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An assistive communication device based on electromyography

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Abstract

Paralysis and incapacity of communication might represent a serious challenge for any human being. The following study explores the impact of an electromyography device on a child affected by paralysis. Initially, the project involves creation of a BCI serious game that aims to focus on analysis of the brain-muscle activity, following closely the background of the participant. High and well developed brain-muscle activity has been found which lead to the improvement of the programme to a system that uses Myo Armbands, providing EMG data. Results and tests imply that the system can support motor mobility rehabilitation and data analysis, representing a solid groundwork for both therapeutical development and future neuroinformatics research.

Key Words: serious game, EMG, BCI, paralysis, rehabilitation, Myo armbands, communication

Kurzfassung

Das ist eine deutsche Kurzfassung meiner in Englisch verfassten Masterarbeit.

Lähmung und Unfähigkeit zur Kommunikation können eine ernsthafte Herausforderung für jeden Menschen darstellen. Die vorliegende Studie untersucht die Auswirkungen eines Elektromyographie-Geräts auf ein von Lähmung betroffenes Kind.

Zu Beginn umfasst das Projekt die Entwicklung eines Serious Games mit Gehirn-Computer-Schnittstelle (BCI), das sich auf die Analyse der Gehirn-Muskel-Aktivität konzentriert und den Hintergrund des Teilnehmers genau berücksichtigt. Es wurde eine hohe und gut entwickelte Gehirn-Muskel-Aktivität festgestellt, was zur Weiterentwicklung des Programms zu einem System führte, das Myo-Armbänder zur Bereitstellung von EMG-Daten nutzt.

Ergebnisse und Tests deuten darauf hin, dass das System die motorische Mobilitätsrehabilitation und Datenanalyse unterstützen kann und damit eine solide Grundlage sowohl für die therapeutische Entwicklung als auch für zukünftige neuroinformatische Forschung bietet.

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1. Introduction

Accidents which lead to brain damage can have significant consequences in limiting communication and attention, movement and speech, emotional stability or social interaction (12). The reduced independence, limited education and a possible social isolation are some of the difficulties that would be faced by a survivor of such situation. It is hard imagining an adult going through a similar condition, but it gets more painful to think that a child would have to suffer their whole life in this manner. An adult would need to adapt his personal and professional life to such a change, but a child would need to start and live their whole life with a disability. Thus, rehabilitation for such children is both critical and difficult, requiring approached that address motor control, coordination and nevertheless, cognitive engagement, while keeping the whole process enjoyable and motivating.

1.1. Disabilities in children

For the correct and coherent development of an effective support system and intervention, understanding the prevalence and types of disabilities among children is necessary. According to UNICEF, around 240 million children worldwide have some sort of disability, the number representing approximately 10% of the global child population (62). In Europe and Central Asia, approximately 10.8 million children have disabilities, meaning that 1 in 22 children across the region (63). In the European Union (EU), 4.4% of children have been reported with health problems in 2021, from which 3.4 % with moderate disabilities and 1.0 % with severe disabilities (19).

The most common types of disabilities in Children are represented by attention-deficit/hyperactivity disorder (ADHD), autism spectrum disorder (ASD), cerebral palsy, hearing loss, intellectual disabilities, learning disabilities and vision impairments, all affecting around 17% of children between 3 to 17 years, located in the United States (U.S.). (10)

Interestingly, the 2021-22 school year impacted 15 % of public school students in the U.S., receiving services under the Individuals with Disabilities Education Act (IDEA), the most prevalent category being specific learning disabilities. (45)

All the percentages highlighted represent the base of the rehabilitation therapies' importance which can support the diverse needs of children with disabilities all around the world.

1.2. Rehabilitation therapies for children with disabilities

There are various rehabilitation therapies designed for children with disabilities, who can benefit of mobility, communication, cognitive skills and overall independence improvement.

Physical therapy (PT) improves gross motor skills, muscle strength, balance and coordination, thus it helps children with cerebral palsy and even current injuries rehabilitation. The most common goals are strength training, reducing pain and mobility aids, so the therapy is being considered highly effective for improving mobility and preventing muscle atrophy.(64) Significant improvements in upper limb function in children with CP have been observed by introducing intensive PT programs like Constraint-Induced movement Therapy (CIMT), in addition studies have shown that early intervention PT improves the outcomes in motor functions for the patients. (40)

Occupational Therapy (OT) improves fine motor skills, sensory processing, and also daily living skills, focusing mostly on helping children with autism spectrum disorder (ASD), developmental coordination disorder (DCD), cerebral palsy and sensory processing disorders.(14) Sensory integration therapy, fine motor skill development, adaptive equipment training are the common techniques that characterize this type of therapy, leading to effectiveness in hand-eye coordination and self-care abilities in children with DCD after the structured therapy programs and many more. The sensory therapy is researched and observed as having great results for children with ASD. (46)

Speech and Language Therapy (SLT) intend to enhance communication, language processing, social skills, focusing on children who suffer from speech delays, stuttering, cleft palate, ASD and Down syndrome. (55) Its improving effects on language outcomes are observed in a research on 25 children with primary speech and language delays or disorders (33), also another study observing the same effects after only 6 months from starting the therapy procedure (4).

Cognitive and Behavioral Therapy (CBT & ABA) is another type of help therapy which focuses on behavior modification, emotional regulation and cognitive skill development for children who experience autism, ADHD, anxiety disorders and intellectual disabilities. As the name suggests, the Applied Behavior Analysis (ABA), Cognitive Behavioral Therapy (CBT) are the most common techniques, the first one being used mostly in anxiety treatment and the second mentioned helping with emotional regulation.(Riley Children's Health)(15) The effectiveness of the ABA therapy is registered in children with ASD and the CBD methods shows impressive results in improvement of focus and emotional regulation for children with anxiety disorders. (38) (21)

Assistive Technology and Virtual Rehabilitation refines the effectiveness of technology-assisted interventions for children with motor disabilities, speech impairments and cognitive challenges (3)(11). Serious games can help integrate the therapy and provide important positive outcomes, observing that Wii-based therapy could also be a benefic factor, as long as parents consider a good way of usage for their children. (8) Nevertheless, this type of therapy is incredibly beneficial for patients that suffered from stroke, including gait improvement (37).

1.3. Serious games

In this context, there have been studies done on serious games that have emerged as promising tools in rehabilitation(26)(50)(2). Even if they are not designed for entertainment, they include a multitude of fun elements, in such way that the patients will use interactive platforms that integrate therapeutic tasks into immersive experiences. By ascending to elements which value the competition, goals and feedback, the serious games can truly enhance motivation and adherance, which are particularly beneficial for children.

The study conducted by Deutsch et al.(17) explores the common Nintendo Wii as a rehabilitation tool for improving the balance and mobility in patients who suffered from strokes. This way, the specified rehabilitation was compared to the traditional physical therapy to determine whether the interactive gaming would enhance the recovery. The results are meaningful, as the study showed that the Wii-based therapy helped significantly with the balance and coordination, observing also how the patients have been more engaged in participating in the rehabilitation sessions, leading to higher adherence to the prescribed exercises. Another study has been conducted on Wii by Gil-Gomez(23) and his team, where they introduce the eBaViR system, which uses the Wii Balance Board to improve the balance in patients with acquired brain injury (ABI). They can experience balance deficits that impact their mobility and independence, which lead to being split in two groups, one receiving traditional rehabilitation and another using the eBaViR with the Wii Balance Board. Consistent improvement was shown in control group rather than traditional rehabilitation group, thus the patients themselves reported an increased engagement and enjoyment with the serious game-based therapy, which contributed to a frequent participation.

Another robust type of game rehabilitation is documented in the paper conducted by Piron et al. (47), where virtual reality (VR) is used for arm motor rehabilitation. The research analyses how the VR assists the patients in recovering their functions after suffering from strokes, by following special exercises, also receiving real time feedback. The immersive environment increased the patient engagement, in addition observing the arm mobility and strength getting notable improvements. The VR based research has allowed for analysing velocity, duration and morphology using Fugl-Meyer scale, creating a valid observational environment.

These studies have collectively demonstrated that the serious games have significantly improved rehabilitation for patients who suffered from different conditions. The interactive and repetitive nature of the addition of devices and gadgets have contributed to better motor function, patient satisfaction and cognitive improvements.

1.4. Serious game developed for upper limb rehabilitation

As the serious games have proven their utility and effectiveness, due to the valuable observations brought with the results, this study introduces a football-themed serious game designed specifically for people who suffer from upper limb impairments, where the first and only participant is a child who has suffered from brain damage which lead to a locked in state. This has been impacting the upper limbs, thus the game focuses mostly on such rehabilitation, the first part including a real-time feedback using brain activity monitoring via BCI (Brain-Computer Interface), and the second part using EMG (electromyography) into addressing the muscle activity. The feedback has been extracted and analyzed in a controlled manner and it led to improving the game and the possibility of expanding the goals of the game. The football tasks are specifically tailored to improve the upper limb movement, controlling and limiting the spastic moves while assessing amusement by improving cognitive-motor integration. They include controlling the upper limbs through repetitive tasks which aim to lead to a better coordination movement.

The use of the BCI technology helped into identifying if the brain activity data can guide the therapy ([66]). It allowed for adaptation brought to the game, where the game options are bringing real help in the child's brain activity and engagement levels, providing a personalized and evidence-based approach. The game stands as a tool designed to possibly maximize the potential for neural plasticity and functional recovery for a child facing such complex challenges.

1.5. Goals and plans

"Is a custom-developed EMG-based software system able to provide signs of effectiveness in enhancing neuromuscular motor activity in a child with paralysis? "

This is the question that we are going to investigate, which also represents the goal of this study: creating a serious game which could serve as a rehabilitation tool. The game includes a football ball which can be moved in the left or right, based on the level of muscle strength. EMG will serve as a measurement instrument for guiding the patient to keep a controlled position of his upper limb. The goal includes also observations upon the effective movements during the gameplay using the IMU (inertial measurement unit). It is important to mention that this study is based on two phases observations on the child's behavior, first one being defined by playing the game without the implementation of the EMG, where BCI has been used to monitor the brain activity and analyse the possibility of improvements in the motor functionality and another one based on the introduction of EMG. The BCI helped in adapting the game difficulty to improve the engagement and also the entertainment for the patient.

Evaluating the effectiveness of the serious game in reducing spasticity and dystonia and improving a way of communicating by moving the ball in the game are over the goals suggested, representing possible improvements that would ensure the safety of the patient and his ease of accessibility to the platform.

Planning and designing the game are among the first steps, where development is exclusively tailored with ease usage, with different type of tasks and difficulties. Collecting data is important for capturing and researching the real progress using the platform, recording important highlights about the process of successfully finalizing the tasks.

1.6. Medical implications - Myo armbands usage

Prosthetic control and hand gesture recognition, augmented reality for prosthesis control and even physiotherapy and rehabilitation are worth mentioning when describing how the Myo armbands are impacting medical field. As the name suggests, the first one implies that the Myo armband is a great usage for the prosthetic control applications. There are studies which research how the electromyography is used in analyzing the muscle signals for controlling upper-limb prosthetics. Significant results were found ([26]), where support vending machine (SVM) was used together with random forest which can classify EMG data and lead to notable accuracy of 83.9% accuracy in gesture recognition.

In addition to the typical prosthetics, controlling these devices in augmented reality environments was tested also and in this situation, the EMG data was combined with deep learning techniques to manage to create an intuitive control systems for prosthetics and therefore improve the interaction with the artificial limbs ([54]).

1.7. Research on Integration between Myos and Serious Games-State of Art

1.7.1. Myo Armband and Multiple Sclerosis

Introduction - Definitions and Goals

Selena-Marcos Anton et al ([2]) come to consistent results by researching the effects of serious games developed for Myo Armband for the patients with multiple sclerosis (MS) who suffer form upper limb (UL) limitations. This first paper represents a valuable proof of the work with Myo Armbands and their usefulness in rehabilitation.

Multiple Sclerosis is a chronic neurological disorder where the immune system mistakenly attacks the protective sheath (myelin) that covers the nerve fibers, leading to inflammation and damage in the central nervous system (CNS), which includes the brain and spinal cord. The damage disrupts the normal flow of electrical impulses along the nerves, leading to a wide range of physical, cognitive and sensory symptoms. This impacts the quality of life of the affected patients in a very significant way. Their upper limb is affected mostly, thus the patients lose their dexterity and their muscle control, leading to major changes in all the aspects of their life.

Multiple studies mentioned by Anton et al. propose that the strength is affected as a primary variable for daily activities, and also that manual dexterity is limited, having as a consequence the predisposition to developing cognitive deficits. Having no curative treatment for multiple sclerosis, the only way tested for overcoming the progression of the disease is physical therapy combined with pharmacological treatment. The treatment is often considered to get in time really monotonous for the patients, which is a big cause of their lack of motivation in this manner.

New methods have been introduced, including virtual reality, an option that would keep the patient engaged and excited for the rehabilitation session. This is leading to using the Myo Armband, used in this context due to its impressive design to recognize arm gestures based on the muscle activation. Even if it reflects a great range of usefulness, there have been only a couple of studies which are investigating the use of Myo Armband device as a tool for UL impairments rehabilitation.

The paper is now following a list of milestones which have as a final objective the observation of patients using the Myo armbands, including both positive and adverse effects and their level of satisfaction. The main approach include the specifically designed video games in combination with the traditional physical therapy, which would be assumed to be an enhancement for the active wrist range of motion, also the "grip strength, motor dexterity, fatigue, functionality and quality of life in patients with MS".

Methodology - Study design and Participants

The type of study is characterized by randomized controlled trial, which is crucial for demonstrating evidence-based effectiveness. The participants were chosen based on specific criterias, which are detailed in the paper. They were split into two groups: an experimental group (EG), which used the MYO Armband along with the serious games, and the other one being the control group (CG), which only received the mentioned traditional therapy. Both of the groups have been included in two 60-min sessions per week over a period of eight weeks, this being a suitable schedule which reflects the trial's approach to an improvement characterized by sustainability and graduality. In order to improve the sampling accuracy, the team performed gesture calibration and also the system's gesture classifier to optimize it.

Video Games

Four video games were created in order to observe eight important gestures: hand opening, hand closing, wrist flexion, writ extension, finger pinch, forearm pronation, forearm supination, resting position (relaxed arm), presented in figure 1.1. The Myo Armbands were used in order to capture patients movements as sEMG activity and were processed by MATLAB software by transforming the captured signals into information about wrist and hand gestures. Also, more virtual environments were created by using Unity (game development). Two modules were generated with the system: game module and gesture recognition module, each implemented on different development platforms. The games created are presented in 1.2, in the following order: MYO-Gesture, MYO-Arkanoid, MYO-Space, MYO-Cooking.

Myo-Gesture is presenting colored rings associated with different gestures falling from the top. When the patient performs correctly the gesture, they earn a point and the music is playing.

Myo-Arkanoid is showing a bouncing ball which needs to break the colored blocks, being controlled by a paddle which moves based on the wrist flexion and extension or by forearm pronation and supination movements. The patient lose a life if they do not catch the ball or earn points by breaking the blocks. "The game ends when all the blocks are destroyed or when the player loses all three lives given at the beginning of the game".

