome was that specific to the expectation, that even subcategories were introduced by the neurologist to make it better understandable. An interesting fact beforehand is, that the extended health conditions were completely ignored.

The clear answer was that if a few specific symptoms that indicate a stroke occur, it doesn't matter if there are other risk factors, the neurologist wants to see the patient, which is exactly what the logic intends to fulfill: seeing the doctor who decides about further steps, even if the final correct diagnose is not a stroke but it could have been one with a high probability.

The new arrangement of the cards is visualized in Figure 53. While the set of extended health conditions remained unvalued, the assignment to columns (d) and (e) expanded. All symptoms that indicate a stroke were subcategorized to following items: paralysis, visual loss, lost consciousness, loss speech/language. They were collected in the lower left corner and assigned to (d) via placeholder cards named like the subcategories. Items with value 0 in the NIHSS were assigned to (e) and others remained in the columns (a) and (c). Column (b) was useless because the symptoms related to the ones of column (e).

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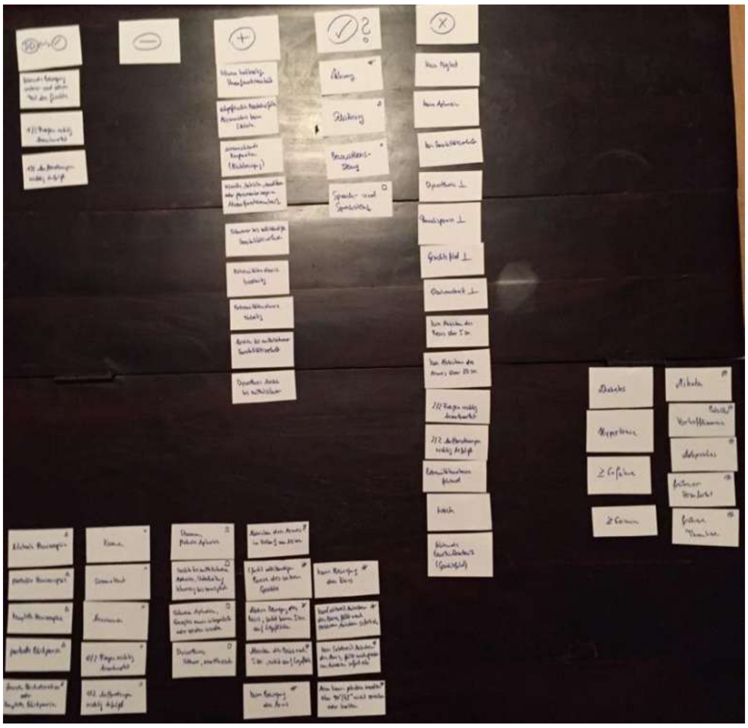

Figure 53: Card Sorting 2nd attempt

Card Sorting Interpretation

The interpretation of the 2nd attempt seemed vague, which is why it was necessary to align the resulted categorization with other research studies. To be able to base the informative value of the card sorting a study about distinguishing strokes and mimics in 2006 was considered as good reference because it highlights numerical values for each factor that is known in the neurological field.

Over a period of time, four doctors were performing a predefined bedside assessment with about 300 patients with potential brain attack. The gathered clinical factors were opposed to the final diagnose, stroke or mimic. Figure 54 illustrates the odds ratio of each clinical factor for predicting a stroke or a mimic. Squared dots in the area < 1 stand for a variable that indicates a mimic while the area > 1 indicates a stroke. Horizontal lines to the left and right of a dot symbolize the variance. [15]

Having a detailed look at the sector “Past Medical History” it is noticeable that a patient that suffered from cognitive impairment in the past is rather having a mimic than a stroke. In contrast, peripheral vascular diseases favor a stroke. Furthermore, it is predictable that a patient with no lateralizing or neurological signs or someone who shows signs in other systems (skeletal, muscular, digestive, urinary, nervous, reproductive, lymphatic, endocrine or respiratory system) is rather suffering from a mimic, while sensory loss or motoric impairment significantly predicts a stroke.

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The motoric impairment is mentioned in the critical symptoms listed by the American Stroke Association too, pointed out as “arm weakness”.

The sector “Presenting complaint” is listing a selection of meaningful symptoms that could be determined by the doctor instantly seeing the patient, while the sector “Neurological Examination” lists factors resulting from an examination based on the NIHS scale.

The “General Examination” represents laboratory and further exploration results. A “Diagnostic Formulation” allows neurologists to classify the type of stroke by the extent of initial symptoms.

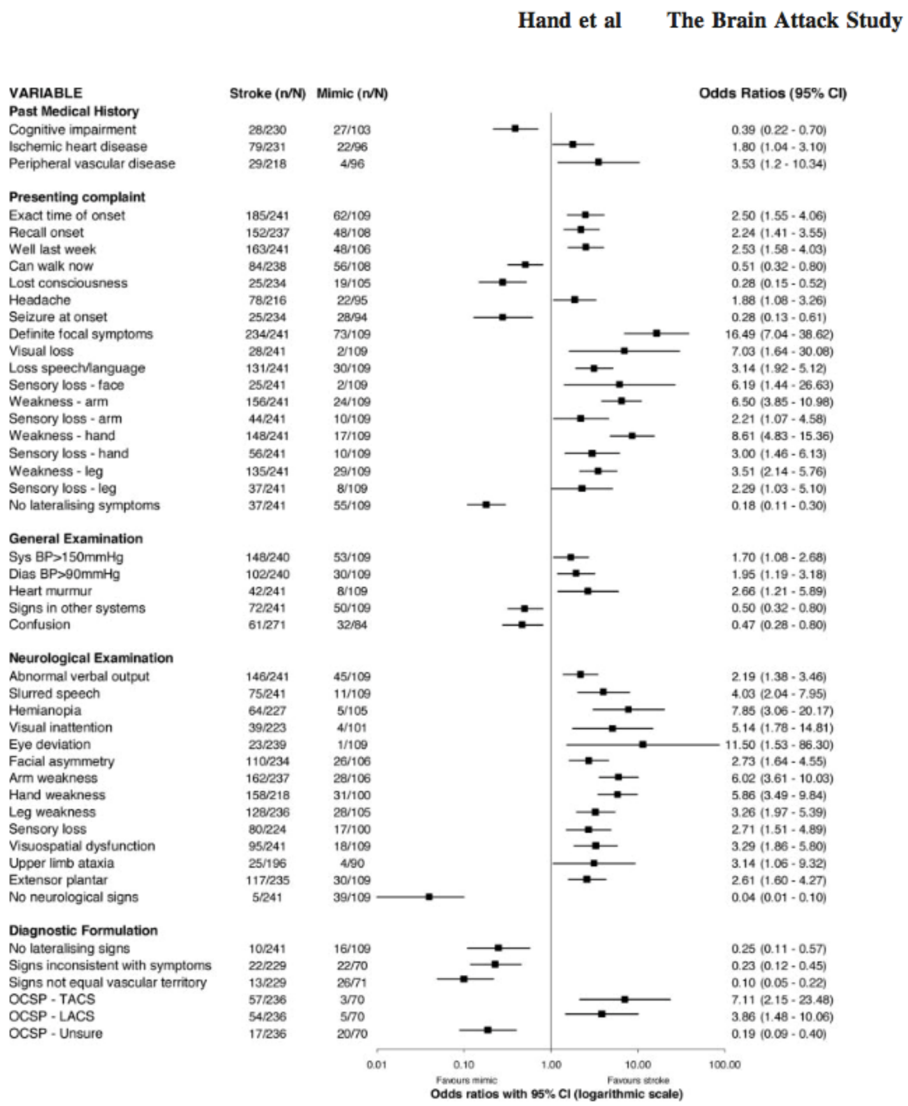

Figure 54: Prediction of strokes and mimics [15]

In summary the medical examination for strokes in general (see Figure 54) outline following actions that need to be considered during a stroke assessment:

- check past medical history

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- analyze presenting complaint
- execute general examination
- execute neurological examination
- find correct OCSP diagnostic formulation

The neurological examination is mostly performed with the NIHSS.

Figure 55 shows that the higher the NIHS value (and therefore the identified impairment), the higher the probability to discover a stroke rather than a mimic.

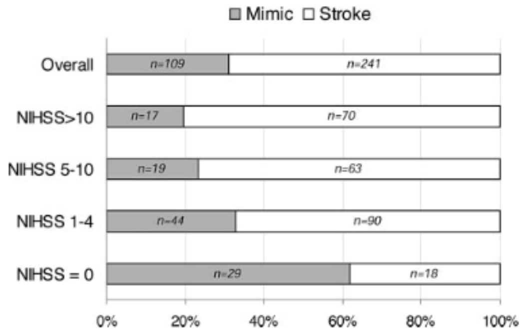

Figure 55: Stroke or mimic subdivided by NIHSS score [15]

It turned out that the study about distinguishing strokes and mimics [15] was using the same categorization as the second card sorting attempt. This enabled a comparison between the result of the study and the card sorting, considering the dichotomy. The card sorting's categories a – e could be similarly dichotomized into stroke or mimic by defining (c) and (d) as stroke and (a), (b), (e) as mimic. The extended health conditions and the subcategories are represented in the study as well but enlarged by more items.

The results in the card sorting correspond to the ones in the study insofar as the items in (e) mainly represent the items “No lateralizing symptoms” and “No neurological signs”, seen in Figure 54, that predict a mimic. All symptoms of (c) and (d) are predicting a stroke, considering that the loss of consciousness was handled in more detail in the card sorting. Consciousness is evaluated asking the patient two questions and rating if 0, 1 or 2 questions are answered correctly (see the NIHSS in detail in the appendix). The card sorting realization differs between “1 of 2 questions performed correctly” (assigned to (a)) and “0 of 2 performed correctly” (assigned to (d)). “2 of 2 questions correctly” is assigned to (e). This differentiation is not done in the study, which might be the reason why the item “Lost consciousness” is not clearly predicting a stroke there.

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Other items in Figure 54 that predict a mimic are not covered in the card sorting. The role of historical and general conditions is unclear as far as these items were ignored during the card sorting but predict a stroke according to the study. All findings are summarized in chapter 4.2.1.

4.3.2 Realization Paper Prototype

After the realization of the card sorting a first attempt for a recognition logic was designed (see chapter 4.2.1). The logic was verified in a paper prototype with the neurologists P01, P03, P04 and P05.

The paper prototype was matched to bricks and elements that were available in the private environment of the author. They were used to perform iterations of the logic with a representation of all needed elements in a game. It seemed to correspond that the vehicle represents the player that “carries” along different health conditions.

Paper Prototype Setting

The vehicle in Figure 56 and Figure 57 represented the player. The medical characteristics of the player is arranged randomly using the numbered bricks.