Myo-Space is based on the "Space Invaders" game, where the patient will move a spaceship from left to right using the gestures, where enemies need to be attacked. "The

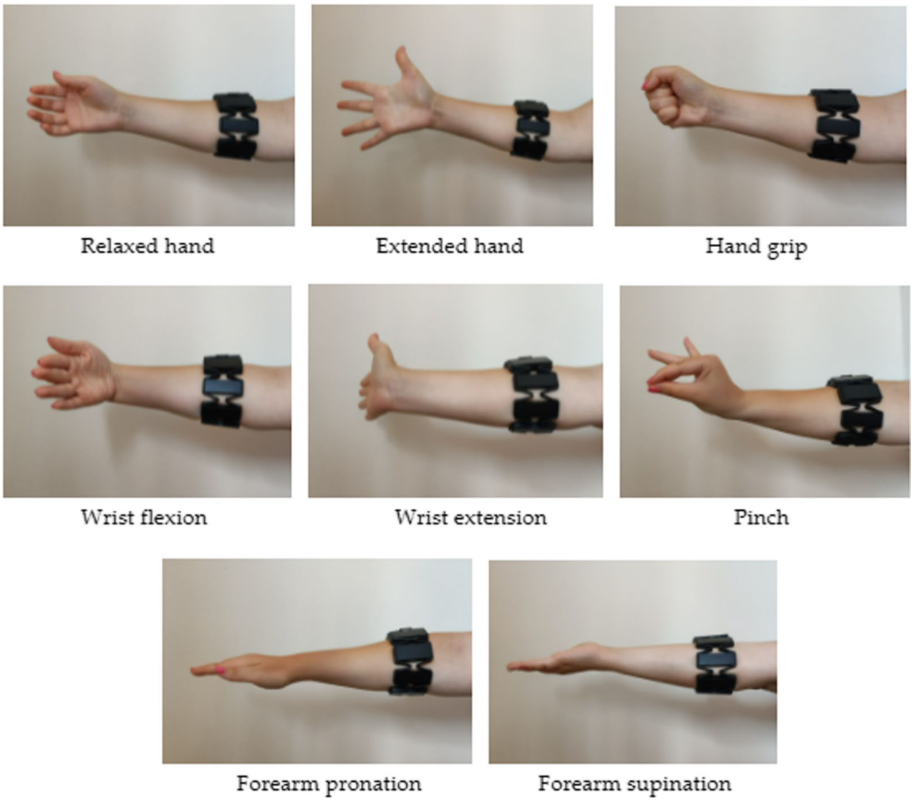


Figure 1.1.: Fig SOA-1.1
([2])

game ends when they eliminate all the invaders or lose all the three lives given at the beginning of the game".

A therapist will help configure a cooking recipe with specific ingredients and steps, in the Myo-Cooking game. Following a sequence of UL movements is the main goal of this game, thus the game will end at the completion of the steps.

Outcomes and observations

The following outcome measures were observed in both of the groups at the beginning, at the end and 15 days after the intervention. A universal ganiometer was used to asses the active range of motion, a hydraulic hand dynamometer measured the strength of the handgrip, also an important evaluation on the coordination, speed of movement and unilateral gross motor skills were tested using the "box and block test", which concentrates on moving boxes from a side to the other of a box, in a specific amount of time. Obviously, the score is directly proportional with the dexterity that a patient has.

Another interesting measure used is the "Fatigue Severity Scale", which will analyze the severity of fatigue and its effects in the daily activities and lifestyle of the patients included in the research. The score obtained from evaluating each of the 9 questions on

Figure 1.2.: Fig SOA-1.2
([2])

scale is from 1 (lowest) to 7 (highest) will be transformed into percentage at the end of the questionnaire. As the name might suggest, "ABILHAND" evaluates the manual ability of adult patients in their daily life, having as scale outcomes as "impossible", "difficult", "easy". "Multiple Sclerosis Impact Scale" assesses physical and psychological questions, while the "Short Symptom Questionnaire" evaluates the "possible manifestation of adverse effects resulting from the experimental treatment using the MYO Armband, which has provided well contoured observations.

For the EG group, "NASA-Taskload index" was used to obtain the participants feedback regarding the workload, while the "System Usability Scale" was used to analyze the usability of the VR device itself. Moreover, "Quebec user evaluation of satisfaction with assistive technology" was used in order to retrieve the level of satisfaction for using the the device and related services, including comfort and durability, being considered one of the principal tool of evaluation for the MS patients who use a technical device.

"Customer Satisfaction Questionnaire" will help the researchers understand how the patients felt regarding care and treatment, for both EG and CG group. Only the EG group has completed the "Questionnaire on satisfaction with the technology employed", for observing the satisfaction with the MYO device, the according technology and nevertheless, with the professional who conducted the therapy.

Statistical analysis was also conducted, "comparing pre-treatement with post-treatment measurements, and pre-treatement with follow-up measurements; and the satisfaction level of the subjects and therapy attendance rate".

Results

There were a total of 30 participants for the study, from which 14 were more affected on the left side, and the left 16 were more affected on the right side. There were interesting differences between the CG and the EG, from which we can consider the handgrip strength in the group*time comparison (F=6.665, p=0.004). ANOVA analysis showed also differences for wrist dorsiflexion in active joint range of motion in the group*time comparison and also for forearm pronation (F=3.515, p=0.048) and forearm supination (F=7.293, p=0.004) in active joint range of motion int he group*side*time.

A significant information relies in how satisfaction with the rehabilitation intervention was perceived in the EG, with a score of approximately 90 points, compared to CG, which was approximately 94.79 points, out of 100, thus there is statistically not a difference between the two. Also, satisfaction with technology achieved approximately 84.36 for the EG group.

Moreover, the attendances have significant differences, as the EG attended treatment with a score of approximately 97.08, while the CG obtained approximately 91.25 points out of 100.

No statistically significant changes were observed on the three measurements related to the active range of motion in wrist dorsiflexion. Though, the wrist palmar flexion show significant improvements between the pre-treatement and the follow-up evaluation, in the EG. Both forearm pronantion and forearm supination show significant changes between pre-treatement and post-treatment, pre-treatement and follow-up evaluation of the more affected side in EG. all of these results can be observed in the figure 1.3.

The SSQ showed an average of approximately 7 out of 100 points, the NASA-Task Load Index questionnaire has achieved approximately 25 points from the EG group, while the SUS obtained 80.66 out of 100 points and the question related to satisfaction with the device achieved approximately 16.66 out of 20 points. Interestingly, post-intervention session for assessment of satisfaction with the Myo arband showed a proudly approximately 84.36 points for the EG, thus the patients showed interest and satisfaction with the VR Myo usage.

Discussion and conclusion

Based on the results obtained, it is directly implied how these show a significant consequence by using the Myo armbands, where the statistical analysis showed these significant increased results for the active range of motion and grip strength. The research team considers that these results lead to the fact that the game protocol has had a massive impact on the patients, as following repeatedly the same task had lead to the changes in range of motion.

The differences between the two groups are clear as well, as the pronation mobility has been on a wider range for the CG. However, the EG managed to reach similar results in the follow-up evaluation, as it can be seen in the figure 1.3, showing that the protocol proposed through the MYO Armband has brought improvements for the patients with MS.

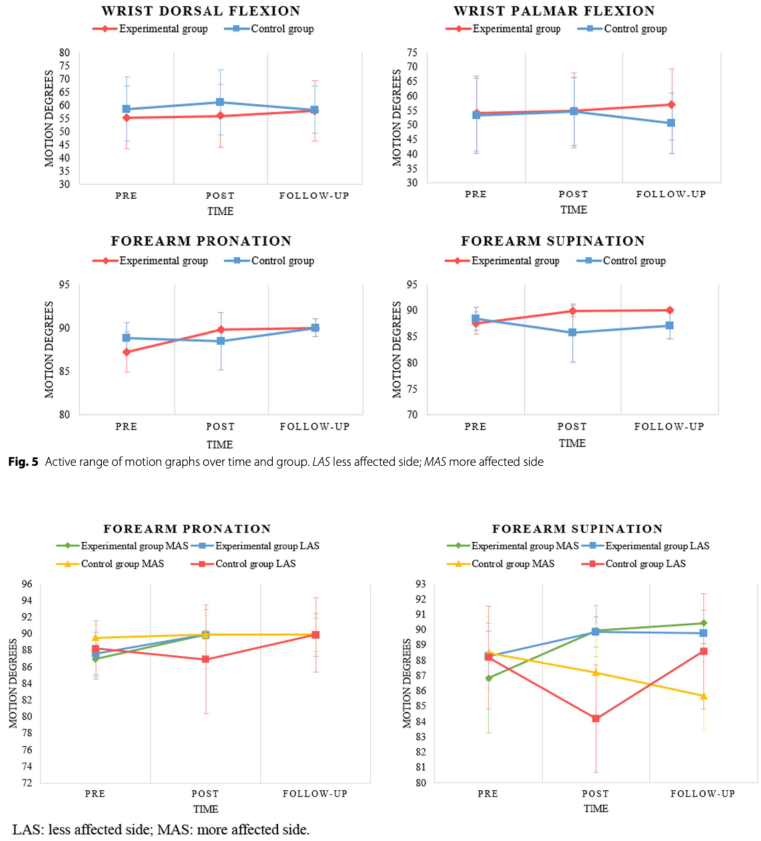


Figure 1.3.: Fig SOA-1.3
([2])

Compared to obvious positive results, the BBT has remained stagnant throughout the protocol, where the team considers that this might be due to the limited period of time that the study has taken place and maybe more results would come with more treatment. Also, only one side was used in the VR experiment, situation that might mark the lask of inter-group differences, thus it would be expected for better effects on manual dexterity and coordination to be gained in MS patients.

The low scores in SSQ and NASA-Task Load Index implied that the chosen protocol was a well-accepted therapeutic approach, while the positive reactions after using the Myo system and the technology itself indicated a great compatibility with it. As mentioned in the paper, "greater treatment adherence" resulted from the combination of physical therapy with the Myo, and the EG showed higher treatment adherence than CG. Moreover, results could be the real consequence of how the association chose the patients, as these were some of the ones engaged in therapy and comfortable in such environment.

Concluding, the study still needs to be continued as it cannot be generalized for all the people who are diagnosed with MS, as the patients were chosen based on specific requirements. Future work focuses on including more people with different and maybe more specific backgrounds of the MS, from more associations and also follow-up evaluations would need to be continued for a constant analysis. All in all, combining Myo Armband system with a typical physical therapy program came with significant improvements in the patients lives, based on the results and discussion mentioned.

1.7.2. Myo Armband and Subacute stroke

Hao-Ping Lin et al. (27) have been researching the impact of usage of Myo Armband by the patients who suffered from a stroke and a subacute stroke, as the rehabilitation for the upper-limb has been incompletely observed and explored. The study will include evaluations of the MyoGuide usage by the targeted patients.

Introduction

One of the most impacting disability leading cause in humans is stroke. A stroke is a medical emergency that occurs when the blood supply to a part of the brain is interrupted or significantly reduced, depriving brain cells of oxygen and nutrients. Without oxygen, brain cells begin to die within minutes, potentially causing long-term neurological damage, disability, or death. The team reminds that around 50 % of the patients who suffered from a stroke have limitations in their upper limb impairments, which can lead to a big impact in the day to day life. The therapy itself can become difficult in the subacute phases and it is pointed out the fact that an early intervention in rehabilitation has better results, implying that the patients responsiveness to the therapy in "the first 60 to 90 days following a stroke" helps in motor recovery. Similarly to the presented paper, the team is outlining the need of repetitive tasks in this rehabilitation, which can become tiring and monotonous, thus proposing a solution of combined therapy with exploration of a serious game created in collaboration with the Myo Armband. The surface electromyography (sEMG) biofeedback comes as a great and versatile method of helping "detecting movement intention in cases of upper limb paresis", being previously researched for the stroke patients.

The team introduces "MyoGuide", a mobile application based on a serious game and Myo Armband, which will be used by post-stroke patients in their rehabilitation and analyzed therefore for its consequences. Focusing on wrist extension, a potential indicator in the upper limb recovery, there was developed a calibration feature that would highlight different impairments among stroke patients.

MyoGuide training platform

Usability evaluations were introduced in the beginning of the MyoGuide development in order to observe the possible difficulties that both the patients and the therapists might encounter during the usage, also representing one of the main goals of the study.

The MyoGuide Mobile Training Platform includes development of a serious game, created with the help from Unity Engine, used in combination with the Myo Armband which will transmit live the sEMG data collected. The application starts and the pairing with the Myo armband is done directly, afterwards the battery level and the pairing status being displayed on the tablet. The creation of a user profile is mandatory to be done by the therapist, so the training tasks can be accessed. These include the stability assessment and dynamic tasks, each being valid for selection in a specific order. There are three colors used for identifying the tasks statuses: blue - available task, green - completed task, gray - inaccessible task. When a task is selected, the EMG calibration is performed in order to ensure the usage of maximum range for good performance.

Sessions Sessions were conducted in a 1:1 manner between the patient and the therapist, who positioned the armband on the stroke affected forearm, which aimed to access the sEMG signals specifically from ECR muscle. The next figure shows the steps of using the Myo Guide, from left to right: the introduction task represents the connection between the myo armband presented above; the EMG calibration including a trial of a "maximal voluntary contraction" of the ECR muscle for a minimum period of one second, observed on the plots for each of the 8 sEMG channels, where it can be identified the "extensor channel", i.e. the one with the highest sEMG range. The stability assessment is the next step, where the wrist extensor (ECR) activity is measured, by asking the patient to control and move the yellow cursor inside the targeted green circle. The first position of the yellow circle represents the filtered sEMG amplitude of the selected channel, while the green circle represents the min sEMG. The goal of the stability assessment focuses also on holding the cursor in the targeted area for the maximum of time. 1.4

Figure 1.4.: Fig SOA-2.1
([27])

The step includes "three target areas which are associated with a specific calibrated maximum EMG level (25 %, 50 %, 75 %), each being repeated for 5 times. Moreover, each task is marked with 100 points, summing up to a total of 1500 points, showing the overall performance of the participant.

Dynamic Task The dynamic task assess controlling a panda avatar, positioned based on the recorded sEMG level for the extensor channel, where its movement is activated by the EMG signals. The goal of the task is for the panda to achieved the coins placed in different points. The level of difficulty (LoD) has been constantly increased in order to activate the extensor sEMG activity. This was achieved by the team by placing the coins at distances that would constrain the patients to use more effort to achieve the goal of the task. Also, the height of the obstacles were altered in the same manner, having as a base reason the usage of more muscle activation that would lead to a better rehabilitation.

LoD Moreover, the LoD has been customized for each patient's previous task, in such way that the difficulty to still be achievable, thus in case of falling below the threshold, the difficulty would be adapted accordingly. This ensures future improvement in the tasks and also maintains a correct and realistic level of challenge.

The following image represents the time system of using the platform, where each of the daily five training blocks has allocated 2 minutes, followed by 30 seconds break, on a duration of 10 days, in two weeks. The last day of the training included also receiving feedback regarding the system's usability. Not only the patients are included in the feedback, but also the therapists are observing the participants and documenting this analysis. 1.5

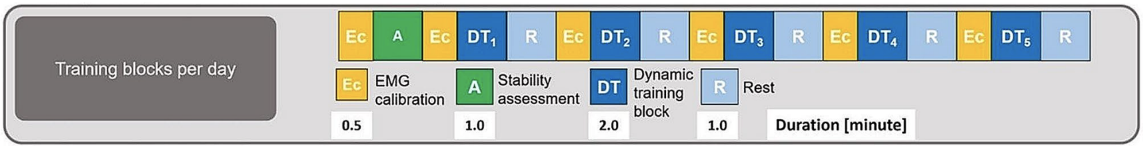


Figure 1.5.: Fig SOA-2.2
(27)

Patients As mentioned above, the patients are people who have survived a subacute stroke, whose wrist of the affected arm had suffered a significant deficiency. The team selected 10 participants based on a very specific criteria, which is detailed in the paper, only from one rehabilitation center from Liaoning, China. Unfortunately, the analysis in the end has been done on seven patients' data because two got lost due to technical issues and one of the patients was not able to participate anymore. Three therapists have worked closely to the project, from which one conducted the screening for eligibility, while the other two facilitated the training sessions and noted their observations.