Figure 56: Paper Prototype brick elements

Figure 57: Paper Prototype player’s profile

Each number on a brick represented a former illness:

1 Hearth Arrhythmia
2 Thrombosis
3 Heart Attack
4 Diabetes
5 Hypertonia
6 Ischemic Heart Disease
7 Peripheral Vascular Disease
8 Cognitive Impairment

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Illnesses 1 – 5 were taken from the card sorting and 6 – 8 from the section "Past Medical History" in Figure 54. The only predefined characteristics was the age of every player. It was defined as ≥ 60 years based on the ABCD-Score.

The symptoms that were written on paper cards for the card sorting were reused. Additional cards were created to be able to eliminate the most frequent differential diagnoses. Those cards were hidden behind a cover so that it was traceable at which moment the participant needed the information.

There were three additional cards behind the cover: blood sugar, blood pressure, other. The bricks with different shapes (cross, circle, hexagon) resulted in a characterization of a condition in combination with one of those cards.

The combinations result as listed in Table 17.

Brick	Blood Sugar	Blood Pressure	Other
✚	Blood sugar too high	Blood pressure too high	Fever
●	Blood sugar too low	Blood pressure too low	Confusion
⬢	Null	Null	Heart Murmur

Table 17: Combinations of bricks and additional paper cards

The last set of bricks was introduced based on the proposal of a neurologist who performed one test sequence with the Paper Prototype in its making. It represented the prescribed drugs of the player.

Brick	Drug
④	Antiepileptics (Note: brick ④ got lost after the evaluation and is absent in Figure 56 and Figure 57)
△	Antidiabetics
□	Blood thinners

Table 18: Drug bricks

To explain what was expected, each participant received an introductory description:

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This is part of a thesis in the field of medical informatics, where serious games are currently in focus. Games are used in serious context, in the medical field e.g. for rehabilitation purposes so far. The presented setting should help to verify if it is possible to use games for diagnosing strokes in early stages. We are about to verify a primary algorithm by visualizing how you, as an expert, estimate the risk for a stroke.

Imagine you are in charge during the nightshift and you receive information about a person who is about 60 years or older. The information you receive in a first step consists of symptoms. You have the possibility to check other health conditions using the objects and you are supposed to move within a specific scale to visualize your thinking.

Figure 58: Paper scale

Figure 58 illustrates the scale that is used to represent the risk estimation by the neurologist. It consisted of the resulting categories in the card sorting, that were paraphrased to a few sentences each expert can relate to in the context of a nightshift. The mapping of the items is described in Table 19.

Storyboard Scale	Color	Card Sorting
This must be a stroke.	Red	d
I need to have a look at this now.	Orange	c
Irritating. I don't know. Let's wait and see. I will have a look at this later.	Blue	a
This can wait until tomorrow. I am going to sleep.	Green	e

Table 19: Mapping paper scale to card sorting categories

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Further explanation about the setting was given and questions were answered until the aim of the paper prototype was clear for the participant. To allow easier documentation of each turn, every item was assigned to a specific identification:

- Symptoms: “S” + “continuous number”
- Scale: “00”, “01”, “10” and “11” as visible in Figure 58
- Historical conditions: “1” – “8” listed as “former illness” at the beginning of this chapter
- General conditions: “L” (= “laboratory”) + shape of brick
- Contact: “K” + number of correct performed actions + “/2” (“out of 2”, e.g. K0/2, K1/2, K2/2)

Further outlined and highlighted in Figure 60, this identification leads to following example: S17 – 10 – L – 01 – S21 – 01 – S5 – 01. In words it means that symptom “S17” caused an increase of risk to “10” but the laboratory indicates a mimic so the risk decreases to “01”. The second and third symptom didn’t change the risk interpretation.

It was expectable that the procedure might end in situations similar to loops. To avoid that, following constraints were added:

- After three symptoms, the participant needed to decide on a final scale position.
- Direct contact to the player was allowed only once.

The participants were resident physicians in the field of neurology with different levels of experience, starting from two years to five years and an approval as medical specialist for neurology.

Paper Prototype Realization

The participant was sitting in front of the examiner, bricks and scale were placed in the middle of the table, the explanatory cards were hidden behind their covers and arranged side by side in a row. A salt shaker was improvised as indicator within the scale.

Figure 59: Paper Prototype realization

Figure 59 displays an ongoing turn with the described elements.

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Each turn started with the definition of the player's condition. This was done by the participant by selecting a set of bricks and placing them on the vehicle. In Figure 57 the player is defined by preconditions "2" and "8", general condition "hexagon" and drug "triangle". This results in a patient that suffers from a thrombosis and cognitive impairment, having heart murmur and taking antidiabetics.

The examiner described the player's former illnesses (preconditions) at the beginning and then revealed one randomly selected symptom in the middle of the game setting. The participant moved the salt shaker within the scale or asked some more information that was hidden behind covers (general conditions, drugs). This was repeated until the participant was sure about the condition of the player but a maximum of three times.

Paper Prototype Interpretation

The insufficient outcome is better traceable with a detailed look at the documentation:

	Abfolge									
1	S10 - H - 01 - S6 - 11	S10	01	S6	11					
2	S1 - 10 - Kontakt 1/2 Auff. - S2 - 10 - S22 - L - 10	S1	10	K	S2	10	S22	L	10	
3	S20 - 10 - S23 - S25 - 10	S20	10	S23	S25	10				
4	S25 - L - 00 - S13 - 01 - S7 - 10	S25	L	00	S13	01	S7	10		
5	S6 - 10 - S30 - 10 - S15 - 11	S6	10	S30	10	S15	11			
6	S1 - 10 - H - S17 - 10 - S8 - 10	S1	10	S17	10	S8	10			wenig Erfahrung, scheu vor konkreter Aussage
7	S4 - 11 - L - 10 - S20 - 10 - S5 - S26 - 10	S4	11	L	10	S20	10	S26	10	
8	S3 - 00 - S26 - S11 - L - 00 - S22 - 00	S3	00	S11	L	00	S22	00		keine Halbseite, keine Aphasie
9	S1 - 10 - S4 - 11 - S28 - 11	S1	10	S4	11	S28	11			Halbseite und Aphasie
10	S17 - 10 - L - 01 - S21 - 01 - S5 - 01	S17	10	L	01	S21	01	S5	01	Halbseite, aber niedriger Blutzucker
11	S24 - H - 10 - S27 - 10 - S18 - 10	S24	10	S27	10	S18	10			wenig Erfahrung, scheu vor konkreter Aussage
12	S15 - 10 - S28 - S7 - S29 - 11 - L - 10	S15	10	S28	S29	11	L	10		Halbseite, Aphasie!! Aber niedriger Blutzucker
13	S21 - 00 - S18 - 10 - L - S26 - 11	S21	00	S18	10	L	S26	11		Halbseite und Aphasie
14	S23 - 10 - L - 10 - S16 - 11 - S9 - 00 > Epi	S23	10	L	10	S16	11	S9	00	Einseitig, einseitig !!! aber Blickdeviation, -parese > Epi-Anfall
15	S18 - 01 - S19 - 10 - S14 - 11	S18	01	S19	10	S14	11			Halbseite, Halbseite, Halbseite
16	S2 - 01 - S29 - 10 - L - 10 - S27 - 11	S2	01	S29	10	L	10	S27	11	Aphasie in Kombination mit anderen Symptomen
17	S17 - 10 - S21 - L - 00 - S12 - 00	S17	10	S21	L	00	S12	00		Erst einseitig dann beidseitig, niedriger Blutzucker
18	S5 - 00 - S27 - 10 - L - 11	S5	00	S27	10	L	11			keine Halbseite, Aphasie, Labor OK >> Stroke
19	S4 - 10 - S25 - 10 - S3 - S26 - 10	S4	10	S25	10	S26	10			wenig Erfahrung, scheu vor konkreter Aussage

Figure 60: Paper Prototype documentation

Figure 60 shows the original documented sequence in the left column. The shortcuts, previously described in this chapter, were used and medically impossible symptoms in combination with the already documented, were colored grey to symbolize an exclusion and the replacement with the next random symptom. For an easier evaluation, each symptom and condition check was then split into an own column with a colored column at the end of the row that represents the finally selected scale item. Optional additional comments were added in a column right to the scale color.

The first attempt for discovering a pattern was to check if one symptom mostly causes a risk increase or risk decrease. Starting with line 2 (line 1 is reserved for the column name) in Figure 60 the first symptom S10 caused an increase of risk from 00 to 01. S10 couldn't be reused to check if the symptom always causes a risk increase because it didn't appear a second time in any turn. Therefore, the next symptom in line 2 was analyzed. S6 caused a significant increase from 01 to 11 and an increase from 00 to 10 in line 6. It didn't appear any further but it didn't cause a

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conflict too, therefore the next symptoms were analyzed continuously. S4 in line 8 was a symptom that raised doubts in categorizing symptoms in mainly increasing or decreasing the risk because it first caused a significant increase from 00 to 11 but after laboratory check the risk was lowered to 10 and remained in this stage regardless of other symptoms. In line 10 it increased the risk to clearly recognize the patient's health status as dangerous but in line 20 it didn't.

This rose the hypothesis that the combination of symptoms is more meaningful and the second attempt was formulated to discover combinations of symptoms and conditions that indicate risk increase or decrease more explicitly. Comparing lines 11 and 18 it is recognizable that S17 first increased the risk and subsequent S21 combined with a laboratory check with lower values (low blood sugar, low blood pressure, and unconsciousness) decreased the risk again. S17 represented unilateral weakness while S21 expands the symptoms bilaterally. Starting the examination with S21 as in line 14 and continuing with S18 (a similar symptom to S17) the risk increased from 00 to 10 and even 11 after laboratory check with similarly low values. Most of the symptoms didn't appear more than once in the executed turns which means that a clear answer to this hypothesis would need much more experts than the originally planned.

It was helpful that the participants often thought loudly, which made another alternate hypothesis possible. Unilateral motoric symptoms (highlighted yellow) and aphasia (highlighted orange) were often loudly commented as "bad" which is why the third attempt was to discover if there could be a pattern including them. Unilateral symptoms were colored yellow and aphasia was colored orange. Afterwards it was checked if there has always been an increase of risk after these symptoms. This hypothesis could not be verified as well because there were two turns where the risk estimation remained the same after these symptoms.

Furthermore, the level of experience of the participant seemed to be decisive as far as the final risk estimation is concerned. The neurologist with the least practice was not confident enough to decide on any other area except the orange one ("I need to have a look at this now").

Chapter 4.2.2 outlines the findings of this paper prototype and triggers adequate consequences (the development of interim results for the logic).

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4.3.3 Derivation ERGSS

The ERGSS was derived as a consequence of the unsatisfying findings of the prototypes so far and the extended literature research about further stroke assessment scales. In a first step all similar examination items, that were found in different scales, were consolidated and their occurrence in the scales was analyzed, then a reduction to the most significant and occurring ones was done to finally illustrate the items of the new ERGSS which are summarized in chapter 4.2.3.

Consolidation of Examination Items

One aim was to create an overview of all known examination items (body functions) of all scales in chapters 3.1 and 3.2. Therefore, the items and their individual characteristics were opposed to their appearance in different scales. Similar items were summarized for example Facial Movement: Facial Palsy (N15), Facial Paresis (N8), Facial Droop (CPSS).

Additionally, the mapping offers a cross check of the informative value of each examination item and their importance valued by the frequency of occurrence. In other words; as far as the "sNIHSS-1" identifies motoric limitations in the stronger (mostly right) leg as most valuable item, it implies that this item is examined within other scales too and therefore relevant for a new digital scale, which is to validate.

Table 20 offers an overview of all items and their occurrence in each scale. The symbol "X" marks that an item appears in the scale that names the column. Further analysis of the data is done in Table 21.

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#	Item	N15	N8	N5	N1	mN	LAP SS	CP SS	AB CD	AB CD²
1	Level of Consciousness	X	X							
2	LOC Questions	X				X				
3	LOC Commands	X				X				
4	Best Gaze	X	X	X		X				
5	Visual Fields	X	X	X		X				
6	Facial Movement	X	X				X	X	X	X
7	Motor Arm Left	X				X	X	X	X	X
8	Motor Arm Right	X				X	X	X	X	X
9	Motor Leg Left	X	X	X		X			X	X
10	Motor Leg Right	X	X	X	X	X			X	X
11	Limb Ataxia	X								
12	Sensory	X				X				
13	Speech	X	X	X		X		X	X	X
14	Dysarthria	X	X							
15	Extinction and Inattention	X				X				
16	Age						X		X	X
17	History						X			
18	Time						X		X	X
19	Ambulatory at Baseline						X			
20	Blood Glucose						X			X
21	Grip						X			
22	Blood Pressure								X	X

Table 20: Examination items and their appearance in stroke scales

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Reduction of Examination Items

Without questioning the medical details, it is visible that LAPSS and ABCD(2) combine some of the items of the NIHSS with higher frequency. Especially ABCD(2) seems to cover all valuable items while the LAPSS completely ignores the examination items with the highest frequency (#10 Motor Leg Right, #13 Speech). First conclusion of this mapping is that a replacement of the NIHSS with the LAPSS is no option because the game would ignore the most valuable examination item.

To review the outcome in all detail, the mapping is enhanced with calculated sums in Table 21. Appearing in 7 out of 9 scores, the items "Motor Leg Right" and "Speech" are identified as most valuable, followed by other motoric limitations and "Facial Movement".

Each item that appears in less than four scales is rated as an item with "Limited Informative Value" and as a consequence, subtracted, to deviate a conclusion about each scale's total coverage of informative items. The allover low coverage ratio (<=10 out of 22 items) illustrates why none of the scales could be reused as gaming scale.

	A	B	C	D	E	F	G	H	I	J	K	L
1	#	Object	N-15	N-8	N-5	N-1	mN	LAPSS	CPSS	ABCD	ABCD2	#Scores
2	1	Level of Consciousness	1	1								2
3	2	LOC Questions	1				1					2
4	3	LOC Commands	1				1					2
5	4	Best Gaze	1	1	1		1					4
6	5	Visual Fields	1	1	1		1					4
7	6	Facial Movement	1	1				1	1	1	1	6
8	7	Motor Arm Left	1				1	1	1	1	1	6
9	8	Motor Arm Right	1				1	1	1	1	1	6
10	9	Motor Leg Left	1	1	1		1			1	1	6
11	10	Motor Leg Right	1	1	1	1	1			1	1	7
12	11	Limb Ataxia	1									1
13	12	Sensory	1				1					2
14	13	Speech	1	1	1		1		1	1	1	7
15	14	Dysarthria	1	1								2
16	15	Extinction and Inattention	1				1					2
17	16	Age						1		1	1	3
18	17	History						1				1
19	18	Time						1		1	1	3
20	19	Ambulatory at Baseline						1				1
21	20	Blood Glucose						1			1	2
22	21	Grip						1				1
23	22	Blood Pressure								1	1	2
24		Examination Items	15	8	5	1	11	9	4	9	10	22
25		Limited Informative Value	6	3	1	0	3	1	0	0	0	7
26		Total Coverage	9	5	4	1	8	8	4	9	10	15

Table 21: Reduction of mapping to valuable items

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Subsequently the scales N-15, mN, LAPSS, ABCD and ABCD2, that are the scales with the best coverage, were compared.

N-15 covers all most valuable items but as well the most ones with limited informative value. Many of these items are not easy to evaluate in a gaming scenario which is why the effort to do this would need a good informative outcome as reason to implement. But then, items that could be easily tracked (#16-20, #22) are not covered at all.

Likewise, the mN includes items with low informative value and additionally misses out the facial movement, which is one of the most valuable items.

ABCD and ABCD2 seem to be the scales with the best outcome in gaming because they cover all most valuable items as well as some that are easily traceable with specific devices. There are many possibilities to track the blood glucose, which is why ABCD2 is considered as the more informative scale. Further, having a detailed look at the covered items in these scales, they seem easily expandable to a few more items. Column L in Table 21 colors items in light green that are as well easily traceable with technologies outlined in chapter 2.4.

None of the existing scales was meant to be reused in a digital setting or for a digital transformation, consequently it was necessary to derive a new scale for the specific aim of a gaming scenario. The resulting new scale is described in chapter 4.2.3.

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4.4 Implementation

The third phase of this work represents the fifth and last prototype and is the final implementation of the game. It was done in five steps [I0-4]. The evaluated wireframes [AD7.i4] offered a good fidelity for the definition of requirements [I0], design of a system interaction diagram [I1], definition of use cases [I2] and the development of a coded prototype [I3].

Since the evaluations of all prototypes in the previous phase were done with medical experts and had the purpose of correctness in the technical design, the user acceptance was missed out. Therefore, the engineering and implementation of the system is an iterative process on its own, followed by methods of user centered design and starting with a first user evaluation [I4]. For the coded prototype existing car racing prototypes were researched that are easy to play on a browser and where the source code was editable. [83]

So far, this work has revealed three interim results to be considered for the implementation.

It is the Early Recognition Game Stroke Scale (ERGSS) that summarizes symptoms, risk factors and the current health condition into one newly developed digital stroke assessment scale.

The Recognition Logic for Strokes in Games (RLSG) uses the information from the ERGSS to define the necessary steps for stroke detection in four sections: stroke risk prediction, stroke recognition, stroke exclusion and stroke warning.

The Stroke Prediction Serious Game (SPSG) defines activities within a car race scenario that enable the collection of data from the ERGSS.

The findings triggered an update of the assumptions to requirements of different validity, described in the following chapter.

4.4.1 Requirements

During the initial research phase [R0] – [R2], invalidated assumptions were collected. The validation was done with each iteration in the phase of analysis and design. Finally, the assumptions are updated as follows.

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#	Invalidated Assumption	Update
A01	It is possible to fetch each symptom of the NIHSS technically.	RT01
A02	It is possible to calculate a numerical positive value that indicates the necessity of a neurological consultation.	RU08, RL02, RL05
A03	It is possible to determine a combination of symptoms and conditions that always asks for a neurological consultation.	RU02, RU03.
A04	It is possible to identify other health conditions that help estimating the probability of a stroke.	RU09, RM04, RT03
A05	It is possible to clearly separate symptoms that mimic a stroke and symptoms that represent another disease.	RL04
x	It is possible to isolate accidently faked symptoms with intended actions.	Out of scope, AI topic.
A07	It is possible to verify if a symptom is alarming or only alarming in combination with other symptoms or health conditions.	RU03, RL01
x	An already existing serious game for the therapy of post stroke impairments could be reused for the diagnosis.	The focus was set to a car race.

Table 22: Assumptions to requirements

Further more functional requirements for the serious game design evolved during the phase of analysis and design. A total number of 37 requirements of different validity was defined. Their validity categories are defined in Table 23 while their details are outlined in Table 24.

Requirement derived as necessary for the rest of the system but not validated in any iteration with an expert or user.	Unvalidated
Requirement validated in one iteration with at least one person or validated but other options could exist that are not researched.	Vague
Requirement validated in more than one iteration with at least one person or validated but expected to be extendable.	Firm
Requirement validated in more than one iteration with more than one person or because of the nature of the whole system.	Validated

Table 23: Description of validity categories of requirements

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#	Domain	Functional Requirements	Validity
RU01	Universal	A Stroke Prediction Serious Game (SPSG) has a game scenario that enables the collection of data for stroke risk prediction.	Validated
RU02	Universal	The SPSG builds on the medical basis ERGSS so that it's clear which data is necessary.	Validated
RU03	Universal	The SPSG contains the recognition logic RLSG so that the stroke risk is calculated.	Validated
RU04	Universal	The SPSG contains activities that monitor the symptoms of the ERGSS.	Validated
RU05	Universal	The SPSG visualizes that the patient record of the player is connected.	Unvalidated
RU06	Universal	The SPSG visualizes that a game history of the player is available.	Unvalidated
RU07	Universal	The SPSG visualizes the alert stage with a risk indicator.	Unvalidated
RU08	Universal	The SPSG includes a definable threshold for the stroke warning based on the stroke severity range	Unvalidated
RU09	Universal	The player of an SPSG wears a smart watch that measures blood pressure and blood glucose	Validated
RL01	Logic	The recognition logic RLSG considers 4 sections: stroke risk prediction, stroke recognition, stroke exclusion, stroke warning.	Validated
RL02	Logic	The RLSG calculates the stroke risk based on risk factors so that an initial stroke risk is available.	Firm
RL03	Logic	The RLSG tracks symptoms so that the stroke risk is updated.	Validated
RL04	Logic	The RLSG monitors the health condition parameters so that stroke mimics are excluded.	Validated
RL05	Logic	The RLSG releases a warning according to the defined threshold.	Validated
RG01	Game	The SPSG includes activities that ask questions that need to be answered so that the analysis of speech is possible.	Validated
RG02	Game	The SPSG includes activities that request to perform commands so that the analysis of consciousness is possible.	Validated