Outcomes and analyses

System usability scale The System Usability Scale (SUS) has been used in order to evaluate the overall usability of the platform, from the patients' perspectives. This type of questionnaire was used due to its efficiency, simpleness and quality of being standardized in usability assessment, having also previous usage in studies on stroke patients. A Likert scale with 1-5 range is used, consequently the SUS score being calculated based on the following computations: "the sum of the responses to the odd-numbered questions is subtracted by 5" and the sum of the even-numbered questions is subtracted from 25. Both results are summed up and multiplied by 2.5, which gives the final SUS score, where higher scores suggest better usability.

Self training The possibility of training home represents the second outcome, as it is an important tool to know if the patients have the willingness and the confidence that they can use the platform at home. The survey included six questions rated also on the 1-5 scale, consisting also on Myo specific information, where the goal is gathering enough information on how the patients perceive the ease of using the armbands. Closely monitoring followed the process of the study, which aimed the stability assessment of the participants and the LoD resulted from the dynamic tasks.

Data Analysis A completed explanation on how the data was gathered is presented in the paper, thus what is important to mention that the team observed how the SUS scores, the baseline characteristics and the training performances for each participant correlate, results that will be highlighted in the next section.

Results

There were a total of seven patients who completed ten training sessions and the questionnaires.

SUS The patients were satisfied with the Myo Guide mobile training platform, result observed in the median SUS score which is "good" (82.5). Only one participant found the platform "excellent", while six patients found it "good" and another one considered it only "ok". Consequently, the users gave a favorable feedback and felt confident to use the Myo Guide at home as well, but would still consider that technical support would be necessary. Interestingly, there were no correlations between SUS score and age or between other meaningful measures used in the data analysis, fact that contributes to the idea that the availability was perceived unitary among all the patients.

MyoGuide Training - LoD An increase of LoD was visible on all the ten days of the training, as it can be observed in 1.6. The "session number" fixed factor has reached a statistical significance of $p<0.0001$, thus the progress of difficulty observed among the days. Though, it is important to highlight that the LoD has not been consistently increasing for all participants, as for the most impaired patients the rates of progression were significantly low.

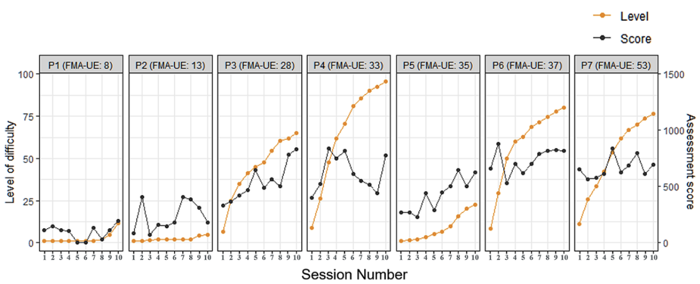


Figure 1.6.: Fig SOA-2.3
([27])

The change in LoD and the SUS score have no correlation, implying that a higher usability score is not reflected necessarily by a better LoD progression.

The stability assessment tasks were observed to have generated a better performance of the less upper-limb impairment patients and also "no significant correlation was found between the mean assessment score and SUS score".

The therapists have noted down the high usability of Myo Guide, the ease of portability and the well resulted combination between the device and traditional rehabilitation. They are enthusiastic about the use of the MyoGuide at home, as they observed that the most interested patients in technology would actually be keen on using the programme after the study. Also, it is important to note that the visualisation of the performance has been a great way of observing the progress, which ambitioned the patients into making use of the MyoGuide. They are still slightly thoughtful regarding the usage without assistance, as it can be observed in the following figure.1.7 The feedback helps into adding an onboarding for the patients at the beginning of unsupervised MyoGuide navigation.

Survey Question	P1	P2	P3	P4	P5	P6	P7	Median
I think the training improved my functional recovery.	5	4	5	4	5	5	5	5
I need others to help with putting on Myo.	5	5	5	5	5	5	1	5
I would like to continue the training.	5	4	5	5	5	5	5	5
I need others to help with operating the tablet.	5	5	2	5	5	5	1	5
I could perform the training independently.	4	1	4	2	3	3	5	3
I would like to take the training device home (if it is free of charge).	5	3	5	5	5	5	5	5

Likert scale: 1 (strongly disagree), 2 (disagree), 3 (neutral), 4 (agree), 5 (strongly agree)

Figure 1.7.: Fig SOA-2.4
([27])

Discussion and conclusion

The first goal of this study was researching of any challenges that both patients and therapists would find by using the Myo Arbands in combination with a special serious game designed for rehabilitation. As discussed in the results, the feedback report is highly motivating to classify the MyoGuide as a real help. The SUS scores between good and excellent, which only reflects the participants' overall impression. Thus, it might be considered the time used into using the platform as a bias because the participants got used to it over time. The therapist helped them into using the platform, so a possible influence in the independent interaction needs to be taken into consideration.

For severely impaired patients, the inclusion into the active training presents difficulties, but the training with MyoGuide showed an impressive improvement for all kind of patients, also for the ones with really limited wrist movement. The willing to continue using the platform, also at home, is a great achievement even with the need of assistance, fact that can be improved by adding an adequate training and provide possible remote support.

The increase of LoD and the correlation with the sessions show how the patients had real progress over the time, notably that the patients with the mild impairments had better progress than the ones with severe impairments. Also, a more randomized controlled trial (RTC) is considered for future work for observing motor recovery, considering each patient's condition accordingly. The armband remains in the same position, so the team considers that in the future they might cancel the calibration step presented. Moreover, a LoD customized for each patient capacities and impairment might have better results on rehabilitation.

The future work includes redesigning the Myo armband to "address challenges such as independent donning and doffing". The results from the SUS and survey regarding unassisted usage conducted the team to reconsidering the work on a revised version, which would include also clearer instructions and smoother user experience.

In conclusion, the MyoGuide demonstrated through this study that it is capable to help in stroke patients rehabilitation. Usability challenges, such as donning the armband and also the ease of navigating the application, are taken into consideration for future improvements. The low number of the study participants imply that it cannot be generalized, thus a more robust applicability of the training programme would generate a better understanding among more participants. Nevertheless, the results assess an important improvement among the stroke patients, providing a study that can be developed in a broader environment.

2. Methods - System Development and Implementation

2.1. Programs and devices

2.1.1. Electromyography(EMG) and Inertial Measurement Unit (IMU)

Electromyography (EMG) is a monitoring technique that measures the electrical activity of muscle during contraction and at rest. Electrical signals are detected and recorded when the nervous system is activated. The EMG includes electrodes, more specifically we use the sEMG (surface EMG), that are placed over the skin in order to measure the muscle activity, where their mission is processing the signals, as extracting features like amplitude, frequency and signal power, all of these are important key features to analyse muscle strength, coordination and speed. It is used most of the times in medical diagnostics and rehabilitation, due to its real-time feedback and its easy to use electrodes. (36)(7)

Inertial Measurement Unit (IMU) is a device that measures an object's force, angular rate and most important, the orientation in the 3D space. It includes the accelerometer, which measures linear acceleration along x,y,z axes; the gyroscope which assesses the angular velocity around the three axes, tracking rotation and orientation; the magnetometer, which focuses on the magnetic field strength to determine the heading. It is widely used in healthcare and rehabilitation, gaming and also robotics, as it is compact and proves its usefulness by having a high sensitivity and ability to capture motion in real-time. (39)

Combining both EMG and IMU represents a powerful tool into tracking the improvements in mobility, thus in serious games the EMG can control game inputs, while the IMU records the motion and posture.

2.1.2. Hardware - Myo Armbands

Interacting with computers, smartphones and even projectors, Thalmic Labs created the Myo Armbands, gesture control devices which are used worldwide.??(60) The users can interact with smart devices through gestures and motions, by muscle activation, being known for its ease and popularity to use in presentations and virtual reality situations. (18)(6)

Myo Armband, Thalmic Labs(60)

Placement of Myo based on anatomy of the arm

The Myo needs to be always placed on the muscle that needs measurement, the place being most of the times the forearm. These muscles are layered, which represents the fact that the muscles closer to the surface of electromyographyc (sEMG) sensors will lead the reading compared to the others.

The hand includes around 30 muscles, all being connected by tendons. Obviously, the finger muscles can be found far away from the forearm skin, thus the forearm muscles. This fact will have a consequence in how the sEMG signals will be perceived, with a lower amplitude, due to the filter that comes along with the forearm signals. The picture below show how placing the Myo can differentiate in detecting the muscles.

Interesting muscles that can be found in the fingers, that spread the index, middle and ring fingers, can be detected by Myo Armband, while the adduction muscles is less likely to be detected my the Myo Armband. (44)

EMG and Myo

As mentioned, EMG measures the electrical activity detected at muscle surface at contraction time. The Myo Armband includes eight such EMG sensors which detect the activity when different gestures are interpreted, such as fist clenching, finger tapping, waving in and out, spreading fingers and pinching, each associated with distinct muscle contractions. (35)

IMU and Myo

Observing and correctly tracking the orientation, motion and position in a 3D space, the IMU includes the accelerometer, gyroscope and magnetometer. Myo integrates all these elements by defining an acceleration force through accelerometer, detects rotations by following the angular velocity with the gyroscope, and measures the magnetic field by including a compass functionality with the magnetometer.

All these sensors are critical in defining a correct position of the arm, which comes in great help with the EMG data collected.

The Myo armbands are connecting through bluetooth and sends data wirelessly to the laptop it is connected to.

Usage

Myo armbands include a big variety of usages, from which presentations can be reminded, being widely used. Controlling media is another known usage, such as manipulating the music streaming, playing and stopping it, changing the volume and others, while gaming and both virtual reality and augmented reality would give the possibility to the user to adapt the Myos to enhance the experience by interacting with each of their essential particularities.

Moreover, intuitive arm movements could help in applications regarding robots or drones, which would make both of these fields prosper by testing features with remote control.

Nevertheless, medical field is where we can find its primordial usage and even the most impactful. Prosthetics and physical therapy can both use the Myo armbands, in such a way that the patients would activate the natural muscle movements, moving the artificial limbs and the progress could be tracked, following by giving feedback to the therapists, as presented in previous chapter. Developers can also use the Myos to map gestures into applications that would perform different tasks. The thesis in cause is combining both medical research and developing into one by producing a thriving project which aims to be continued and hopefully change people's lives.

The proposed game has been designed as an interactive and intuitive game, emphasizing one of the most known sports, football. The purpose highlights the movement of the ball from the middle of the screen to either left or right gate. This paper includes all the methods that have been used to create an environment for rehabilitation, stating the process from the beginning until present. This project includes understanding main necessities in game development, creating a work frame that would test upper limb abilities, the development of an improved game that would suit motor rehabilitation and communication and the testing of the new product that would represent a possible helping tool for people, but specially children, that encounter these insufficiencies. Moreover, there will be presented the obstacles that had to be faced on the way and the arguments for all the decisions that had to overcome the challenges. Thus this project has not represented only the creation in a straight line of a system that would serve as a useful tool, but also all the determination invested in the project to become a real product, all the ups and downs detected on the working path and the limitations that this project had to adapt to.

The following parts represent the milestone in the process of creating the system, including some of the results achieved on the way, which created the base to create and innovate the system.

2.2. Part I

The early steps included creating this game with Psychopy framework, where sensors from his arms would move the ball around. Respecting the sense, the ball will be manipulated by the EMG sensors towards the corresponding gates, this way observing how responsive the upper limbs of our participant are. The sensors would help into recording the force measure used, detecting the muscles that have higher receptivity and the speed used for the signals to travel from the brain to the muscles. The game has been created solely using the keyboard, afterwards being possible to connect it to the hardware, a special hand sensor. ([41])

2.2.1. Modes

There are two modes in the game, "Practice" which includes three level of practice, each of them corresponding to increasing the distance between the ball and the gate, while "Game" mode includes the biggest distance between the ball and the gates, giving the user the possibility to move the ball in any direction they would like.

2.2.2. Psychopy

Psychopy represents a widely used tool for setting up experiments, contributing in an efficient way to the development of behavioral science. It is a platform that supports running psychological, visual auditory and cognitive experiments, it can collect responses and record data, as well. ([41])

The graphical interface represents a perfect match in this manner, having also the possibility of adding code in Python. Accurate timing and synchronization are important pluses of using Psychopy, letting the experimenter have fully control over the presentation, experiment itself and collection of data, including here either keyboard presses or mouse clicks.

An interesting feature that Psychopy shows is the ability to define specific parameters, create trial sequences, by also implementing logical structures. Logging and storage of participant response becomes much easier and more efficient to export and use the data for analysis or any further interpretation.

2.2.3. Game set-up

Having a friendly GUI and providing a big help for the experiment itself, I used the "Builder" feature, which includes important tabs that are explained in figure 2.1.

Flow shows the experiment, with routines and loops. **Routine** is a main section, which can include components, images, keyboard response, text or code. Its header is intuitively respecting the pointed routine. The game starts when pressing the key "y", which completes the present routine and jumps at the next one, where the player can choose between the two modes explained above, "Game" and "Practice", observed in figure 2.2.