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RG03	Game	The SPSG includes activities that request to make a grimace so that a detection of facial asymmetries is possible.	Validated
RG04	Game	The SPSG includes activities that display objects in the corners of the view so that an analysis of the visual field is possible.	Validated
RG05	Game	The SPSG includes activities that asks to use a hand so that a measurement of the muscle power in an arm is possible.	Validated
RG06	Game	The SPSG includes activities that asks to use a leg so that a measurement of the muscle power in a leg is possible.	Validated
RG07	Game	An activity to analyze the speech must include more than three sentences spoken by the patient.	Validated
RG08	Game	An activity to analyze the facial expression must include the usage of mouth corners e.g. when showing teeth.	Validated
RG09	Game	An activity to analyze visual field must display an object moving from one side of the screen to the other.	Validated
RG10	Game	An activity to analyze the muscle power in an arm must enable a separate interpretation of the power in each arm.	Validated
RG11	Game	An activity to analyze leg muscle power must enable a separate interpretation of the power in each leg.	Vague
RM01	Medical	The medical basis ERGSS considers 3 types of items: risk factors, symptoms, health condition.	Firm
RM02	Medical	The SPSG tracks 9 symptoms: LOC questions, LOC commands, visual field, facial movement, arm movement right, arm movement left, leg movement right, leg movement left, speech.	Firm
RM03	Medical	The SPSG tracks 4 risk factors: age, history, time, ambulatory at baseline.	Firm
RM04	Medical	The SPSG tracks 2 health condition parameters: blood pressure, blood glucose.	Firm
RT01	Technical	The SPSG tracks symptoms with 4 technical examination methods: analysis of speech, visual field, facial movement, muscle power.	Validated
RT02	Technical	The SPSG is connected to the patient record of the player so that risk factors are available for stroke risk calculation.	Validated

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RT03	Technical	The SPSG is connected to the smart watch of the player so that blood pressure and blood glucose are measurable.	Validated
RT04	Technical	The SPSG is displayed on a multi-monitor-setup so that the visual field is assessable.	Validated
RT05	Technical	The SPSG is connected to a smart wheel so that the muscle power in arms is measurable.	Validated
RT06	Technical	The SPSG is connected to a smart pedal so that the muscle power in legs is measurable.	Validated
RT07	Technical	The SPSG integrates the mHealth App so that the analysis of speech and facial expression is possible.	Vague
RT08	Technical	The SPSG saves the game history of the player so that the information about an anomaly in the past is available.	Validated

Table 24: Requirements

RU05-RU07 are defined as unvalidated because these elements are necessary during the prototypical implementation but it is expected that this information is not essential for the player.

RU08 is unvalidated because the stroke severity range as part of the NIHSS was not adapted to the ERGSS. P01 and P03, both mentioned that the patient's health status is suspicious to them from the very first anomaly detected. It is expected that the release of a warning with the very first anomaly is not viable hence there are far more questions to be answered.

RL02 is defined as firm because some research was done about the stroke risk calculation but not adequate for a decision about the best calculation method.

RG11 is vague because the evaluation of wireframes revealed that if a patient has problems with this activity the stroke must be of such high severity that the patient would have problems to walk to the game setting. This activity requires one specific muscle that is easily controllable, hence a slight anomaly is not easy detectable.

RM01-RM04 are firm because they based on the findings within the card sorting and paper prototype, as well as the extended literature research about stroke assessment scores. The final characteristic of this score needs at least one more evaluation with medical experts.

RT07 is vague because the approach was published lately and seems to perfectly fulfill the expected analysis but it is not clear if it is possible to integrate the algorithm in a game.

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4.4.2 System Interaction Diagram

Numerous aspects and data sources need to be summarized into one system. For this reason, an interaction diagram was designed to visualize the interactive behavior.

Figure 61 illustrates the SPSG as high level system where all external devices and their information is combined.

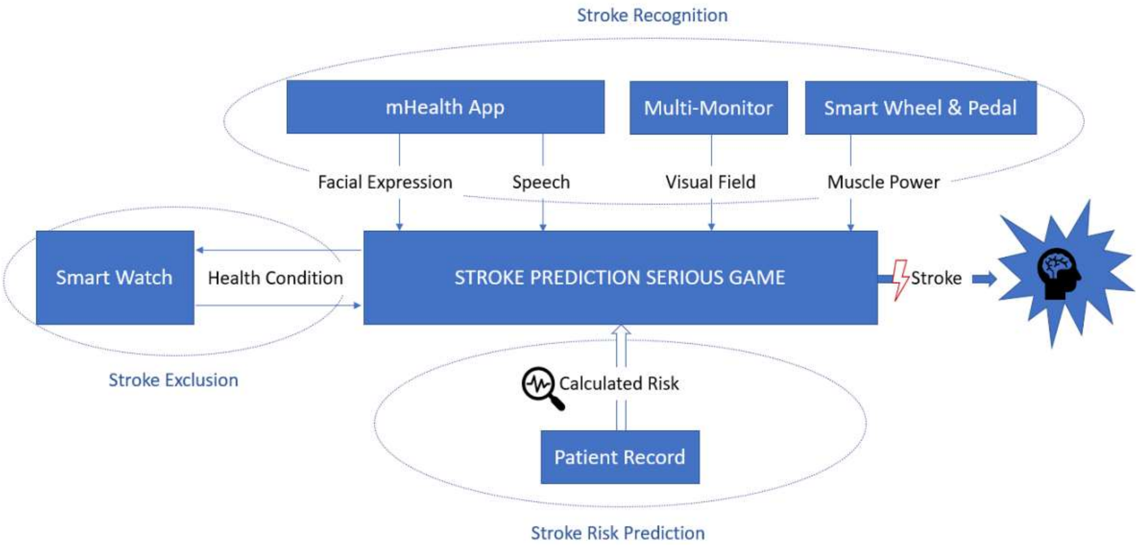

Figure 61: System Interaction Diagram

4.4.3 Use Cases

Subsequent use cases are basis for the implementation of three high level workflows. The first use case correlates with the first step in the prediction logic RLSG (AD4.ir2) where the player is identified and its pre-existing risk is calculated. The second use case represents all activities that are necessary for the recognition of symptoms and the third use case is integrating the wearables for an accurate risk calculation.

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UC01 Identify Player:

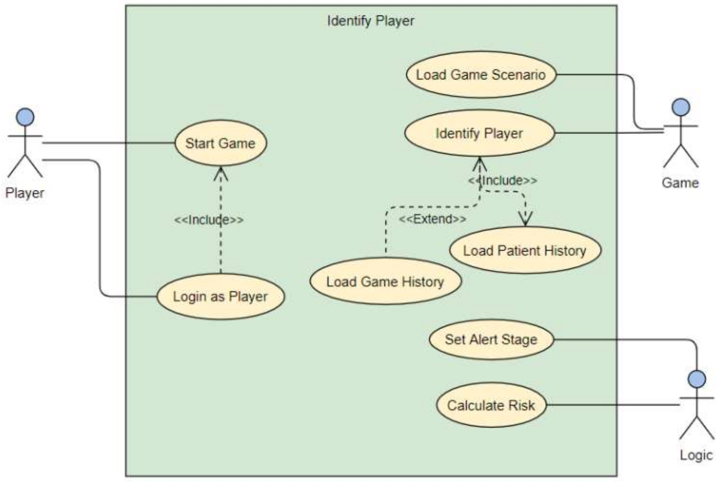

Figure 62: Use Case Diagram UC01 Identify Player

ID	UC01
Name	Identify Player
Description	Person starts the game and logs in as player.
Actor	Player, Game, Logic
Dependencies	Player needs to be connected to its patient record.
Trigger	Player starts the game.
Precondition	Player needs to be registered.
Postcondition	The pre-existing risk is calculated and the according alert stage defined.

Table 25: Use Case Description UC01 Identify Player

UC02 Perform Activity:

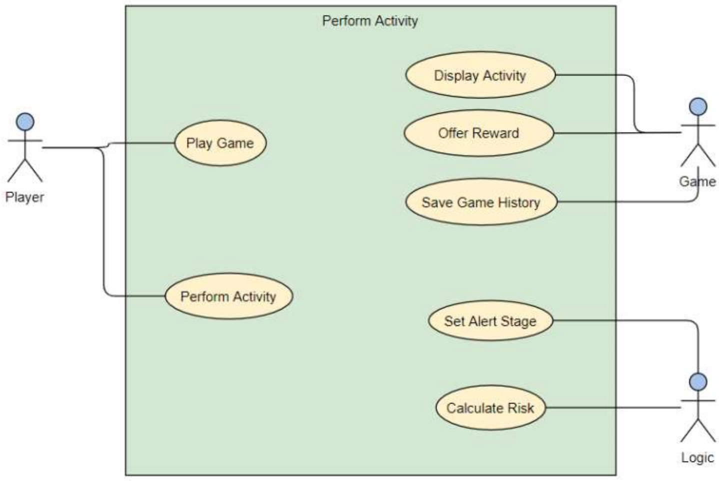

Figure 63: Use Case Diagram UC02 Perform Activity

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ID	UC02
Name	Perform Activity
Description	Player performs a stroke prediction activity during his regular game.
Actor	Player, Game, Logic
Dependencies	External devices are connected.
Trigger	Random display of stroke prediction activity in the regular game.
Precondition	Game is ongoing.
Postcondition	A reward is offered for performing the activity.

Table 26: Use Case Description UC02 Perform Activity

UC03 Predict Stroke:

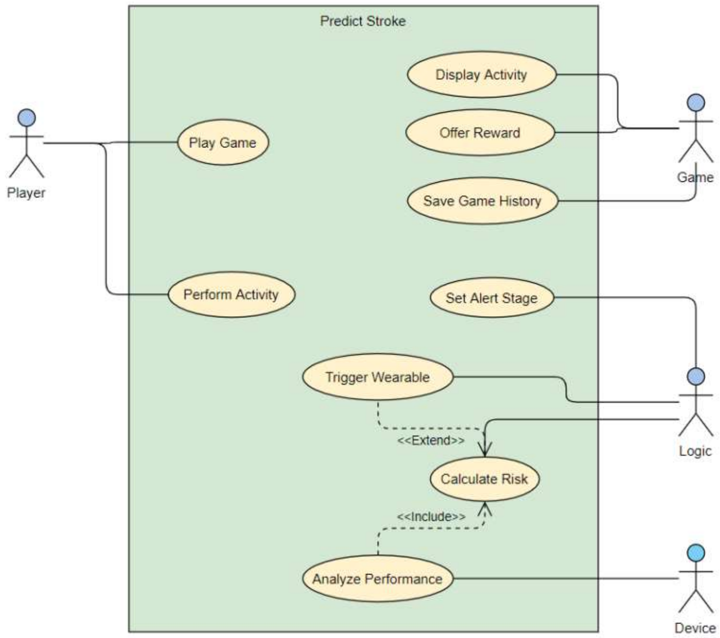

Figure 64: Use Case Diagram UC03 Predict Stroke

ID	UC03
Name	Predict Stroke
Description	The performance of the activity is analyzed and considered in the prediction logic. Wearables are triggered to deliver data that indicates stroke mimics.
Actor	Player, Game, Logic
Dependencies	Wearable is connected.
Trigger	Stroke prediction activity is performed.
Precondition	Wearable is triggered.
Postcondition	The risk is calculated and the alert stage updated.