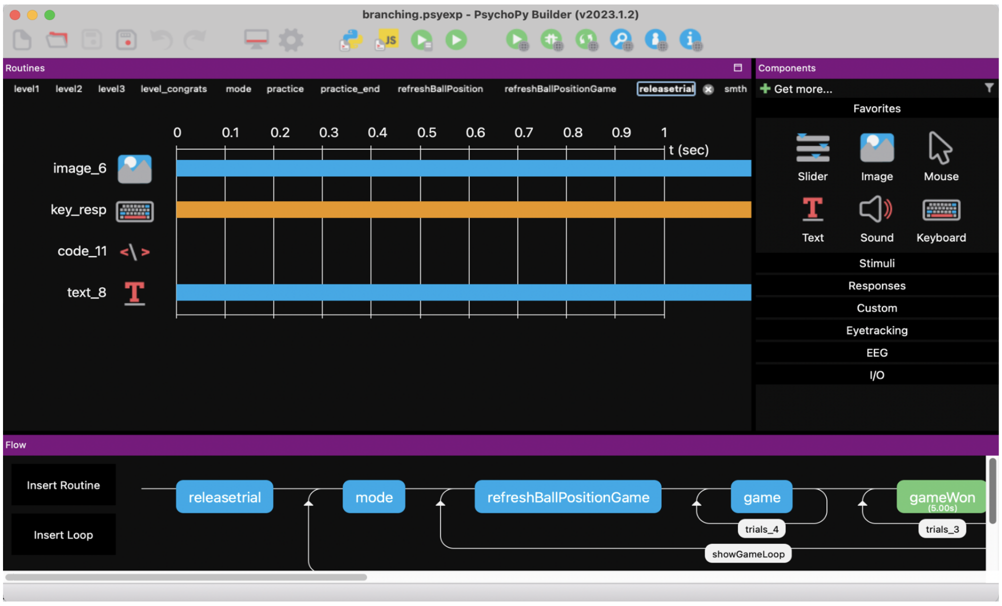


Figure 2.1.: Fig PsychoPy Builder

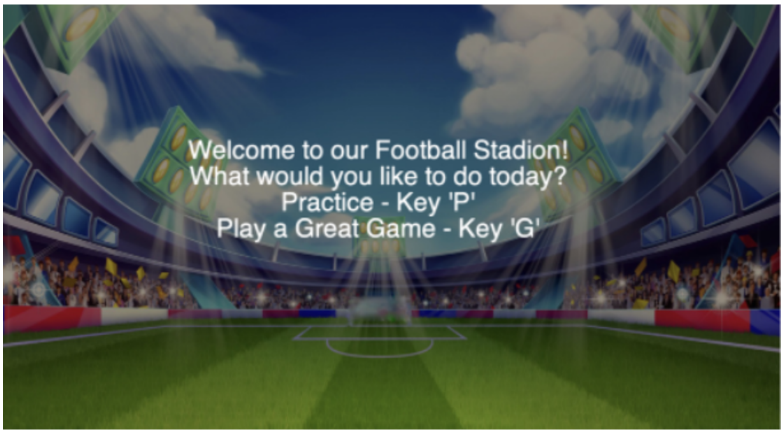


Figure 2.2.: Intro Page
Symbols seen in the screenshot
https://in.pinterest.com/pin/349169773372622693/

Figure 2.3.: Practice Mode
Symbols seen in the screenshot https://in.pinterest.com/pin/349169777372622693/,https://es.pinterest.com/pin/657947826843666293/,https://www.pngaaa.com/detail/500450

Three options of levels are presented in the experiment. First level shows a small distance between the ball and the gates, in the second level the distance becomes slightly bigger and in the third level the distance is maximized. All these distances have been perceived to represent increasing challenge for our future participant, as their possibilities of moving are limited, thus the rehabilitation needs to include small changes between the levels.2.3

The success of scoring a goal with the bal in one of the gates leads to a new image, accompanied by a congratulations sound, making the game interactive and joyful. The user is shown after 5 seconds the possibility to end the game or to play another time, referencing figure 2.4.

"Game" mode is resembling the "Practice" mode by keeping the same distance that is represented in the third level shown, the only difference consisting of free movement, meaning that the participant can play around in both directions, giving the possibility to the team to arise observations upon user's abilities.2.5

Besides the Routine benefits, the Code is the part that can be attached to any routine. Code written in Python can be converted into JavaScript (or directly in JS), the stack base for the builder. Setting a timer for blocks of code has also been used, for example at the beginning of the experiment, at the end of a routine etc., necessitating a structured

Figure 2.4.: Congratulations/Outro Pages
Symbols seen in the screenshot https://www.canva.com

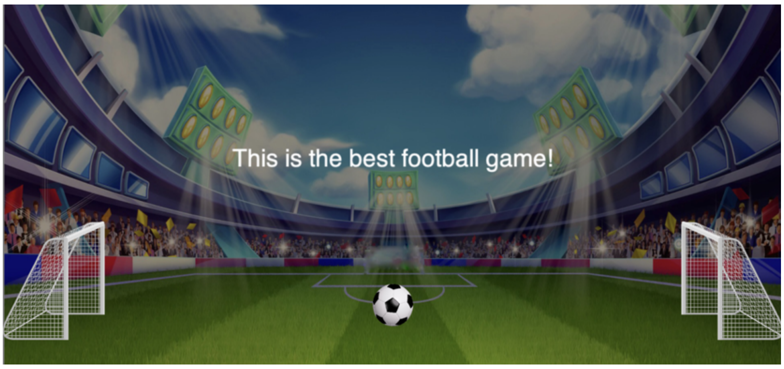


Figure 2.5.: Game Mode
Symbols seen in the screenshot
https://in.pinterest.com/pin/349169777372622693/,https://es.pinterest.com/pin/657947826843666293/,https://www.pngaaa.com/detail/500450

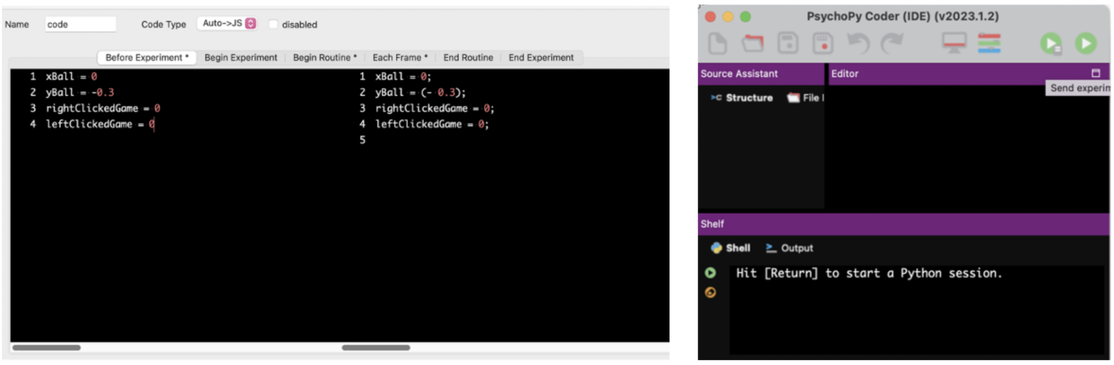


Figure 2.6.: Coder

attention for the time, due to the sequence of the code blocks in a special order and their conversion in the final application.

The Coder, on another hand, is not part of the Builder. It replaces the builder itself, thus code can be written in other files as well, shown in figure 2.6.

2.2.4. Observations and improvements

Being a framework that has brought newness to me, I found its benefits really captivating and useful for the experimental side of the Neuroscience, representing a complete tool that can be used in multiple languages (Python, JavaScript) and can be easily followed by any student who is interested in the domain. A downside that Psychopy shows is the limited number of tutorials and forums where people present their errors. Moreover, there have been some keyboard limitations that had to be overcome, these representing the fact that Builder distinguishes between pressed and release keys, and having as a goal the continuous movement of the ball, it had become as a real challenge. The solution consisted in deleting the keyboard component and import specific keyboard class in the Code component.

The next steps were the integration of the game with technology in the laboratory, by adding the hand sensor in a hardware connection. Gather of live data represented another goal for this step in the project, by developing the practical steps in the environment of the experiment.

2.3. Part I - Results in early stages

The results that will be provided in this section represent the next steps mentioned in the previous subsection, as the team made possible the integration of the Psychopy game with the hardware technology and already include the participant in the experiment for early observations and analysis on his motor movements and capacities. This is the reason why BCI has been included in this part of investigation, which has been followed closely with the EMG system. It gave enough insights into his brain-muscle activity, presented

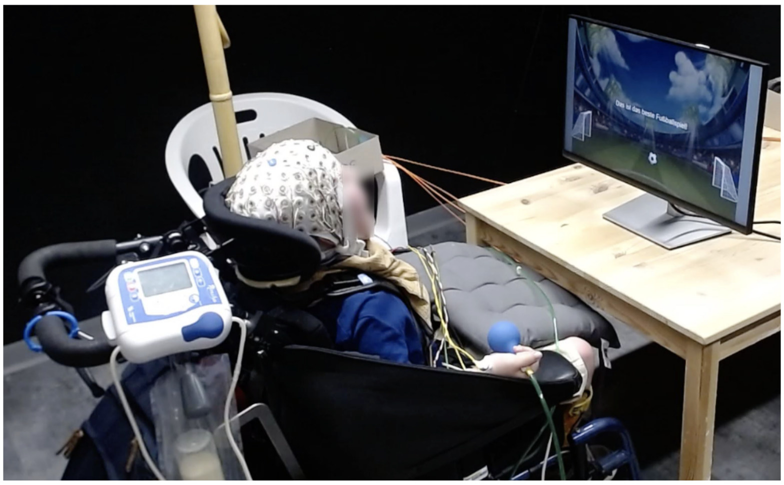


Figure 2.7.: Set up for our participant
(50)

in the following lines, referencing (50).

As the mentioned researched showed in section 3.3 , BCI has proven its efficiency and its valuable results, thus it has been used in the proposed study. The precision of BCI application joined with EMG has improved the communication and control, expanding its practicability to technology. The study has started with investigation of both EEG, on channels F1,Fz,F2,FC3,FC4,C3,C1,Cz,C2,C4,Cp3,Cp4 and Pz and EMG, where the EMG has been recorded with the Bittium NeurOne Tesla EEG system for flexor digitorul profundus, extensor digitorum and abductor pollicis longus. Both psychological signals together with event records have been storred in specific timestamps, for further analysis. More information about the participant are presented in the next chapter.

Online signal processing has been processed by using lab streaming layer (LSL) and the Python interface pylsl, while the special created Psychopy game framework has been created. The processing of EMG signals also gives a feedback to the user for further adjustments of the movement. Offline data has been processed by Python and processed for each channel.

The results represent the EMG and EEG signals recorded in four sessions and P1 run. **Resting state EEG** show the stabilization of the personalized frequency bands, meaning mu and beta rhythms. The power spectral density figure show how the alpha/mu rhythm is slower than the average adult's, representing just a normal fact, as the alpha rhythm increases accordingly to the age.

Run-level analysis focuses on P1 analysis. The right hand and left hand movements, shown with blue and respectively orange, can be observed below. It is important to mention that the right-hand EMG power is higher than the left-hand EMG power, a consequence of a Botox treatment on the left arm, previous to the session.

Following observations relate to a negative correlation between EEG power and both left and right hand EMG at time 0, meaning that activation of muscles show non-pathological

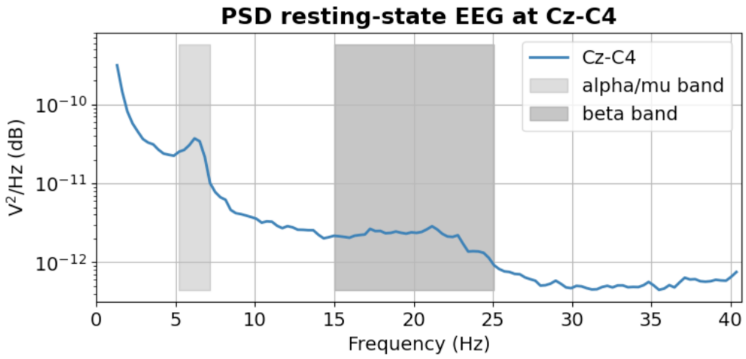


Figure 2.8.: PSD at resting state
([50])

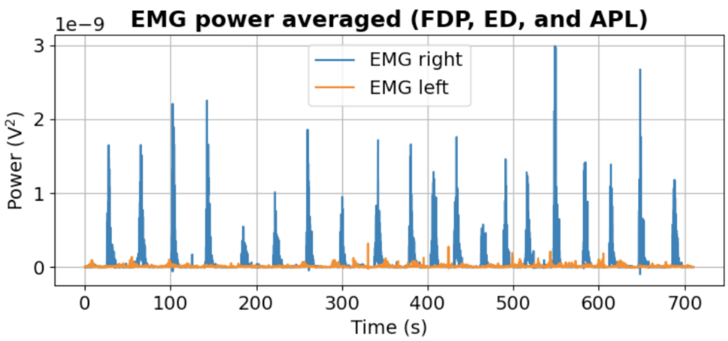


Figure 2.9.: EMG power
([50])

event-related desynchronization (ERD). Unusual behavior is also reported on the right hand, desynchronization appears 2.5 seconds before the muscles are activated, while for the left hand the same thing happens only 5 seconds before. Being very slow compared to the healthy people, the mu rhythm desynchronization show a quick reaction to instruction for our patient, the activation of the motor system to contract muscles taking more time than usual. Possible arguments for this situation is one of his medical conditions that is impacting the basal ganglia section 3.2 or the Botox treatment on the left hand.

Trial-level analysis is defined by the left and right goal split. Six trials of run P1 have been successfully completed by our participant, consisting of scoring goals for three times in the right and the same amount in the left. Right-goal trials include observations regarding the negative correlation between EEG mu power and right hand EMG power but no correlation between mu power and left-hand EMG. These suggest that only the right hand has been intentionally used to move the ball to the right goal, exactly the behavior that was expected. Left-goal-trials showed negative correlation between EEG mu band power and both left-hand and right-hand EMG. An observation about this idea is that both hands have been used to move the ball to the left, situation that has been observed also during the recording sessions.

The recording sessions have been successfully finalized by our participant, by using the EMG and the bulb, being continued with the third session in which he understood the verbal instructions, which also could be considered successful. Based on the results showed, there are some indicators that lead to getting to the conclusion that the ball has not been randomly moved: upper and lower thresholds have been used in order to record precise muscle activity which created the ball movement, the successful completion of the trials in run P1 and the responsiveness at verbal instructions and the different behaviors in hand movement demonstrated above.

2.4. Part II

Part I has demonstrated that our participant is able to control a football game, following perfectly the instructions, being able to answer yes-no question by moving the ball to the left or right. The results and the abilities observed in our patient have demonstrated that the system created is efficient. This way, refinements have been considered and improvements have been added to the project and the system has been upgraded, the whole process being explained precisely in this second part.

2.4.1. Overview on software and hardware

The figure 2.10 shows the flow between the hardware and the software of the presented system. Each part has an extremely important contribution to the whole system, making it a better configured product by providing a more stable state.

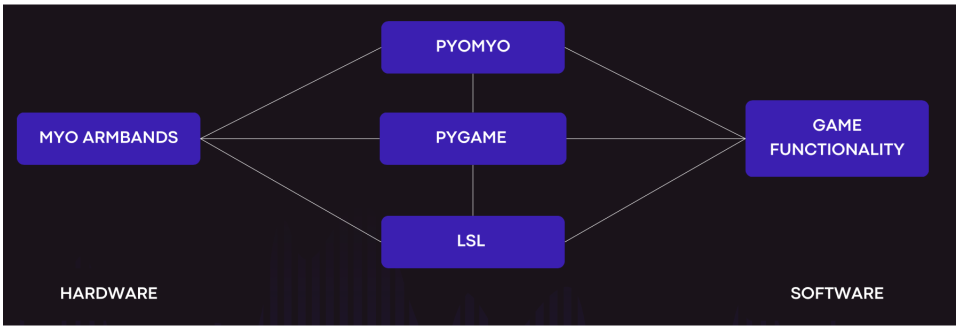


Figure 2.10.: System Hardware-Software Flow
Created on https://www.canva.com

Pygame - transition from Psychopy

Pygame, a robust library that it is mainly used for developing 2D games and multimedia applications, has been used in the second part of the project. Compared to the Psychopy, the Pygame related to more raw code and versatility in application customization, which of course it can be considered as both advantage and disadvantage, as it increases the time of setting up the game, the experiment and testing it. The Pygame library is built on SDL (Simple DirectMedia Layer), which encourages the efficiency of easy access to graphics, sound and user inputs.

The benefit of being a cross-platform means that it can work on multiple software systems: Windows, macOS, Linux, which makes possible the usage of the application on different devices and its improvements over time, specifically for each software. Blitting, transformations and image scaling are a great benefit of handling graphics, providing also the possibility to add audio and sound effects and similarly to Psychopy, it handles inputs from keyboard, mouse and joystick. It provides a large amount of information and documentation, making it feasible to have support in unexpected situations. (48)

Myo armbands and their usefulness

As Myo has been already defined in the section 2.1.1, it can be reminded why these devices have been chosen to be used in this project. They offer a great way of processing data derived from muscle contractions, and also giving more insights regarding the muscle contraction. Myo armbands are compatible with Windows, macOS, iOS and Android, representing a suitable choice with Pygame.

The core of the Myo armband are electromyography (EMG) sensors that are making contact only with the inner surface of the participant's skin, situation convenable for him and also for the process of the whole experiment. The armband has an impressive ability to interpret various hand and arm movements, where the Inertial Measurement Unit (IMU) sensors bring a positive note to the possibility of capturing data related to orientation and movement of the participant's arm.

The microcontroller of the Myo processes the data sent by EMG and IMU sensors, by interpreting muscle activity and arm movements in real-time, besides this, the wireless communication Bluetooth-based module integrated in the Myo establishes the connection with external devices such as computers, as it is in this project's case.(42)

LSL Library

Lab Streaming Library (LSL) represents a pivotal communication protocol utilized for real-time recording of time-series data and behavioral data, being recognized as a great tool in Neuroscience, Brain Computer Interface applications, psychology and biomedical engineering. LSL presents important features that help this project with streaming real-time data, being compatible with multi-platforms, such as Windows, macOS and Linux, being suitable with both Pygame and the Myo armbands. Moreover, it is an open-source library, which contributes to easy access and great support from the community. (31)

The functionality, applicability, and advantages that add up to the reasoning of using this library are shown in the present and upcoming chapters. LSL represents a significant communication protocol that has been created especially for time-series data arrays transmission, highlighting how EEG, electrocardiography (ECG), motion capture systems can be accompanied along the experiment. LSL is well defined in combination with multiple programming languages, including the known Python and C++, representing a well defined tool to be used for data reception and analysis.

LSL ensures synchronization and collection of data, providing also timestamping mechanisms, which facilitates the coherent analysis and interpretation of research findings. Moreover, the documentation is well updated and represents an assisting tool that ensures support for all the users. All in all, LSL defines itself as a really dynamic and versatile protocol, merging multiple domains that have great potential of growth.

MioConnect

MioConnect repository is the main tool that was used in order to ensure the connection between the Myo Armbands and the system, which is done via Bluetooth, more specifically, through OSC protocol. It uses raw EMG data, which, as it will be discussed later, this will be used and process accordingly. This Github repository serves as a significant framework that provides a complex code that is based on the Bluegiga BLE Bluetooth library, and ensures a good connection among multiple Myo Armbands. It has a very intuitive code, including a configuration, data handler and myo connection files, that ensures a stable connection and secure disconnection, while being able to observe the EMG and IMU data that is sent by the Myo Armband. (25)

GitHub

A great tool for providing the most updated code that has been used is GitHub. Due to the fact that code has been written on both a personal laptop and the computer that the Laboratory from University of Vienna provides, pushing the code and knowing from which host has been written has been greatly important for the correct development of it. As background, it can be reminded that the first part of the project section 2.2 has been a system that used solely the keyboard, i.e. the software, and it has been used afterwards with the Bittium NeurOne Tesla EEG, i.e. the hardware, only a small part of the code being used for part 2 (some orientations for UI and UX). The code in Part 2 is from the scratch planned to have both software and hardware combined, as there was no other possibility like in Part 1, to separate the development of the software and adding the hardware. The collaborative side of Gihub, along with the code sharing feature and the version control, have been represented the base of a solid base for a code that provides longevity and sustainability. GitHub has been buid on top of Git, which mainly represents a version control system, helping developers all over world to host and manage code repositories, contribute in projects, open discussions about the code and even issues about possible improvements. Besides the mentioned benefits, pull requests are a part of Git that show versatility, due to the fact that the code for the system has also been cloned on some of our colleagues in the team, in order to contribute with research about the Myo. The cloning, pulling and pushing are typical actions that a developer will do with Git, which will keep an integrated code that will always have older versions as back-up. As it represents a code for a research study, the README.md file is shown on the start page of the git repository, where it is explained what the code includes and also information about the start of the project, along with requirements for libraries and their version. GitHub has not been used only for storing and managing the code for the system described here, but also it has been used as a research tool for support in discovering open source for the connection of Myo armbands and softwares. As the documentaiton of the armbands is not enough, the GitHub represented a great base point for a stable connection with the software. ([24])

PyoMyo Library

The PyoMyo library is an open-source support for connecting the Myo armband and a software, found on GitHub with the help of the research team. The surface electromyogrphy (sEMG) readings are printed at a frequency of 200Hz directlz form the Myo's analog-to-digital converter (ADC) in the raw EMG mode. The EMG sends signals that are between -128 and 127, representing the most raw data that the Myo can send. This means that the data needs to be further processed for the regulation of the range and the possible analysis or features in the application. Moreover, Serial commands which are sent by Bluetooth for the communication with the Myo device are recorded in a file for support and assistance. The repository includes examples of how to connect the armbands to the software, documentation and even information about how the data is sent to the Myo armbands, included in the following section. For example, the plot_emgs_mat.py script is a great way to test the Myo armbands with the Python script, as it plots data for each of the channel that the Myo provides. Another interactive and more complex example is dino_jump.py, which also provides example of how the pyomyo uses a classifier that can be used in real time. This example relates to how keypresses generation lead to playing games, by labeling pressed data from 0 to 9. An important example that has been representing an inspiration for the current system is the multithread code example, which can print the EMG signals. **Common Issues** are as well listed in this repository documentation, emphasising how the Git bash terminal is not permitting to open serial ports and providing some possible solutions that can be considered as support.(44)

Bio Signals

The surface electromyogrphy (sEMG) readings are printed at a frequency of 200Hz directly form the Myo's analog-to-digital converter (ADC) in the raw EMG mode. The EMG sends signals that are between -128 and 127, representing the most raw data that the Myo can send. Also, the data can be either filtered and then sent or streamed directly. The football application uses raw data, thus also meaning that the data had to be further processed for the regulation of the range and the possible analysis or features in the application.

Serial commands which are sent by Bluetooth for the communication with the Myo device are recorded in a file for support and assistance. The data can be streamed over Bluetooth Low Energy (BLE) at 50HZ, as sending BLE data The Bluegiga BLE dongle uses a virtual COM port for support that makes it easier to be used, as the opposite, using a BLE library, would make accessing the BLE cross platform much more difficult. (44)

2.4.2. Game content architecture and system design

The following figure represents the football game flow, including all the possible directions that the user could do while using the system. This section includes an overview of the flow of the game, while more information will be described in a later section. Moreover, the game has been created in german, thus most of the pictures and also the flow include the german option, together with the english translation.

Connection start menu includes the intro page and the connection of the Myo armbands, the system giving instant feedback on the order of connections to them. By clicking on "Spiel" (translation in english Play/Game), the **Main menu** appears which is intuitively including three types of games, "Spiel" (Game), "Trainieren" (Training), "Ja/Nein" (Yes/No), where the first game mode (presented in the flow as Game Mode or GM), **Spiel** shows the ball in the middle of the screen and both of the gates at the biggest distance, where randomly an audio, synchronized with an arrow on the screen, will mention where the ball needs to be scored. A successful move will lead to the **Congratulations page**, which will get back in a couple of seconds to the game. The possibility of clicking on "Zurueck" (Back) assures that the user can go anytime to the main menu.

The second mode, **Trainieren**, includes six types of training, either to the left or right gate, each with three types of distance, "small", "medium" and "far". Scoring the ball in the gate will again show the Congratulations page, being directed back to the Trainieren Menu. The third mode, **Ja/Nein** shows the ball and both of the gates, placed at "far" distance. Being asked a question, the user can move the ball to either left or right, which each will represent either yes or no. To overcome the possibility of learning where yes and no are placed, each goal will reset randomly the attribution of the responses to the gates.

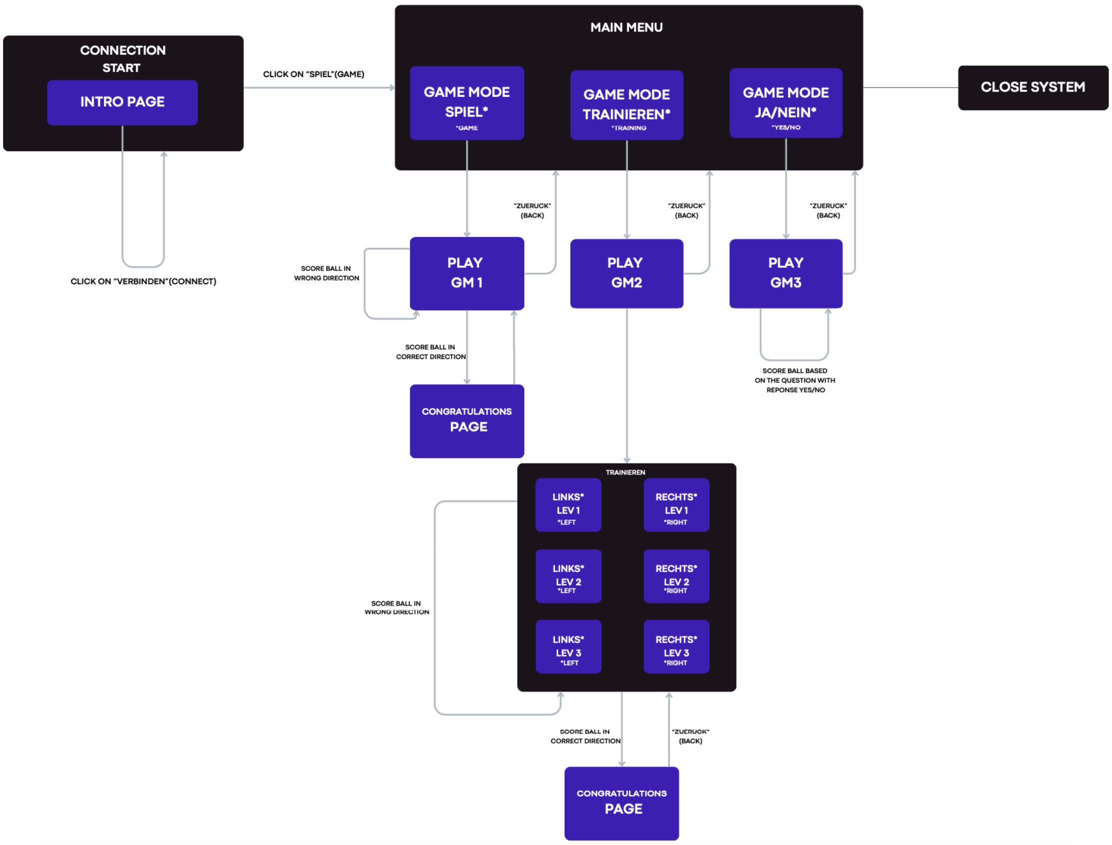


Figure 2.11.: Football Game Flow
Created on https://www.canva.com

2.4.3. Game-based pediatric rehabilitation

This small section includes information regarding the satisfaction, motivation and engagement. The clear incorporation of achievable goals within game-based rehab can significantly boost the motivation among children. Specific studies show that the engagement in tasks with defined objects, in our situation scoring a ball, help with experiencing a sense of accomplishment that would reinforce their commitment to the therapy. ([5]). Other studies include the highlighting of how gamified elements boost engagement in social interaction, motivation, offering a more interesting way of therapy than the traditional therapy, in an important review that analyzes 19 studies on serious games for children with cerebral palsy (CP). ([57])

In an article published in "Computers in Human Behavior", it is presented the impact on participants who experienced the success in game, reporting a significant change in mood, situation that suggests how winning represents an effective enhancing mechanism. Besides this, the study showed how the increased enjoyment and positive emotional outcomes are a direct result of the successful fulfilling psychological needs, such as competence and autonomy. Nevertheless, these findings represent important observations due to the implications that come as a consequence for rehabilitation: especially for children, experiencing success and psychological needs satisfaction in therapeutic games enhance motivation and engagement, which are extremely critical factors in effective rehabilitation. ([52])

2.4.4. System architecture

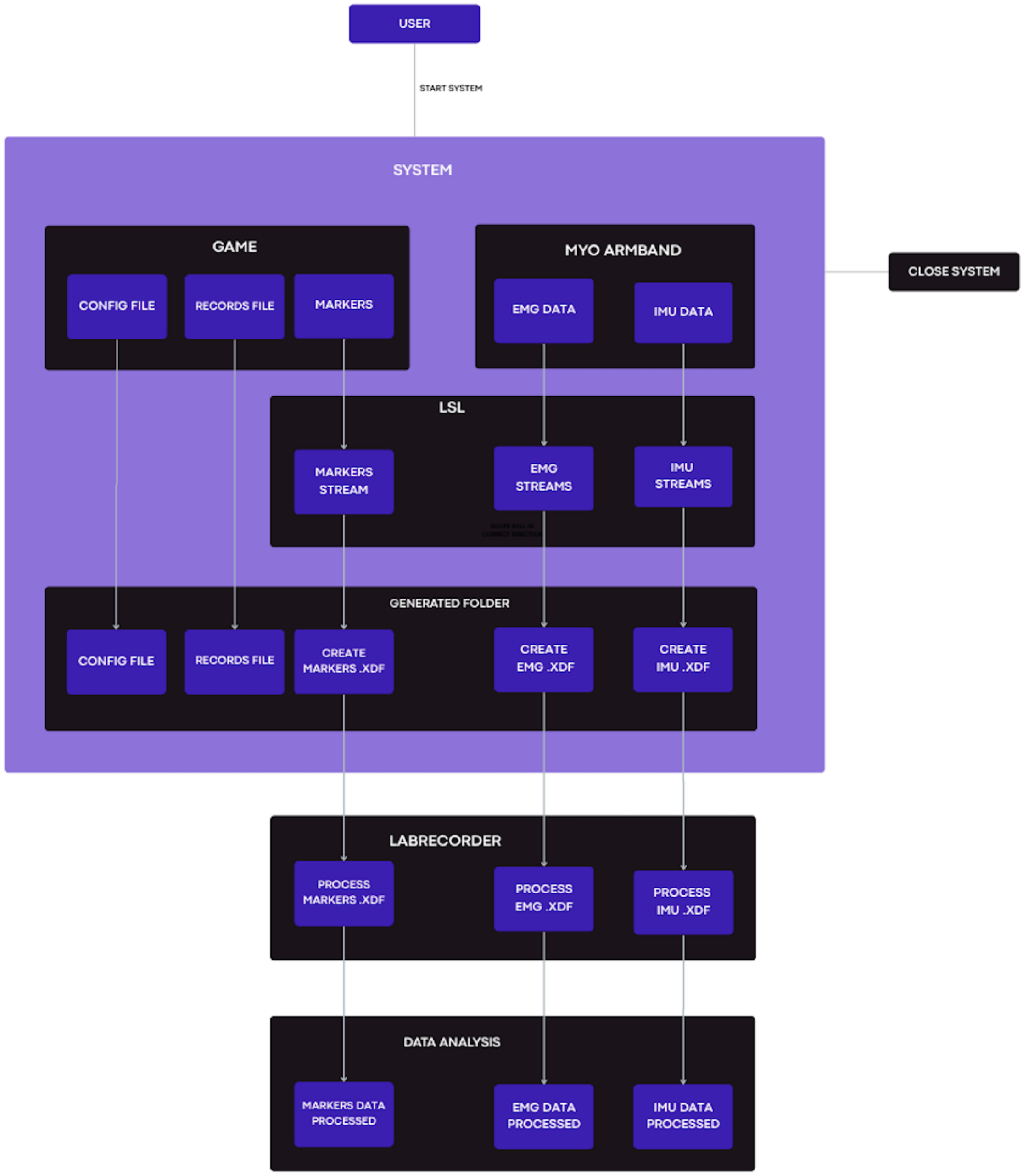


Figure 2.12.: System Flow
Created on https://www.canva.com

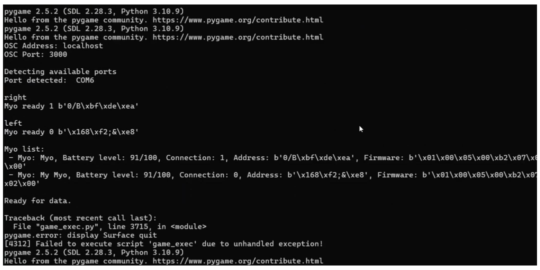
This subsection briefly describes the flow that can be found in the system, where the figure can be followed along for an easier interpretation of the flow, through a descriptive diagram. The figure includes the start of the system, where the user will access the game while using the Myo armbands. While starting one of the types provided by the game, the configuration file which includes the thresholds and the maximums, also the recording file which keeps the marker values and their time, will be created. Moreover, the start provides an input stream of markers, while Myo armbands will include EMG and IMU data, all three factors being afterwards situated in LSL streams, which handle real-time signal transmission. The ending of the game will generate .xdf files for each of the mentioned streams. These files will be found in a folder specific for that game day, also containing the configuration and recording files mentioned at the start of the game, which are closed as well when the game ends. The .xdf files are actually created with the help of LabRecorderCLI, but the system does not serve as a vizualisation tool, thus the standalone LabRecorder application can be used also to observe the new data incoming. Finally, Python, MATLAB, EEGLAB or others can be used as data analysis tools, which can process offline the .xdf files.