Table 27: Use Case Description UC03 Predict Stroke

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4.4.4 Coded Prototype

In [AD5.i3] sketches were designed to decide for a car race as game scenario for stroke prediction. After some research, an existing open source car race based on javascript, css and html was found [83]. It was suitable to extend it with the defined use cases and game activities.

Following objects were added to the existing car race scenario:

1. SPSG logo
2. Login name (indicator for an available game history)
3. Patient record indicator (green if connected)
4. Alert stage / risk indicator
5. Footer (feedback and rewards after performing activities)

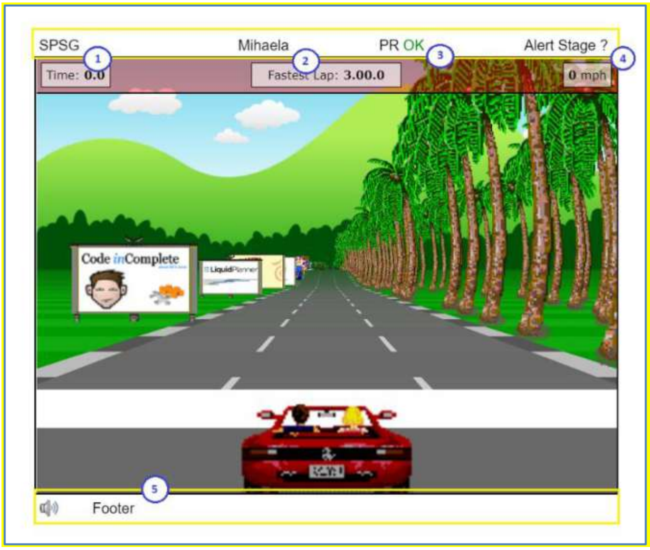

Figure 65: SPSG car race prototype

Furthermore, four activities were implemented, all visualized by an alert window in the middle of the screen. The appearance of the window is intentionally kept subtle so that the distraction from the main game is not too big and the motivation for continuing the race is maintained high.

ERGSS#7,8 Motor Leg was missed out in the implementation as it was stated in the evaluation of the wireframes that a person would not even get to the point to play the game if an impairment would exist here. Furthermore, the prototype didn't miss out any major process, it was simply one less prompt very equalize to the implemented one ERGSS#5,6 Motor Arm.

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LOC Questions (ERGSS#1) + Speech (ERGSS#9)

NIHSS	ERGSS	Examination Item	Risk Increase Characteristics
#2	#1	LOC Questions	Person doesn't answer both questions correctly: - Which month is it? - What is your age?
The neurological test to verify the level of consciousness is done by asking the patient questions and analyzing the correctness in content. The SPSG translates this test activity into a game activity by displaying questions during the game that need to be answered. This activity could but doesn't have to be combined with the examination of speech. Therefore the answers would need to be more than one word.			

LOC Commands (ERGSS#2) + Facial Movement (ERGSS#)

NIHSS	ERGSS	Examination Item	Risk Increase Characteristics
#3	#2	LOC Commands	Person is not able to perform both tasks correctly: a) Open and close eyes. b) Grip and release (non-paretic) hand.
The neurological test to verify the level of consciousness is done by requesting the patient to perform commands. The SPSG translates this test activity into a game activity by displaying request for commands during the game that need to be performed. This activity could but doesn't have to be combined with the examination of other items, e.g. a request to open and close eyes would enable the analysis of facial movement in the same step.			

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Visual Field (ERGSS#4)

<table>
<tr><th>NIHSS</th><th>ERGSS</th><th>Exami-nation Item</th><th>Risk Increase Characteristics</th></tr>
<tr><td>#5</td><td>#3</td><td>Visual Field</td><td>Visual fields (upper and lower quadrants) are tested by confrontation, using finger counting or visual threat, as appropriate. Patients may be encouraged, but if they look at the side of the moving fingers appropriately, this can be scored as normal.</td></tr>
<tr><td colspan="2">The neurological test to verify the visual field is done by moving a hand from the far left / right side of the view of the patient to the middle.

The SPSG translates this test activity into a game activity by moving an object (e.g. ghost) from the left to the right of the multi-monitor-setup screen.</td><td colspan="2"></td></tr>
</table>

Motor Arm (ERGSS#5,6)

<table>
<tr><th>NIHSS</th><th>ERGSS</th><th>Examina-tion Item</th><th>Risk Increase Characteristics</th></tr>
<tr><td>#7,8</td><td>#5,6</td><td>Motor Arm (L+R)</td><td>The person is not able to hold the arm for 10 sec. without a drift.</td></tr>
<tr><td colspan="3">The neurological test to verify the motoric power in an arm is done by requesting the patient to hold both arms to the front and analyze if one arm drifts.

The SPSG translates this test activity into a game activity by requesting the patient to hold the smart wheel in the front to manage a difficult road.</td><td></td></tr>
</table>

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4.4.5 Evaluation Coded Prototype

The coded prototype was evaluated with two users P06 and P07, visible in Figure 66 and Figure 67. Main goal was to verify the flow of play, as well as the motivation to continue. It was to verify if the requests to perform neurological test activities was integrated good enough to maintain a good motivation for the continuation of the game play. As well, the prompts themselves were questioned. It was interesting if the way in that the prompts were taken are of good usability in terms of good appropriateness, recognizability and operability.

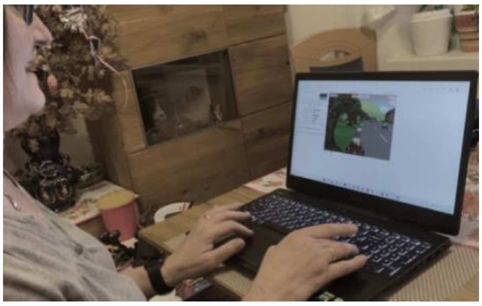

Figure 66: User Evaluation with P07

Figure 67: User Evaluation with P06

Coded Prototype Findings

The most interesting and unexpected finding was identified during the very first attempt. The user didn't even realize at any time during the game, that there was anything else expected than to win the car race. Not even one prompt was recognized. The user was 100 % focused at the car race and completely ignored the alert windows in the middle of the game screen.

Requests and prompts should be very short as the users don't want to be distracted too much from the car race itself just to read the instructions.

Both users had a lot of fun playing the game and felt the in-between-activities as positive interruptions.

It was good that the alert window didn't stop the whole game scenario. Even if it would be easier to read the whole instructions, the motivation and fun factor would be negatively influenced.

Vibrations on the wrist, caused by the smart watch, weren't distracting at all.

The rewards didn't have any impact on the motivation to execute the activity. Everything that wouldn't distract the player from winning the race was done with pleasure.

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5 Discussion

When it comes to health serious games for stroke patients, the main focus in the past years was the rehabilitation of specific body manifestations after a stroke occurred. This work, for the first time ever, had the aim to design and evaluate a serious game scenario that enables the early recognition of strokes and prevents serious body impairments upfront.

For this reason prototyping and user centered design methods were in use. After collecting 8 assumptions in the early research phase, 4 iterations of prototyping [AD1.i1], [AD2.i2], [AD5.i3], [AD7.i4] were done to evaluate the prediction logic and suitable game activities with 4 neurologists (P01, P03, P04, P05). Another, 5th prototype [I3] was implemented in the sense of user centered design. It was the basis to evaluate the usability and user experience with 2 users (P06, P07), hence to receive a very early feedback about the game scenario.

In the research phase the current literature and state of the art was aligned with interviews with P01 and P02. While brainstorming all collected information, the idea arose to combine the score for stroke examination, named National Institute of Health Stroke Scale (NIHSS), with an existing stroke rehabilitation serious game and achieve an approach for the early recognition of strokes in serious games. Further research showed that there was no previous attempt for this.

The analysis and design phase was done for the prediction logic and the game scenario separated. A card sorting prototype was performed with the neurologists P01 and P03. It had the aim of categorizing stroke predictors from the NIHSS. With the findings it was possible to define a first pseudo algorithm which was verified with a paper prototype and P01, P03, P04 and P05. It turned out that the NIHSS is not the suitable basis for a stroke prediction logic in games.

Further systematic literature research revealed far more stroke prediction scores but none of them was considered as good basis for the purpose of this work. Consequently, a new digital score, the Early Recognition Game Stroke Scale (ERGSS) was developed. It contains items of three different types:

- Risk Factors
- Symptoms
- Health Condition

Based on these items, the pseudo algorithm was updated.

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The newly suggested Recognition Logic for Strokes in Serious Games (RLSG) is now defining four necessary sections

1. Stroke Risk Prediction (based on risk factors)
2. Stroke Recognition (based on symptoms)
3. Stroke Exclusion (based on the health condition)
4. Stroke Warning (according to stroke severity range)

The next iterations had the purpose of translating the knowledge about stroke prediction into a game scenario. Sketches helped to decide in favor of the better suitable car racing game scenario. The decision based on the identification of four technical examination methods that are needed. The analysis of:

- Speech
- Facial Expression
- Visual Field
- Muscle Power

Finally, the ERGSS was translated into activities in a car racing game. This fully represents the Stroke Prediction Serious Game (SPSG). It was illustrated in wireframes to be verified with P01 and P03. The wireframes were basis for the implementation of a coded prototype that was verified with two users P06, P07.

In conclusion, the research questions that were focus in this work are answered subsequently.

5.1 Research Question 1: Validated Requirements

Which requirements for a stroke recognition serious game can be defined, using qualitative interviews and prototyping evaluations with neurologists and therapists?

To answer this question it was necessary to do systematic literature research, perform interviews with medical experts and brainstorm about the earned knowledge about the stroke disease itself, the therapy and existing serious games in this field. All assumptions that were made, lead to the idea of stroke recognition in serious games rather than another serious game for the rehabilitation of post stroke symptoms.

The assumptions were questioned in detail in two prototypes for the definition of a prediction logic (card sorting [AD1.i1], paper prototype [AD2.i2]) and in two prototypes for the design of a

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game scenario (sketches [AD5.i3], wireframes [AD7.i4]). As well, two interim results for the logic [AD3.ir1] and [AD4.ir2] and one for the game [AD6.ir3] were developed.
In total 37 resulting requirements are outlined in detail in chapter 4.4.1. They are categorized in five domains: universal, logic, game, medical, technical.

Universal. Requirements declare the necessity of the medical basis ERGSS (symptoms, risk factors, health condition), the prediction logic RLSG and a game scenario with activities summarized as SPSG. As well, the connection to several external devices is specified. The patient record (age, diabetes, …), game history, a smart watch (blood pressure, blood glucose), a multi-monitor setup are listed as technologies for the analysis of speech, facial expression, visual field and muscle power in arms and legs.