2.4.5. Software-based data retrieval

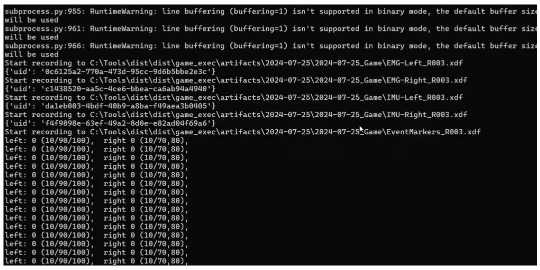
While the user interface represents an important part of the whole rehab process, as it ensures a more dynamic tool than the traditional rehab, a great role is also achieved by retrieving the data sent from the Myos that was presented in the description of the system architecture diagram. It is used in such way that not only the joy of the user is accomplished, but also analysis on their capacities and if the serious games rehab is having scientific results or not. This means that sending and retrieving data has been observed, tested and annalysed many times before the system becoming complete. The first picture 2.13a shows information about the start of the application, including all the moments of Myo connectivity (right and left connected, in this order), together with information about the battery, which connection port and address and also the firmware. Retrieving "Ready for data" means that the Myos are ready to send data and the connection is established.

The second picture, 2.13b shows how the recording started creating specific files that are described in the next section, also showing multiple similar lines with "left" and "right", with 0 (10/90/100). The 0 represents the pressure from Myo, the 10 represents the lower threshold, 90 is the upper threshold and 100 is the sum of the two, representing the maximum shown on the UI. An important reminder is that these are the default values, that can be changed during the game. Referring 2.13c, all these measures are constantly printed in terminal for ensuring live connectivity between Myo armbands and the application, to observe any blockage or any malfunction in the system. The next picture, 2.13d shows already some movement in the right hand, with some observations on the left hand that show small values, this meaning that the left hand might contract with low pressure while moving the right ball.

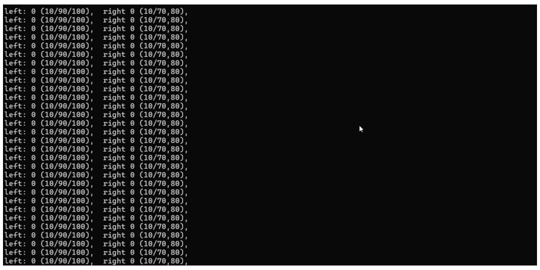
(a) Pic.1



(b) Pic.2



(c) Pic.3



(d) Pic.4

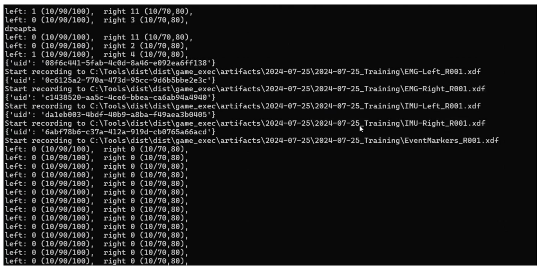


Figure 2.13.: Data Retrieval observed in Terminal

2.4.6. Automated report generation during gameplay sessions

A mentioned in the previous subsection and observed in 2.14a, a directory is created with the game playing date. This will include information about the types of games are played, as well as recording of the data. The first image shows the directory "2024-07-25_Game", which identifies the fact that the Game mode has been started and the specific files, for EMG and IMU each, for each hand will be generated and can be used afterwards for analysis and observation. Moreover, a file named Event Markers includes all the moments when the game starts and stops, ball is moved to right or left. This helps to keep up with the movements and their timestamps, representing important triggers processed in the game time.

An important information is that there is another file which is a report file, with the same information, but the difference is the file extension. The picture 2.14b shows an example of movement and timestamp. The Event Markers with the xdf extension help with recording biosignals, especially in BCI environment. This type of file stores time-series data, in our case including EMG and IMU signals, at high frequencies. These files have been created with LSL and can be loaded to LabRecorder which ensures a proper visualization of the data. ([13])

The next set of picture represents another example of how the Game mode is finalized and Training, is started; similarly to the Game mode, a new folder is created, each with the creation and the overwriting of the five new files specifically to the right and left hand, EMG and IMU and general Event Markers.

(a) Pic.1 (b) Pic.2

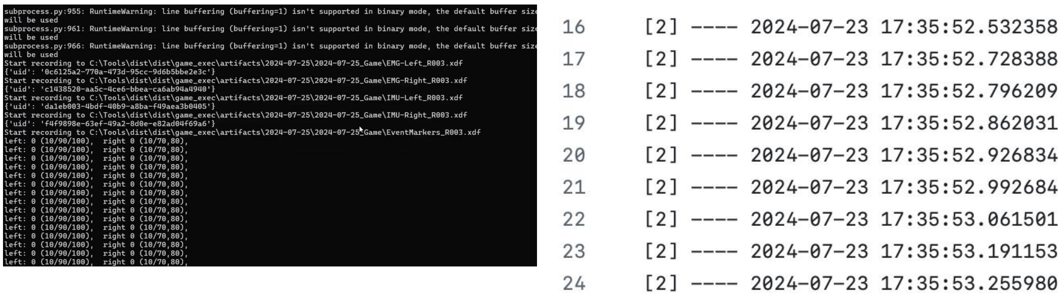


Figure 2.14.: Report generation

2.4.7. Algorithms-Code

In this subsection the focus will be on some code parts that have an important impact on the process of arriving to the final product that is described here.

Retrieving EMG Data Delays in the movement of the ball appeared in the beginning, thus addressing the issue consisted in implementing a strategy of involving utilization of two ques for data transmission. The approach seemed that it would work, the only issue consisted in accessing the elements in each queue because the data was being sent in a very rapid time. Researching where the issue might be, the solution conducted to including both data transmission in a single queue, that later on to be correctly accessed and processed accordingly to the resource armband. A dictionary is used where the connection number points to the Myo, behaving as the key, while the value consisting of the values that are received on the stream. This ensured clean and rapid access to the data stream, while refining data management strategy. Important note: before creating the dictionary, critical information sent by OSC protocol had to be normalized.

```
data_new = []
builder = udp_client.OscMessageBuilder("/myo/emg")
builder.add_arg(str(conn), 's')
for i in struct.unpack('<8b ', data):
    builder.add_arg(i / 127, 'f')  # Normalize
    data_new.append(i)
if conn == 0:
    dict0 = {'emg': {str(conn): data_new}}
    self.myo_imu_data.put(dict0)
if conn == 1:
    dict1 = {'emg': {str(conn): data_new}}
    self.myo_imu_data.put(dict1)
```

Listing 2.1: gameexec.py

```
while not (myo_driver.data_handler.myo_imu_data.empty()):
```

```
data_both_samples = myo_driver.data_handler.myo_imu_data.get()
emg1 = [], emg2 = [], imu1 = [], imu2 = []
if (data_both_samples.get('emg')):
    if (data_both_samples.get('emg').get("1")):
        emg2 = list(data_both_samples.get('emg').get("1"))
    if (data_both_samples.get('emg').get("0")):
        emg1 = list(data_both_samples.get('emg').get("0"))
#same approach for imu data
if emg1 != []:
    outlet_emg1.push_sample(emg1)
# same approach for emg2, imu1, imu2
```

Listing 2.2: gameexec.py

Getting the EMG data Arriving at the correct behavior of the code has been successfully done with help from the team, as accessing the EMG data needed a good understanding of how the Myo is even capturing the signals. The following snippet will show just the main steps, as the code is not exactly in the order that can be observed, it is organized this way for the sake of explanations. Extracting the force, the data and also the time, which represents actually the number of seconds needed to catch enough data so it can be processed and when the time is out, it is cleared out so more chunks of data can be pulled. This happens with the first 2000 elements (code snippet does not include this part), which will be pulled, transformed into positive numbers (as there will be negative numbers due to how the Myo is transmitting the data) and created an average for all 8 channels. Dicrete Time Fourier Transform (DTFT) technique is used to assess the data accuracy, showing that the data that Myo is sending is raw data and also providing the right EMG value in the end.

```
force_right, data_lsl_right, timeout2 = self.get_emg(lsl_inlet=inlet2,
    data_lsl=data_lsl_right, emg=emg2, win_len=win_len, timeout=timeout2)
# same approach for left
# in get_emg function:
avg = 0
for row in data_lsl:
    avg = 0
    for i in row:
        avg += abs(i)
    emg.append(avg / 8)
win_samp = win_len * fs
emg_chunk = 0
if len(emg) > win_samp:
    emg_win = emg[-win_samp:-1]
    emg_filt = lfilter(self.b, self.a, emg_win))
    emg_env = np.abs(scipy.signal.hilbert(emg_filt))
    chunk_size = 20
    emg_chunk = np.mean(np.power(emg_env[-chunk_size:-1], 2))
```

Listing 2.3: gameexec.py

Creating the streams and starting the game The following snippet relates to how the streams with the EMG, IMU and markers are manipulated. A custom function will start each stream, by accessing the according one based on the name, continuing with starting the Lab Recorder which is processing the streams and transform them in according .xdf files that can be analyzed later.

```
inlet1 = start_lsl_stream('EMG-Left')
inlet2 = start_lsl_stream('EMG-Right')
imu_inlet1 = start_lsl_stream('IMU-Left')
imu_inlet2 = start_lsl_stream('IMU-Right')
inlet_markers = start_lsl_stream('EventMarkers')

start_lab_recorder(self.source_directory, inlet1.info().name(), inlet1.
    info().uid(), self.process)
#same for each of the other streams
```

Listing 2.4: gameexec.py

2.4.8. IMU Data Collection

The IMU (Inertial Measurement Unit) combines the gyroscope, acceleromenter and orientation. The gyroscope measures the angular velocity along three axes, meaning that it checks how fast something rotates, by detecting rotational motion, in our case an example being how the wrist is turned, while the accelerometer records the acceleration in three axes, by capturing motion and orientation changes. The orientation, on the other hand, is derived from the accelerometer, gyroscopes and magnetometers, and providing three type of rotations: roll, pitch and yaw. The first represents a rotation around the front to back axis, the second around the sided to side axis and the last one around the vertical axis. All of these measures are also recorded in our study, as observed in 2.15 and also recorded in the specific report with IMU data. The code is an adaptation of the MioConnect code from handling data. Important research shows how the accelerometer and gyroscope are used in tracking symptoms for Parkinson's disease (43). Nevertheless, another study conducted by (51) shows how the chronic stroke survivors can use wearable technology to monitorize the safety in real time.

2.4.9. Internationalization

The software has been developed in such way that other languages beside german can be used, for the future practicality of the system. For the moment, the only language that can be used is english, being actually the default language. Each language has a specific file that includes all the words used on the UI of the game, exactly like in the picture, where a comparison between the files can be observed.

```python
def handle_imu(self, payload):
    Handle IMU data.
    :param payload: imu data in a single byte array.
    """
    if self.printImu:
        print("IMU", payload['connection'], payload['atthandle'], payload['value'])
    # Send orientation
    conn = payload['connection']
    data = payload['value'][0:8]
    builder = udp_client.OscMessageBuilder("/myo/orientation")
    builder.add_arg(str(payload['connection']), 's')
    roll, pitch, yaw = self._euler_angle(*(struct.unpack('hhhh', data)))
    # Normalize to [-1, 1]
    builder.add_arg(roll / math.pi, 'f')
    builder.add_arg(pitch / math.pi, 'f')
    builder.add_arg(yaw / math.pi, 'f')
    self.osc.send(builder.build())

    # Send accelerometer
    data = payload['value'][8:14]
    builder = udp_client.OscMessageBuilder("/myo/accel")
    builder.add_arg(str(payload['connection']), 's')
    accelerometer = self._vector_magnitude(*(struct.unpack('hhh', data)))
    builder.add_arg(accelerometer, 'f')
    self.osc.send(builder.build())

    # Send gyroscope
    data = payload['value'][14:20]
    builder = udp_client.OscMessageBuilder("/myo/gyro")
    builder.add_arg(str(payload['connection']), 's')
    gyro = self._vector_magnitude(*(struct.unpack('hhh', data)))
    builder.add_arg(gyro, 'f')
    self.osc.send(builder.build())

    new_dict = {'imu': {str(conn): [ roll / math.pi, pitch / math.pi,  yaw/math.pi, accelerometer,  gyro ]} }
    #print(new_dict)
    self.myo_imu_data.put(new_dict)
```

Figure 2.15.: Code for IMU data collection
Part of the code is used from ([25])

translate_de.ini — game-all-scripts-app > translate_de.ini

```ini
[Translate]
thlu = OGL
thru = OGR
thll = UGL
thrl = UGR
start.game = Spiel
game = Spiel
game.mode = Spielmodus
train = Trainieren
training = Training
yes = Ja
no = Nein
training.mode = Trainingsmodus
yes.no = Ja/Nein
yes.no.mode = Ja/Nein Modus
back = Zurueck
congrats = Glueckwunsch
left.level.1 = Links Level 1
left.level.2 = Links Level 2
left.level.3 = Links Level 3
right.level.1 = Rechts Level 1
right.level.2 = Rechts Level 2
right.level.3 = Rechts Level 3
bad.goals = Falsche Tore
```

translate.ini — game-all-scripts-app > translate.ini

```ini
[Translate]
thlu = Th LU:
thru = Th RU:
thll = Th LL
thrl = Th Rl
start.game = Start Game
game = Game
game.mode = Game Mode
train = Train
training = Training
training.mode = Training Mode
yes = yes
no = no
yes.no = Yes/No
yes.no.mode = Yes/No Mode
back = Back
congrats = Congrats!
left.level.1 = Left: Level 1
left.level.2 = Left: Level 2
left.level.3 = Left: Level 3
right.level.1 = Right: Level 1
right.level.2 = Right: Level 2
right.level.3 = Right: Level 3
bad.goals = Bad Goals
```

Figure 2.16.: German and English language generating files

2.4.10. Creating executable file

PyInstaller is a known open-source tool that converts any Python application into stand-alone executable, for Windows transforming it in .exe file, for macOS .app and binaries for Linux. This alternative makes it easier for the users to be in direct contact with the game itself, without being obliged to install PyCharm (IDE for Python) or any other dependencies.