Logic. Requirements summarize the four sections stroke prediction (with risk factors), stroke recognition (with symptoms), stroke exclusion (with health condition parameters) and stroke warning. The first section calculates the stroke risk based on existing risk factors, the second monitors symptoms in an ongoing game, the third section excludes stroke mimics by checking the blood glucose and the fourth section releases a warning if a threshold is reached.

Game. Requirements list the game activities that ask questions and request commands for the assessment of the level of consciousness. In addition, game activities need to request to make a grimace for the detection of facial asymmetries. The game displays objects in the corners of the screen for the evaluation of the visual field and it asks to use an arm or a leg for the detection of anomalies in the muscle power.

Medical. Requirements outline the risk factors (age, medical history, time, ambulatory at baseline), 9 symptoms (LOC questions, LOC commands, visual field, facial movement, arm movement right/left, leg movement right/left, speech) and health condition parameters (blood pressure, blood glucose).

Technical. Requirements list the four technical examination methods for the analysis of speech, facial expression, visual field and muscle power as well as the data sources patient record, game history, smart watch, smart wheel and smart pedal. It specifies the integration of the mHealth App and the usage of a multi-monitor setup.

5.2 Research Question 2: Stroke Recognition Logic

Which medical guideline can serve as basis for the recognition logic?

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The first two prototypes [AD.i1] and [AD.i2] were explicitly done for the analysis of the NIHSS as basis for the recognition logic. Reasoned by unsatisfying findings, other scales were researched and analyzed to be able to make a decision about the medical basis that the logic would build on.

It turned out that, neither the NIHSS nor other stroke assessment scales represent a reusable basis for the recognition logic. Reasons for that are:

- The NIHSS is used to clearly diagnose what exactly is wrong in the patient's brain rather than observing that something might be wrong.
- Prehospital scales are used to alarm that something might be wrong, without diagnosing in detail, but ignoring technically easily collectable information.
- The recognition logic expects to define that something might be wrong using the best technological input that is possible.

As conclusion, the Early Recognition Game Stroke Scales ERGSS [AD3.ir1] was developed. It consists of risk factors, symptoms and health condition parameters and it is a score that is explicitly derived for the purpose of stroke recognition in games.

It evaluates 9 symptoms that are the most diagnostically conclusive ones, considers risk factors like the age or existing illnesses e.g. diabetes from the medical history and includes the blood pressure as indicator for a stroke as well as the blood glucose as indicator for a stroke mimic.

5.3 Research Question 3: Serious Game Design

Which serious game design can cover the defined requirements?

Considering the outcome of the previous questions it is to state that every game that enables the collection of data for the ERGSS [AD3.ir1] is usable or extendable for stroke recognition. It has to ensure that the game activities are suitable for the analysis of speech, facial expression, visual field, and muscle power.

As an example, a chess game could be extended with questions to be answered and commands to be performed. The analysis of the visual field wouldn't be that simple because a multi-monitor-setup is not feasible, possibly there are other technical solutions e.g. (virtual) glasses. As well, deeper brainstorming with neurologists on ideas for the measurement of muscle power could offer ideas for appropriate game activities.

The challenge is to find a game scenario that allows the integration of such activities without big interruptions that have negative effects on the motivation of the player.

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Summary and Future Work

This work offers an introduction into a new-found idea of a serious game for the early recognition of strokes. An existing car racing game was extended with activities that represent parts of the neurological stroke assessment. As well, the game is embedded in a system of devices that interact with it: the patient record for risk calculation, smart game devices for the assessment of symptoms and a smart watch for the exclusion of stroke mimics.

Explorative prototyping was chosen to verify 8 assumptions that were found during the research phase. The assumptions were verified with two prototypes for the prediction logic and two prototypes for the game scenario. A fifth prototype was evaluated with users. In addition, three interim results and 37 validated requirements were developed.

In the research phase literature, interviews and brainstorming came into action. One neurologist and one occupational therapist accompanied this phase. While research helped to gain knowledge about stroke serious games, the interviews helped for the medical understanding. In a brainstorming session all information came together, the idea arose and was put into assumptions.

In the analysis and design phase these assumptions were verified in four iterations of prototypes. The first prototype was card sorting and helped to categorize items from the NIHSS with 1 neurologist. After that the logic was derived and the second prototype was designed which was a paper prototype that helped to verify the logic with 4 neurologists. The NIHSS revealed as not suitable as basis for the game, consequently a new digital stroke scale, the ERGSS, was developed. Then it was possible to update the logic to the RLSG. The analysis and design for the logic was finalized with this step. The third prototype were sketches that served as input for the decision about a suitable game scenario. After the decision for a car race scenario, suitable activities were brainstormed and transcribed in the SPSG. They were illustrated then in wireframes, the fourth prototype, for an evaluation with 2 neurologists.

In the implementation phase a fifth prototype was implemented. It based on an existing car race game that was extended with indicators for the connection to a patient record, an existing game history, an alert stage for the stroke risk and with alert messages that delivered the requests for neurological test activities. These activities were questions to be answered, commands to be

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performed, a request to make grimaces and a request to use arms and legs with the smart game devices. As well, a symbol was displayed from one side of the screen to the other side of the visual field. It is necessary that the player wears a smart watch so that health condition parameters can help to exclude stroke mimics.

In the state of the art of stroke serious games, there are cognitive games, games with motoric activities or visual trigger as well as speech training games. All focusing on the cure of impairments of a specific area. This game is the first one focusing on the recognition of strokes upfront by combining cognitive, motoric and other aspects for diagnosis in one game. The general aspects that need to be considered for it are well elaborated in this work. Nevertheless, there are some aspects that facilitate further research.

Logic. It needs a big collection of data as well as a lot more neurologists, than available within this work, for achieving a viable accuracy in the prediction. In addition, a comparison of the prediction results using different artificial intelligence algorithms is necessary.

Game Scenario. It is not necessarily the only scenario that can offer activities for all four examination methods.

Game Activities. An important factor is the suitability of specific requests. It might be that a mathematical calculation requires a better level of consciousness than a question about the current month. Suitable questions need further evaluation.

Data Sources. It is expected that the smart game devices that are recommended as data sources can offer more reusable data than outlined in the current context. It is to ensure that the full potential of each data source is used for the prediction logic.

Stroke Mimics. If a stroke mimic is detected it doesn't necessarily mean that the player's health condition is good. As example a hypoglycemia is a stroke mimic but it can still cause brain damage if untreated. It is to decide if the warning should only focus on stroke events. A general discussion about serious games for the diagnosis of any disease will lead to far more research activity.

Threshold. The threshold refers to the stroke severity range of the NIHSS. As the ERGSS is a newly developed scale it is to research and evaluate if the NIHSS range is suitable and how a new severity range for the SPSG could be defined.

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ERGSS. The SPSG could be extended to more activities. One example is NIHSS#11 Extinction and Inattention. It would be possible to display a symbol first from the left side, then from the right side and then from both sides simultaneously. If the player sees the individual sides but not the simultaneous display it could lead to an interpretation for NIHSS#11 and imply a stroke.

Risk Calculation. Literature shows a lot of attempts to calculate the stroke risk of a patient with pre-existing data. It is to research and decide which attempt would be the best for the SPSG.

This work offers an all-over introduction into the idea of a serious game for stroke prediction. It does not clarify detailed questions about the prediction logic or about the best suitable external devices for stroke data collection. Rather than that, it evaluates the feasibility, offers partial suggestions for solutions and for further investigation. It draws the big picture with fundamental expert evaluations.

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Appendix

N I H
STROKE
SCALE

Patient Identification. ___ ___-___ ___ ___-___ ___ ___

Pt. Date of Birth ___ ___/___ ___/___ ___

Hospital ______________________(___ ___-___ ___)

Date of Exam ___ ___/___ ___/___ ___

Interval: [ ] Baseline [ ] 2 hours post treatment [ ] 24 hours post onset of symptoms ±20 minutes [ ] 7-10 days
[ ] 3 months [ ] Other ______________________________(___ ___)

Time: ___ ___:___ ___ [ ]am [ ]pm

Person Administering Scale ______________________________

Administer stroke scale items in the order listed. Record performance in each category after each subscale exam. Do not go back and change scores. Follow directions provided for each exam technique. Scores should reflect what the patient does, not what the clinician thinks the patient can do. The clinician should record answers while administering the exam and work quickly. Except where indicated, the patient should not be coached (i.e., repeated requests to patient to make a special effort).

Instructions	Scale Definition	Score
1a. Level of Consciousness: The investigator must choose a response if a full evaluation is prevented by such obstacles as an endotracheal tube, language barrier, orotracheal trauma/bandages. A 3 is scored only if the patient makes no movement (other than reflexive posturing) in response to noxious stimulation.	0 = **Alert;** keenly responsive. 1 = **Not alert**; but arousable by minor stimulation to obey, answer, or respond. 2 = **Not alert**; requires repeated stimulation to attend, or is obtunded and requires strong or painful stimulation to make movements (not stereotyped). 3 = Responds only with reflex motor or autonomic effects or totally unresponsive, flaccid, and areflexic.	_____
1b. LOC Questions: The patient is asked the month and his/her age. The answer must be correct - there is no partial credit for being close. Aphasic and stuporous patients who do not comprehend the questions will score 2. Patients unable to speak because of endotracheal intubation, orotracheal trauma, severe dysarthria from any cause, language barrier, or any other problem not secondary to aphasia are given a 1. It is important that only the initial answer be graded and that the examiner not "help" the patient with verbal or non-verbal cues.	0 = **Answers** both questions correctly. 1 = **Answers** one question correctly. 2 = **Answers** neither question correctly.	_____
1c. LOC Commands: The patient is asked to open and close the eyes and then to grip and release the non-paretic hand. Substitute another one step command if the hands cannot be used. Credit is given if an unequivocal attempt is made but not completed due to weakness. If the patient does not respond to command, the task should be demonstrated to him or her (pantomime), and the result scored (i.e., follows none, one or two commands). Patients with trauma, amputation, or other physical impediments should be given suitable one-step commands. Only the first attempt is scored.	0 = **Performs** both tasks correctly. 1 = **Performs** one task correctly. 2 = **Performs** neither task correctly.	_____
2. Best Gaze: Only horizontal eye movements will be tested. Voluntary or reflexive (oculocephalic) eye movements will be scored, but caloric testing is not done. If the patient has a conjugate deviation of the eyes that can be overcome by voluntary or reflexive activity, the score will be 1. If a patient has an isolated peripheral nerve paresis (CN III, IV or VI), score a 1. Gaze is testable in all aphasic patients. Patients with ocular trauma, bandages, pre-existing blindness, or other disorder of visual acuity or fields should be tested with reflexive movements, and a choice made by the investigator. Establishing eye contact and then moving about the patient from side to side will occasionally clarify the presence of a partial gaze palsy.	0 = **Normal.** 1 = **Partial gaze palsy;** gaze is abnormal in one or both eyes, but forced deviation or total gaze paresis is not present. 2 = **Forced deviation,** or total gaze paresis not overcome by the oculocephalic maneuver.	_____