PyInstaller comes a great tool in bundling all dependencies, creating either a one-file or one-folder executables, being able to handle perfectly the hidden imports and also the complex packages. Customization can be archived through the spec files that are generated after the first step of compiling the executable files.

There are advantages and drawbacks that need to be mentioned. PyInstaller is reliable for GUI and CLI applications, working really well for internal distribution, while avoiding dependencies or version issues and trully be used in academic and commercial software deployments. Nevertheless, the executable files can occupy a large amount of memory, especially the one-file situations and cross/platform build are not native. It might struggle with complex dynamic imports and a security issue is highlighted by the ease of decompilation of the bundled bytecode if it is not obfuscated. (49)

A correct and clear software development has been assured, in some limits, by using the Pyinstaller. It is widely used in academic studies, where reproducibility and dependency management are important factor, in domains like bioinformatics and AI. Security issues have been studied (32).

Constrains

The creation of the executable implied a significant amount of work in research and improvements done along the way. This has been representing an important step of transforming the system into a real product, easy to use and clear to comprehend. One of the limits that PyInstaller had is the creation of an executable based on multiple files. The code has been split into more files, to ensure ease of processing, but using the PyInstaller has failed the creation of an executable. This way, a decision has been made to move the code from all the files in the same file, being a one-file script that serves as the whole application, which is used afterwards to create the executable.

3. System Deployment / Experimental Results

3.1. Team acknowledgement

The privilege to work in the Neuroinformatics team, the importance that all the team provided for the study and the ambition to innovate a communication way, all lead to the presented system which has been supervised and tested thoroughly.

3.2. Participant

The study has been following the usage of the system for the only participant, who is a male of a seven years old. He suffered from a severe hypoxic-ischemic encephalopathy, aiming mosly the basal ganglia, dysphagia, dysarthrophonia, and a severe bilateral spastic and dystonic cerebral movement disorder. ([50]) The suffering comes from a drowning incident, damaging the middle part of the brain, which constituted the cause of limited functionality in his body, precisely only in his legs and hands. ([41])

3.2.1. Medical conditions

Hypoxic-Ischemic Encephalopathy (HIE) with Basal Ganglia Involvement represents a type of brain injury resulted from insufficient oxygen and blood flow to the brain. Basal ganglia are critical for motor control, thus vulnerable to hypoxic-ischemic damage due to the high metabolic demands. Important findings have been reported by ([28]), where there were documented three cases of hypoxic-ischemic events with affected the basal ganglia, having a big consequence on movement disorders, emphasizing the basal ganglia's sensitivity to hypoxia and its own role in diverse motor outcomes.

Dysphagia in HIE with Basal Ganglia Damage has been investigated in a study which reveals that the lesions in the basal ganglia are associated with swallowing difficulties for stroke patients. ([22])

Dysarthrophonia Associated with Basal Ganglia has been explored for over twenty years now and resulted in how the basal ganglia is correlated to speech motor control, emphasizing the consequences to dysathria, a speech disorder.([59]) Dysfunction from basal ganglia could lead to alterations of dopamines D1 and D2, observed in a research by ([58]), affecting also the motor control.

Dystonic Cerebral Movement Disorders has been investigated in western Sweden, especially the Dystonic CP which has been found to be primarily assosicated with basal ganglia damage, often resulting from hypoxic-ischemic events. Moreover, the children with basal ganglia lesions showed severe motor impairments, including speech disorders (dysarthia) ([29]). Observing the impact of magnetic resonance imaging (MRI) in identifying and understanding the perinatal brain injuries, lesions in the basal ganglia and thalamus have been connected as possible injuries that can be shown immediately after birth ([56]).

3.3. BCI-EMG activity

Many researches have as main tool BCI, EMG or even both. The question remains how can BCI help in medical situations and how it can be combined with EMG for attempting to revolutionize the bond between medicine and technology.

Motor impairments in children with hemiparesis caused by perinatal strokes has been put under investigation together with the assumption that the traditional therapies are not able to fully restore motor function, innovating the type of therapy with BCI-controlled electrical simulation. A BCI system has been used to detect motor imagery-related EEG patterns, integrating it with electrical simulation, in order to trigger muscle stimulation. The results are showing that there is robust improvement in motor function in the affected limbs, as well as the motor cortex present increased brain activity, while children demonstrated that they could learn perfectly how to control the BCI system, proving its feasibility. An extended period for tests would be necessary to further observe improvements. ([30])

Neural activity and its correlation to cerebral palsy (CP) has been researched in 2014, investigating EEG patterns in development for better BCI rehabilitation tools. The study assesed mostly the difference between healthy participants and CP patients during motor tasks which were analysed with the help of EEG and event-related desynchronization (ERD). The main findings were reported in significant less ERD and phase synchrony in CP patients, which represents that their motor cortex has been less activated during the movement attempts. CP patients presented lower BCI performance, while worse motor impairments correlated to weaker EEG signals. The study shows the challenges of designing effective BCIs for CP patients due to weaker neural signals, also providing important information of the difference between CP patients and healthy people. ([16])

Motor control deficits were studied in children with primary dystonia, the study focusing as well on how biofeedback therapy is a potential way to overcome them. Real-time feedback has been provided to ensure visual and haptic reactions during the movement tasks, helping the children adjust their movements. The study helped into improving the muscle control for children with dystonia, who show better execution of the tasks, coordination and also reduced involuntary movements. ([9])

3.4. Game design interface

This section includes exclusively discussion about the user interface that can be experienced in the system, altogether with the differences that are to be observed and compared to the Part I interface.

Start The system starts with the first picture of figure 3.1, where two pictures of Myos are positioned at the left and the right, with the word "Verbinden" in the middle. This means "Connect" in german and by clicking it, the word "Starte..." (in english "starting") will appear, which will represent a feedback to the user that the they need to wait, as the connection with the Myos started. Each Myo has a name, either A or B. Depending on which Myo connect first, the app shows this immediately on the screen, mentioning which will be considered the left one and which the right one. Thus after both connections being established, the new button "Spiel", in english "Game/Play", pops up on the screen and the user is ready to start the game.

(a) Pic.1

(b) Pic.2

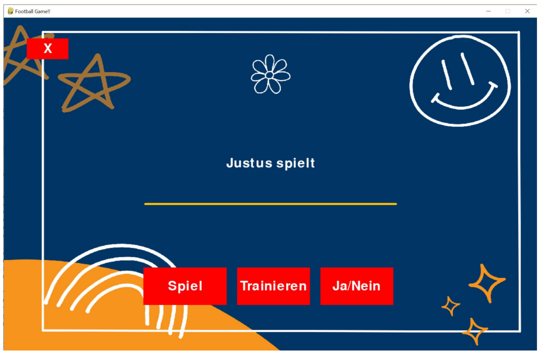
(c) Pic.3

Figure 3.1.: Intro
Symbols seen in the screenshot
https://in.pinterest.com/pin/349169777372622693/,(60)

Main Menu The menu includes only three buttons that also show the three modes of the game, "Spiel", "Trainieren" ("training" in english) and "Ja/Nein" ("Yes/No" in english).3.2a The interface is similar to the one described in Part 1. Similar to the "Connect" button on the intro page, by pressing any of the buttons, the same "Starte..."

will appear, as it takes a couple of seconds for the real game to start.3.2b Also, whenever needed, the game can be stopped by clicking on the "X" button, which will completely shut down the UI and the Myo armbands.

(a) Pic.1



(b) Pic.2

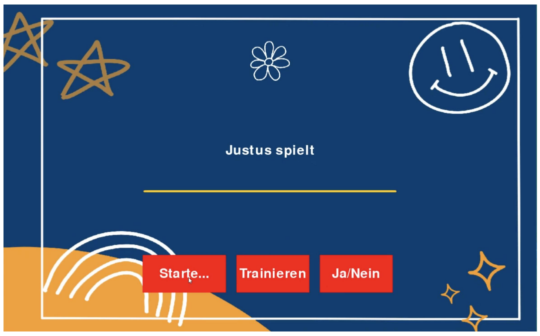


Figure 3.2.: Main Menu
Symbols seen in the screenshot https://www.canva.com

Game Mode The first mode will show the ball at a "far" distance positioned compared to the gates, and hearing an audio that suggests to which direction, left or right, the ball should be moved. The audio is correlated with the arrow on the screen 3.3a, in this case the ball should be moved to the right direction. Under the arrow it can be observed "Falshe Tore" and "Richtige Tore", which mean "Wrong score" and "Right score", this being kept in the center of the game for the whole time of the game. This counts the number of right and wrong goals, in respect of the audio and arrow. The user is able to see also four new fields, each named "OGL","OGR","UGL","UGR", translated in english directly from the abbrevations: upper threshold left, upper threshold right, lower threshold left, lower threshold left. All these thresholds can be changed live by the caretaker of the user which helps in lowering or raising the thresholds. 3.3b There are default values for the thresholds. The image shows a red colour for the bar underneath the left thresholds, which reflects that the pressure that was used on the Myos to move the ball to the right is bigger than the upper threshold, i.e., 70. This way, it is obvious that the goal of the bars in the left and in the right are to give instant feedback regarding the pressure that the user needs to control so they are able to control the ball. Moreover, the threshold values are taken from the upper input and used on the threshold, showing the sum of the threshold on respective side as the biggest value possible on the threshold (70 for upper threshold right and 10 for lower threshold right would determine 80 as being the biggest value written for the threshold bar; of course, what is passing 80 would not move the ball).

The next picture, 3.3c, shows a proper movement of the ball to the right gate, as the pressure recorded by Myo is represented with green, showing it on the threshold bar. In the same idea, the 3.3d will show how the pressure is represented with red when is under the lower threshold, situation that makes the ball stop. When achieving to the gate and scoring a goal, a page with "Glueckwunch" ("Congratulations" in english) will appear, accompanied by a happy sound. 3.4a

In 3.4b it can be observed that the number of the "right scores" increased with 1 and also the fact that the arrow changed to the left. By moving the ball to the right and not following the instructions, the situation is observed in 3.4c, as a new value, 1, is assigned also for "wrong scores". Each and every time a score is achieved, either wrong or right, the game continues and will show the arrow in a random direction. Nevertheless, the button "Zurueck" ("Back" in english) lets the user go back to the main menu and choose another mode.

This mode is represented by a fun and ludic way to use the system, being able to follow instructions and challenge the upper limbs in such way that the ball can be scored and get feedback regarding the correct and incorrect movements.

(a) Pic.1

(b) Pic.2

(c) Pic.3

(d) Pic.4

Symbols seen in the screenshots https://www.canva.com,https://in.pinterest.com/pin/349169777372622693/,https://es.pinterest.com/pin/657947826843666293/,https://www.pngaaa.com/detail/500450, https://www.freeiconspng.com/img/36981

(a) Pic.5

(b) Pic.6

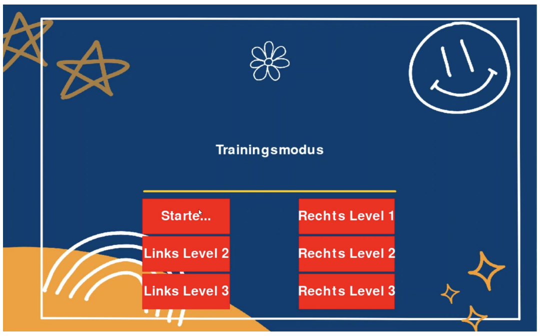
(c) Pic.7

Figure 3.4.: Spiel Mode
Symbols seen in the screenshots https://www.canva.com,https://in.pinterest.com/pin/349169777372622693/,https://es.pinterest.com/pin/657947826843666293/,https://www.pngaaa.com/detail/500450, https://www.freeiconspng.com/img/36981

Training Mode The next mode presented on the main menu is a mode that includes six different levels, three levels for the right hand and three levels for the left one, the image showing the german words "links" and "rechts" for the english equivalent "left" and "right". 3.5a 3.5b As mentioned in the previous chapter, first level shows a small distance, situation that can be observed in the first level of the left side 3.5c. The same requirements are required for the ball to be moved, as it can be observed in 3.5c 3.5d. The right threshold bar and inputs are not available anymore, so the user is not mislead and knows they are able to move the ball only to the left side. The second level on right hand is shown in 3.5e, observing how the same situation happens for the disappearance of the left threshold. The difference between the first mode and the second mode is defined by the possibility of choosing a side of the upper limbs that can be trained more, depending on the context the user finds themselves in. This mode provides more limb focused rehab, the possibility of choosing between the levels giving a great environment for improving and challenging the user into putting enough more effort for each of the levels.

(a) Pic.1

(b) Pic.2



(c) Pic.3

(d) Pic.4

(e) Pic.5

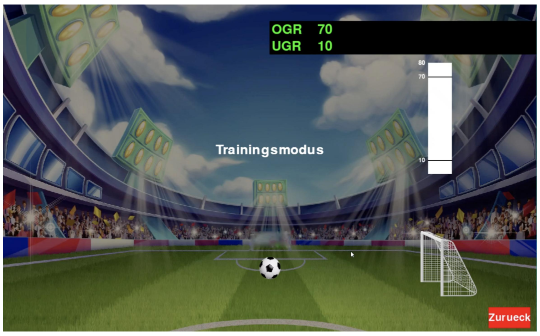


Figure 3.5.: Training Mode
Symbols seen in the screenshots https://www.canva.com,https://in.pinterest.com/pin/349169777372622693/,https://es.pinterest.com/pin/6579478268436662293/,https://www.pngaaa.com/detail/500450

Yes/No Mode This mode has been created to serve as a communication tool between the caretakers and the user, while being asked a question that would have a response as "yes" or "no". This mode gives the user the possibility to interact easily and effectively with the caretakers, while including also specific emoji faces for understanding to which side the ball needs to be directed to. 3.6a After scoring, the game continues with this mode, but this time the "yes" and "no" responses are randomly assigned to the sided, as it can be observed in the next picture 3.6b.

(a) Pic.1 (b) Pic.2

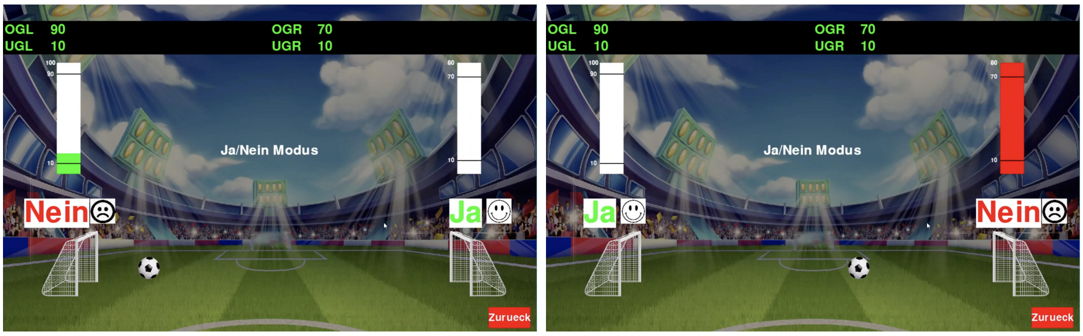


Figure 3.6.: Yes/No Menu
Symbols seen in the screenshots
https://in.pinterest.com/pin/349169777372622693/,https://es.pinterest.com/pin/657947826843666293/,https://www.pngaaa.com/detail/500450, https://www.pinterest.com/pin/355362845527689991/,https://www.onlinewebfonts.com/icon/424001

3.5. Demonstrations and preliminary testing

Testing has been represented a very important part of the whole process, for each and every small-considered step either in the software, in the connection with the armbands or even in the organizational discussions. This way, a series of demonstrations and testings have been conducted in order to validate the whole functionality that the system created around the Myo armbands and the football game provide. These tests have gained slowly a more important role in the whole process as the Myo armbands have shown multiple times that are not always stable, situation that made testing a more critical process in the whole development process.