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N I H STROKE SCALE

Patient Identification. ___ ___-___ ___ ___-___ ___ ___

Pt. Date of Birth ___ ___/___ ___/___ ___

Hospital ____________________(___ ___-___ ___)

Date of Exam ___ ___/___ ___/___ ___

Interval: [ ] Baseline [ ] 2 hours post treatment [ ] 24 hours post onset of symptoms ±20 minutes [ ] 7-10 days
[ ] 3 months [ ] Other ______________________________(___ ___)

3. Visual: Visual fields (upper and lower quadrants) are tested by confrontation, using finger counting or visual threat, as appropriate. Patients may be encouraged, but if they look at the side of the moving fingers appropriately, this can be scored as normal. If there is unilateral blindness or enucleation, visual fields in the remaining eye are scored. Score 1 only if a clear-cut asymmetry, including quadrantanopia, is found. If patient is blind from any cause, score 3. Double simultaneous stimulation is performed at this point. If there is extinction, patient receives a 1, and the results are used to respond to item 11.	0 = **No visual loss.** 1 = **Partial hemianopia.** 2 = **Complete hemianopia.** 3 = **Bilateral hemianopia** (blind including cortical blindness).	_____
4. Facial Palsy: Ask – or use pantomime to encourage – the patient to show teeth or raise eyebrows and close eyes. Score symmetry of grimace in response to noxious stimuli in the poorly responsive or non-comprehending patient. If facial trauma/bandages, orotracheal tube, tape or other physical barriers obscure the face, these should be removed to the extent possible.	0 = **Normal** symmetrical movements. 1 = **Minor paralysis** (flattened nasolabial fold, asymmetry on smiling). 2 = **Partial paralysis** (total or near-total paralysis of lower face). 3 = **Complete paralysis** of one or both sides (absence of facial movement in the upper and lower face).	_____
5. Motor Arm: The limb is placed in the appropriate position: extend the arms (palms down) 90 degrees (if sitting) or 45 degrees (if supine). Drift is scored if the arm falls before 10 seconds. The aphasic patient is encouraged using urgency in the voice and pantomime, but not noxious stimulation. Each limb is tested in turn, beginning with the non-paretic arm. Only in the case of amputation or joint fusion at the shoulder, the examiner should record the score as untestable (UN), and clearly write the explanation for this choice.	0 = **No drift;** limb holds 90 (or 45) degrees for full 10 seconds. 1 = **Drift;** limb holds 90 (or 45) degrees, but drifts down before full 10 seconds; does not hit bed or other support. 2 = **Some effort against gravity;** limb cannot get to or maintain (if cued) 90 (or 45) degrees, drifts down to bed, but has some effort against gravity. 3 = **No effort against gravity;** limb falls. 4 = **No movement.** UN = **Amputation** or joint fusion, explain: ________________ **5a. Left Arm** **5b. Right Arm**	 _____ _____
6. Motor Leg: The limb is placed in the appropriate position: hold the leg at 30 degrees (always tested supine). Drift is scored if the leg falls before 5 seconds. The aphasic patient is encouraged using urgency in the voice and pantomime, but not noxious stimulation. Each limb is tested in turn, beginning with the non-paretic leg. Only in the case of amputation or joint fusion at the hip, the examiner should record the score as untestable (UN), and clearly write the explanation for this choice.	0 = **No drift;** leg holds 30-degree position for full 5 seconds. 1 = **Drift;** leg falls by the end of the 5-second period but does not hit bed. 2 = **Some effort against gravity;** leg falls to bed by 5 seconds, but has some effort against gravity. 3 = **No effort against gravity;** leg falls to bed immediately. 4 = **No movement.** UN = **Amputation** or joint fusion, explain: ______________ **6a. Left Leg** **6b. Right Leg**	 _____

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N I H STROKE SCALE

Patient Identification. ___ ___-___ ___ ___-___ ___ ___

Pt. Date of Birth ___ ___/___ ___/___ ___

Hospital ______________________(___ ___-___ ___)

Date of Exam ___ ___/___ ___/___ ___

Interval: [ ] Baseline [ ] 2 hours post treatment [ ] 24 hours post onset of symptoms ±20 minutes [ ] 7-10 days
[ ] 3 months [ ] Other ______________________(___ ___)

		____
7. Limb Ataxia: This item is aimed at finding evidence of a unilateral cerebellar lesion. Test with eyes open. In case of visual defect, ensure testing is done in intact visual field. The finger-nose-finger and heel-shin tests are performed on both sides, and ataxia is scored only if present out of proportion to weakness. Ataxia is absent in the patient who cannot understand or is paralyzed. Only in the case of amputation or joint fusion, the examiner should record the score as untestable (UN), and clearly write the explanation for this choice. In case of blindness, test by having the patient touch nose from extended arm position.	0 = **Absent.** 1 = **Present in one limb.** 2 = **Present in two limbs.** UN = **Amputation** or joint fusion, explain: ______________	____
8. Sensory: Sensation or grimace to pinprick when tested, or withdrawal from noxious stimulus in the obtunded or aphasic patient. Only sensory loss attributed to stroke is scored as abnormal and the examiner should test as many body areas (arms [not hands], legs, trunk, face) as needed to accurately check for hemisensory loss. A score of 2, "severe or total sensory loss," should only be given when a severe or total loss of sensation can be clearly demonstrated. Stuporous and aphasic patients will, therefore, probably score 1 or 0. The patient with brainstem stroke who has bilateral loss of sensation is scored 2. If the patient does not respond and is quadriplegic, score 2. Patients in a coma (item 1a=3) are automatically given a 2 on this item.	0 = **Normal;** no sensory loss. 1 = **Mild-to-moderate sensory loss;** patient feels pinprick is less sharp or is dull on the affected side; or there is a loss of superficial pain with pinprick, but patient is aware of being touched. 2 = **Severe to total sensory loss;** patient is not aware of being touched in the face, arm, and leg.	____
9. Best Language: A great deal of information about comprehension will be obtained during the preceding sections of the examination. For this scale item, the patient is asked to describe what is happening in the attached picture, to name the items on the attached naming sheet and to read from the attached list of sentences. Comprehension is judged from responses here, as well as to all of the commands in the preceding general neurological exam. If visual loss interferes with the tests, ask the patient to identify objects placed in the hand, repeat, and produce speech. The intubated patient should be asked to write. The patient in a coma (item 1a=3) will automatically score 3 on this item. The examiner must choose a score for the patient with stupor or limited cooperation, but a score of 3 should be used only if the patient is mute and follows no one-step commands.	0 = **No aphasia;** normal. 1 = **Mild-to-moderate aphasia;** some obvious loss of fluency or facility of comprehension, without significant limitation on ideas expressed or form of expression. Reduction of speech and/or comprehension, however, makes conversation about provided materials difficult or impossible. For example, in conversation about provided materials, examiner can identify picture or naming card content from patient's response. 2 = **Severe aphasia;** all communication is through fragmentary expression; great need for inference, questioning, and guessing by the listener. Range of information that can be exchanged is limited; listener carries burden of communication. Examiner cannot identify materials provided from patient response. 3 = **Mute, global aphasia;** no usable speech or auditory comprehension.	____
10. Dysarthria: If patient is thought to be normal, an adequate sample of speech must be obtained by asking patient to read or repeat words from the attached list. If the patient has severe aphasia, the clarity of articulation of spontaneous speech can be rated. Only if the patient is intubated or has other physical barriers to producing speech, the examiner should record the score as untestable (UN), and clearly write an explanation for this choice. Do not tell the patient why he or she is being tested.	0 = **Normal.** 1 = **Mild-to-moderate dysarthria;** patient slurs at least some words and, at worst, can be understood with some difficulty. 2 = **Severe dysarthria;** patient's speech is so slurred as to be unintelligible in the absence of or out of proportion to any dysphasia, or is mute/anarthric. UN = **Intubated** or other physical barrier, explain:______________________	____

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NIH STROKE SCALE

Patient Identification. ___ ___-___ ___ ___-___ ___ ___

Pt. Date of Birth ___ ___/___ ___/___ ___

Hospital ______________________(___ ___-___ ___)

Date of Exam ___ ___/___ ___/___ ___

Interval: [ ] Baseline [ ] 2 hours post treatment [ ] 24 hours post onset of symptoms ±20 minutes [ ] 7-10 days
[ ] 3 months [ ] Other ______________________________(___ ___)

11. Extinction and Inattention (formerly Neglect): Sufficient information to identify neglect may be obtained during the prior testing. If the patient has a severe visual loss preventing visual double simultaneous stimulation, and the cutaneous stimuli are normal, the score is normal. If the patient has aphasia but does appear to attend to both sides, the score is normal. The presence of visual spatial neglect or anosagnosia may also be taken as evidence of abnormality. Since the abnormality is scored only if present, the item is never untestable.	0 = **No abnormality.** 1 = **Visual, tactile, auditory, spatial, or personal inattention** or extinction to bilateral simultaneous stimulation in one of the sensory modalities. 2 = **Profound hemi-inattention or extinction to more than one modality;** does not recognize own hand or orients to only one side of space.	____

____

____

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CINCINNATI PREHOSPITAL STROKE SCALE

Facial Droop

Normal:	Both sides of face move equally
Abnormal:	One side of face does not move at all

Arm Drift

Normal:	Both arms move equally or not at all
Abnormal:	One arm drifts compared to the other

Speech

Normal:	Patient uses correct words with no slurring
Abnormal:	Slurred or inappropriate words or mute

References

Kothari RU, Pancioli A, Liu T, Brott T, Broderick J. "Cincinnati Prehospital Stroke Scale: reproducibility and validity."
Ann Emerg Med 1999 Apr;33(4):373-8

Provided by the Internet Stroke Center — www.strokecenter.org

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LOS ANGELES PREHOSPITAL STROKE SCREEN (LAPSS)

Patient Name: ______________________
Rater Name: ______________________
Date: ______________________

Screening Criteria	Yes	No
4. Age over 45 years	___	___
5. No prior history of seizure disorder	___	___
6. New onset of neurologic symptoms in last 24 hours	___	___
7. Patient was ambulatory at baseline (prior to event)	___	___
8. Blood glucose between 60 and 400	___	___

9. Exam: ***look for obvious asymmetry***

	Normal	Right	Left
Facial smile / grimace:	☐	☐ Droop	☐ Droop
Grip:	☐	☐ Weak Grip ☐ No Grip	☐ Weak Grip ☐ No Grip
Arm weakness:	☐	☐ Drifts Down ☐ Falls Rapidly	☐ Drifts Down ☐ Falls Rapidly

Based on exam, patient has only unilateral (and not bilateral) weakness: **Yes** ☐ **No** ☐

10. If Yes (or unknown) to all items above LAPSS screening criteria met: **Yes** ☐ **No** ☐

11. If LAPSS criteria for stroke met, call receiving hospital with "CODE STROKE", if not then return to the appropriate treatment protocol. (Note: the patient may still be experiencing a stroke if even if LAPSS criteria are not met.)

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ABCD Score

Used to predict the risk of stroke during the first seven days after a TIA. Researchers found there to be over 30% risk of stroke in TIA patients with an 'ABCD score' of six, as compared to no strokes in those with a low ABCD score. Can be used in routine clinical practice to identify high-risk individuals who require emergency investigation and treatment.

ABCD Score

	Risk factor	Category	Score
A	**A**ge of patient	Age >/= 60 Age < 60	1 0
B	**B**lood pressure at Assessment	SBP > 140 or DBP >/= 90 Other	1 0
C	**C**linical Features presented with	Unilateral weakness Speech disturbance (no weakness) Other	2 1 0
D	**D**uration of TIA symptoms	>/= 60 minutes 10-59 minutes <10 minutes	2 1 0
		TOTAL	**6**

Professor Peter M Rothwell, Stroke Prevention Research Unit, University Department of Clinical Neurology, Radcliffe Infirmary, Woodstock Road, Oxford OX2 6HE, UK; T) +44 (0)1865 224237 or +44 (0)1865 224639; F) +44 (0)1865 228572; E) peter.rothwell@clneuro.ox.ac.uk (copied to tracey.brock@clneuro.ox.ac.uk to ensure a rapid response).

For further information please contact the Media Team at The Stroke Association on 020 7566 0328 or e-mail press@stroke.org.uk.

References

Rothwell P, Giles M, Flossmann E, Lovelock C, Redgrave J, Warlow C, & Mehta Z (2005). A simple tool to identify individuals at high early risk of stroke after a transient ischaemic attack: the ABCD score. *The Lancet*; **366:**29-36.

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STROKE (FACE ARM SPEECH TEST)

SPEECH IMPAIRMENT	YES	☐	NO	☐	?	☐
FACIAL PALSY	YES	☐	NO	☐	?	☐
AFFECTED SIDE	L	☐	R	☐		
ARM WEAKNESS	YES	☐	NO	☐	?	☐
AFFECTED SIDE	L	☐	R	☐		

FACIAL MOVEMENTS

Ask patient to smile or show teeth

- Look for NEW lack of symmetry– Tick the 'YES' box if there is an unequal smile or grimace, or obvious facial asymmetry
- Note which side does not move well, and mark on the form whether it is the patient's right or left side

ARM MOVEMENTS

– Lift the patient's arms together to 90º if sitting, 45º if supine and ask them to hold the position for 5 seconds then let go
– Does one arm drift down or fall rapidly?
– If one arm drifts down or falls, note whether it is the patient's left or right arm

SPEECH

If the patient attempts a conversation
– Look for NEW disturbance of speech
– Check with companion
– Look for slurred speech
– Look for word-finding difficulties. This can be confirmed by asking the patient to name commonplace objects that may be nearby, such as a cup, chair, table, keys, pen
– If there is a severe visual disturbance, place an object in the patient's hand and ask him/her to name it

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ROSIER scale proforma

Assessment	Date:	Time:	☐☐☐☐☐☐	☐☐☐☐☐☐
Symptom onset	Date	Time	☐☐☐☐☐☐	☐☐☐☐☐☐

1

GGS E=☐ M= ☐ V= ☐ **BP** ***BM** ☐☐ ☐☐

**** If BM < 3.5 mmol/l treat urgently and reassess once blood glucose normal***

Has there been loss of consciousness or syncope?	Y (-1) ☐	N (0) ☐
Has there been seizure activity?	Y (-1) ☐	N (0) ☐

Is there a NEW ACUTE onset (or on awakening from sleep)

I. Asymmetric facial weakness	Y (+1) ☐	N (0) ☐
II. Asymmetric arm weakness	Y (+1) ☐	N (0) ☐
III. Asymmetric leg weakness	Y (+1) ☐	N (0) ☐
IV. Speech disturbance	Y (+1) ☐	N (0) ☐
V. Visual field defect	Y (+1) ☐	N (0) ☐

*Total Score ______ (-2 to +5)

Provisional diagnosis: ☐ Stroke ☐ Non-stroke (specify) ____________________

*Stroke is unlikely but not completely excluded if total scores are ≤ 0.

BM=blood glucose; BP=blood pressure (mm Hg); GCS=Glasgow Coma Scale; E=eye; M=motor; V=verbal component.

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Appendix 5. Melbourne Ambulance Stroke Screen (MASS)[84]

Clinical history elements
Age > 45 years
no past history of convulsions or epilepsy.
Patient not in med or in wheelchair
Glycaemia between 50 and 400 mg/dL
Physical examination elements
Facial droop
Have patient show teeth or smile
Normal. Both sides of face move equally
Abnormal: One side of face does not move
Strength in arms
Ask patient to close eyes and extend both arms straight out for 10 seconds
Normal: Both arms move/do not move the same .
Abnormal: One arm does not move and drifts down compared with the other.
Handshake
Hold both patient's hands and ask him or her to press hard
Normal: Handshake same in both hands / no shake in either of the hands
Abnormal: Weakness or no shake in one of the hands.
Speech
Have patient repeat a sentence
Normal:
Abnormal: Slurs, unable to speak, wrong words
Criteria for identifying stroke
Presence of any of the elements in the physical examination
and
Affirmative answer in all the elements of the clinical history

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Österreichische Gesellschaft für Neurorehabilitation

Die österreichische **Phaseneinteilung neurologischer Krankheitsprozesse der OeGNR** entspricht folgenden Werten des Barthel Index:

Phase B entspricht Barthel Index **0 – 30 Punkte**
Phase C entspricht Barthel Index **35 – 80 Punkte**
Phase D entspricht Barthel Index **85 – 100 Punkte**

(Weitere Information zum Phasenmodell: http://www.neuroreha.at/Phasenmodell.html)

Barthel Index: Protokollblatt (Hamburger Einstufungsmanual)

1. Essen:

10 _____ komplett selbständig oder selbständige PEG-Beschickung / -Versorgung
5 _____ Hilfe bei mundgerechter Vorbereitung nötig, aber selbständiges Einnehmen oder Hilfe bei PEG-Beschickung / -Versorgung
0 _____ kein selbständiges Einnehmen und keine MS/PEG-Ernährung

2. Aufsetzen und Umsetzen:

15 _____ komplett selbständig aus liegender Position in (Roll-)Stuhl und zurück
10 _____ Aufsicht oder geringe Hilfe (ungeschulte Laienhilfe)
5 _____ erhebliche Hilfe (geschulte Laienhilfe oder professionelle Hilfe)
0 _____ wird faktisch nicht aus dem Bett transferiert

3. Sich Waschen:

5 _____ vor Ort komplett selbständig inkl. Zähneputzen, Rasieren und Frisieren
0 _____ erfüllt „5" nicht

4. Toilettenbenutzung:

10 _____ vor Ort komplett selbständige Nutzung von Toilette oder Toilettenstuhl inkl. Spülung/ Reinigung
5 _____ vor Ort Hilfe oder Aufsicht bei Toiletten- oder Toilettenstuhlbenutzung oder deren Spülung/Reinigung erforderlich
0 _____ benutzt faktisch weder Toilette noch Toilettenstuhl

5. Baden/Duschen:

5 _____ selbständiges Baden oder Duschen inkl. Ein-/Ausstieg, sich reinigen und abtrocknen
0 _____ erfüllt „5" nicht

6. Aufstehen und Gehen:

15 _____ ohne Aufsicht oder personelle Hilfe vom Sitz in den Stand kommen und mind. 50m ohne Gehwagen (aber ggf. Stöcken/Gehstützen) gehen
10 _____ ohne Aufsicht oder personelle Hilfe vom Sitz in den Stand kommen und mind. 50m mit Hilfe eines Gehwagens gehen
5 _____ mit Laienhilfe oder Gehwagen vom Sitz in den Stand kommen und Strecken im Wohnbereich bewältigen
alternativ: im Wohnbereich komplett selbständig mit Rollstuhl
0 _____ erfüllt „5" nicht

7. Treppensteigen:

10 _____ ohne Aufsicht oder personelle Hilfe (ggf. inkl. Stöcken/Gehstützen) mindestens ein Stockwerk hinauf - und hinuntersteigen
5 _____ mit Aufsicht oder Laienhilfe mind. ein Stockwerk hinauf und hinuntersteigen
0 _____ erfüllt „5" nicht

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8. An- und Auskleiden:

10 _____ zieht sich in angemessener Zeit selbständig Tageskleidung, Schuhe (und ggf. benötigte Hilfsmittel z.B. ATS, Prothesen) an und aus

5 _____ kleidet mindestens den Oberkörper in angemessener Zeit selbständig an und aus, sofern die Utensilien in greifbarer Nähe sind

0 _____ erfüllt „5“ nicht

9 Stuhlkontrolle:

10 _____ ist stuhlkontinent, ggf. selbständig bei rektalen Abführmaßnahmen oder AP-Versorgung

5 _____ ist durchschnittlich nicht mehr als 1x/Woche stuhlinkontinent oder benötigt Hilfe bei rektalen Abführmaßnahmen / AP-Versorgung

0 _____ ist durchschnittlich mehr als 1x/Woche stuhlinkontinent

10. Harnkontrolle:

10 _____ ist harnkontinent oder kompensiert seine Harninkontinenz / versorgt seinen DK komplett selbständig und mit Erfolg (kein Einnässen von Kleidung oder Bettwäsche)

5 _____ kompensiert

0 _____ ist durchschnittlich mehr als 1x/Tag harninkontinent

GESAMTSUMME der PUNKTE: _____ /100

Anmerkungen:

Eine Suche in der Online Version des DIMDI (Deutsches Institut für medizinische Dokumentation und Information) ergibt diese Version des Barthel Index als einzige mit einer 100% Relevanz.

*Diese Version des Barthel Index ist die Kurzfassung des **Hamburger Einstufungsmanuals**, wie es von der Bundesarbeitsgemeinschaft Klinisch Geriatrischer Einrichtungen e.V. zur Anwendung in der Geriatrie empfohlen wird (Version KF 1.1., erstellt 8.11.2004).*
Es besteht kein Copyright. www.kcgeriatrie.de.

Es existiert eine Version des Barthel Index mit einer maximalen Punkteanzahl von 20 (Collin C, Wade DT, Davies S, Horne V. (1988) The Barthel ADL Index: a reliability study. Int Disability Study. 10:61-63.), die in UK Verwendung findet, - die Bewertungen 1, 2 und 3 im „BI 20“ entsprechen den Bewertungen 5, 10, und 15 im „BI 100“.

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