3.5.1. Milestone 1: Signal recording

The first tests highlighted successfully how Myo armband could consistently capture the EMG and IMU data. This stage has represented an important step, as creating a stable connection is discussed in a later section where obstacles have been detailed there. Gesture-based control outside of the game environment are observed at the success of this milestone, ensuring better clarity and the right satisfaction.

3.5.2. Milestone 2: Game integration

The second phase focused on how the Myo armband is connected to the football game interface. As the Myo armband can send either raw signals or processed ones, this milestone has fulfilled the correct transition of Myo signals to the real-time interaction. The gestures captured could initiate now simple actions, such as moving the ball to the left or right. Of course, the basic functionality has been met, creating a great environment for improving the speed, the accuracy of live movement and the smoothness of the motion.

3.5.3. Milestone 3: Full gesture-action mapping

This stage represented a big breakthrough for managing the whole recognition movement, as the smoothness of the ball movement has been improved and represented a motivation of realizing a better product. In a later subsection, more information and code are shown, details that improved the responsiveness of the interface, showing progressively much better results in terms of gesture consistency and live system feedback.

3.5.4. Milestone 4: User experience testing

A milestone that has been always combined with the previous ones presented, the user experience has been thoroughly tested, constantly ensuring the right processing of data and the UI updates. The whole Neuroinformatics team has tested the game at a specific time so objective feedback can arise and further development to be improved. Noteworthy actions have been observed in increasing the motivation to use the system, including new features that appeared along the journey of experiencing.

3.6. Data recording and analysis

The electromyographic signals are recorded used for further analysis, as mentioned in the previous chapter. They Myo armbands process the raw EMG signals and IMU data in real time, which are saved in special files generated even from the beginning of the game. These files are special .xdf files, which are facilitating due to the efficient storage and the post-experiment analysis, being easily visualized using Python or MATLAB, as LabRecorder just processes them, and also other compatible tool, creating the perfect environment for signal quality inspection, synchronization and event markers. The proper setup relies on a solid foundation for both quantitative and qualitative review anytime in the study.

3.6.1. Algorithms-Code

In this subsection the focus will be on some code parts that have an important impact on the process of arriving to the final product that is described here.

Starting In this section, as it was shown in earlier pictures, after clicking the "Start button", the connection with the Myo Armbands is processing and whichever device connects first, information appears immediately on the screen. This process is done by combining more of the classes that are created, shown briefly below. The interesting variables are the "connected" variables and the ones regarding the names of the myos and their direciton, which are passing from the GUI code to the back part of the system, where these events are immediately recognized. The system waits for a couple of seconds for the correct connection to the armbands and then immediately created the new updated UI with the corresponding Myo Armband connected. A very important note represents the fact that adding the name of the myo and the direction has been done in a maintenance phase, where continuous stability of the connection has been improved. This has been done also with help from the team.

```
myo_connected1 = False
myo_connected2 = False
connected1 = Event()
connected2 = Event()
myo_A_left = Event()
myo_B_left = Event()
myo_A_right = Event()
myo_B_right = Event()

process_mio_connect = Process(target=mio_connect.main, args=('sys.argv[1:]',stop_event, connected1, connected2, \
                                  myo_A_left ,myo_B_left, myo_A_right, myo_B_right))
process_game = Process(target=main_game, args=(stop_event,))
```

Listing 3.1: gameexec.py

```

myo_driver = MyoDriver(config)
myo_driver.run(connected1, connected2,myo_A_left, myo_B_left, myo_A_right, myo_B_right)
```

Listing 3.2: class Myodriver

```
while (not myo_connected1 or not myo_connected2):
if connected1.wait(10) and not myo_connected1 :
    if myo_A_left.wait(3):
        text_nr_myo = FONT.render("Nr A", True, WHITE)
    elif myo_B_left.wait(3):
        text_nr_myo = FONT.render("Nr B", True, WHITE)
    else:
        print ("myoNr-event for left not yet set")
    text = FONT.render(translate.get('Translate', 'myo.left.connected'), True, WHITE)
    text_rect = text.get_rect()
    text_rect.center = (X - 400, Y)
    screen.blit(text, text_rect)
    text_rect = text_nr_myo.get_rect()
    text_rect.center = (X - 400, Y + 30)
    screen.blit(text_nr_myo, text_rect)
    pygame.display.flip()
```

```
        myo_connected1 = True

    if connected2.wait(10) and not myo_connected2:
        if myo_A_right.wait(3):
            text_nr_myo = FONT.render("Nr A", True, WHITE)
        elif myo_B_right.wait(3):
            text_nr_myo = FONT.render("Nr B", True, WHITE)
        else:
            print ("myoNr-event for RIGHT not yet set")
        text = FONT.render(translate.get('Translate', 'myo.right.connected'), True, WHITE)
        text_rect = text.get_rect()
        text_rect.center = (X + 400, Y)
        screen.blit(text, text_rect)

        text_rect = text_nr_myo.get_rect()
        text_rect.center = (X + 400, Y + 30)
        screen.blit(text_nr_myo, text_rect)
        pygame.display.flip()
        myo_connected2 = True
```

Listing 3.3: class Main

Plotting EMG signals While recording the game usage and the data from the Myo Armband, direct plots can be checked in the meantime, which accurately show how the pressure on the armbands is increasing or decreasing. This code is originally from the Github repository PyoMyo and it has been adapted to our system, accordingly. ([44])

```
def plot(scr, vals1, vals2):
            global last_vals
            global last_vals2
            DRAW_LINES = True
            D = 5
            if last_vals is None:
                last_vals = vals1
                return
            if last_vals2 is None:
                last_vals2 = vals2
                return
            scr.scroll(-D)
            scr.fill((0, 0, 0), (w - D, 0, w, h))
            for i, (u, v) in enumerate(zip(last_vals, vals1)):
                if DRAW_LINES:
                    # Draw lines for the first set of values (vals1)
                    pygame.draw.line(scr, (0, 255, 0),
                                     (w - D, int(h / 9 * (i + 1 - u))),
                                     (w, int(h / 9 * (i + 1 - v))))
                    pygame.draw.line(scr, (255, 255, 255),
                                     (w - D, int(h / 9 * (i + 1))),
                                     (w, int(h / 9 * (i + 1))))
           #same for the second list of values
            pygame.display.flip()
            last_vals = vals1
```

```
            last_vals2 = vals2
```

Listing 3.4: main class

3.7. Working with executable file

The executable file has been created by using PyInstaller, a commonly known tool that helps with the creation of executable files from python code scripts. Making the final product work has been challenging, as only the script has been transformed in the .exe files, and there have been some modifications done to the final folder. A separate directory had to be manually added, containing the assets used in the game, as well as the configuration file that includes the default values used for thresholds, where the values are changing live with the new values that are use din the game, also a special .cfg file that is used for the LSL connection and the modification in a folder created by the PyInstaller, where a file specific for the LabRecorder executable had to be added. All of these changes had to be done immediately after creating the executable, situation that ensures the good practice and the possibility of running the game without any issues. It has been tested successfully in multiple environments, on Windows 10, demonstrating its good usability and readiness for real-world application.

3.8. Starting the game executable

Starting the executable is straightforward: ensure the activation of the Myo armbands by shaking them and launch executable file. The game will operate exactly as it does when ran in the development environment (IDE). The changes explained in the previous section have been tested multiple times in order to ensure a clear usage and an intuitive startup for the user. These improvements were made to ensure that the application is perceived as software game, and not as a technical system.

3.9. Executable deployment and performance

Some important points need to be highlighted as the performance of the executable has been partially damaged when it was tried by our participant. Some errors appear along the try-outs: although the intro page loaded correctly and the Myo armbands have connected accordingly, immediately after launching the game, errors appeared that showed that the devices are in a wrong state. Moreover, one of the Myos has shown a red LED, indicating that the armband got unstable, situation that immediately leads to the termination of the game and possible error connections to appear.

Immediate attention was drawn to the errors and concrete actions such as troubleshooting began. Trying to connect the Myos with the system on the code and then on executable have been the actions considered for the testing. The development environment has been altered with changes brought to the connection type, in the code, which led to a longer time of responsiveness when connecting it to the Myo, along with a sudden termination of the game after around 30 seconds. This suggested that code for connection has not needed to be necessary changed, thus further testing has been done on the previous state of the code, which proved many times successful connection. This way, no error appeared in neither scenario, the only mention being the common state that the Myos have when connecting multiple times which lead to anomalies that can be ended only by terminating the game and waiting some time before restarting system.

As a corrective measure, new version of executable has been compiled and tested multiple times, to ensure the capacity of the Myo armbands to connect correctly and to eliminate any possibility of disconnections.

3.10. Limitations and future testing directions

3.10.1. Limitations

This study addressed a topic that needs to be grounded with some limitations. From development, to testing, and from using to improving it, there are important matters that lead to the present product, proposing useful tools that helped at the improvement of the system, but also lead the project to a limited state.

Myo Armbands These have shown limited usability along the development of the system. They are tools that are deprecated, unfortunately, and the owners, Thalmic Labs, discontinued the production of these.([65]) This situation lead to a challenging process of general work with them, as there is not enough documentation for how they work, resources of using two or multiple Myo Armbands or even code that can be analysed for investigating the deeper details. They are a great tool for smaller systems, for presentations, for games which make usability only of one Myo, thus our project includes the work with two Myos, which represented a great effort of connecting both of them to the system and reliability on their connection along the game. Obviously, this did not interrupt the ambition of finding a way to make them work, while testing their capacities.

Development and signal processing As the connection between the hardware and the system has been slightly ambiguous and reserved an impressive amount of time to manage the right connection, the development came also with its challenges, as the data transmitted had to be processed and transformed accordingly to the requirements of the game, i.e. ensuring a smooth movement of the ball or processing the Myo oppress in the respective thresholds.

MAC addresses The MAC address of each Myo used in the game are hardcoded in the code and used directly as a connection the Myo Armbands. This had to be done due to the connection of the system to any port that was available at the moment of clicking 'Connect', which resulted in odd behavior and no successful connection. The connection to armbands is not predictible, which made it difficult to realize the connection in a right manner, as both ports were 'rushing' to connect first and they were overlapping in the bluetooth connection. Finding the MAC addresses actually improved some of our discoveries, as we realized that one of the Myos that we were using presented some issues and had to be restored. Thus, hardcoding the MAC addresses ensured substantially stability in the connection. In the end, making sure that whichever Myo connects, it is ensured also the direction of it, i.e. left or right. This means that multiple executions of the game can lead to switching Myos from left to right and the other way around, situation that it is followed from the UI.

Participant localization Our participant is not localized in the same city where the study takes place. In this manner, communication is done solely online, while testing and checking errors engages the challenge of the project. The first part of the experiment has been done in the city where the study takes place, where significant efforts have been done by both the family of the participant and the university team. Nevertheless, the system is not used on the same platform as it was developed (Windows 10). Though, this situation helped the team increase the efforts of achieving a final system that is reliable, trusted and efficient.

3.10.2. Future testing directions

Some possible directions of testing, representing the continuity of the already present tests, would include retesting the improved system to our participant and also a future observation of the recorded data. Resending it would include the change of the MAC addresses with the Myo armbands that he can use, as the system deployed is using other Myos, with the expectation that all issues are fixed and the system is more stable, thus can be continuously used. Obviously, maintenance is part of the cycle of any project's process, thus possible issues can arise or updates can be done to the system. Moreover, visualizing the data processed specifically for the participant is an important step, as this would determine whether or not the system help in his rehabilitation. Analysing the data would need to be done on longer period of time, for a stable and consistent set of insights to be determined.

4. Discussion

4.1. Summary of key results

The previous chapters have been detailed all the methodology, the process, the materials used in the study, thus this section will show some key results that are valuable to be highlighted as a summary. The creation of a simpler software with focus on serious game lead to great results when our participant tested it, implying the observations of significant activity between muscles and brain. Having these robust results, a more complex system has been created to serve as a rehabilitation tool, an entertainment game, a system that exceeds the development area and it is transformed in a true help for the enhancement of neuromuscular motor activity. The present version represents a more developed version that include therapeutical features implemented similar to a game, including variation of types of it and also different levels. Testing and ensuring quality represented a challenging situation which has partially succeed, making the system more stable and feasible, in the existing limitations.

4.2. Performance and limitations

This section includes the discussion about how performance and limitations improved the system, and how overcoming these challenges contributed to shaping a feasible product as a potential technical tool with applications in the medical field.

4.2.1. Obstacles

The process of getting to the final result has been filled with significant research, work and testings. Some of the obstacles that have been faced along this way include the outdating of the Myo armbands which lead to extended delays in achieving a practical work with them. Substantial time has been invested in understanding the connection protocols, resolving compatibility issues and to stabilizing them. Multiple libraries have been explored as reference guide to start working with them. Starting an idea on a path and along the way observing how it slowly does not meet the requirements of stability has been a very common situation that happened a couple of times, creating frustration and doubts regarding the progress of the project. Finally, a helpful repository has been found on GitLab, the one which is used also in our project, as a guide of managing Bluetooth connections, between the system and the Myo Armband.

Obstacles that appeared along the way consisted in the possibility of processing the right and usable signals from the Myo Armbands, synchronizing them with the ball smoothly and maintaining a smooth and responsive UI in a perfect time. Portions of the original codebase used in the Part I, that connected the hardware to the PsychoPy game (presented as well in the Algorithms section), have been modified in more rounds of testing, thus it was possible to test the game and ensure a good flow of the ball. Moreover, the Pygame provides a specific time of updating the UI, so having only the signals ready to calculate the pressure that would move the ball was not enough, that is why more exploration needed to be conducted in this manner, successfully managing the drawback.

A final challenge worth to be mentioned is the actual possible decision of finalizing the usage of the Myo armbands and transitioning to more powerful and sustainable devices. This idea is still in discussion, as errors that have already been mentioned appeared at the trial of the game. These errors are possible to be corrected, situation that could lead to the completion of the project at the stage that has been originally envisioned.

4.2.2. Highlights

Important benefits conclude from this complex project. As mentioned in the other chapters, many of the initial goals have been accomplished and are worth to be mentioned, reflecting both the technical depth and applied potential of the system.

The responsiveness of the system improves the state of the project, as it can be either used from the IDE or from the executable, contouring the possibility of the user to use the system with confidence. The user is not required to have technical knowledge, which makes the whole process easy to understand and follow. The game has been developed in such a way that the managing of it does not imply complex understanding of the UI and the process of navigating through it, as it has been showed in previous chapters.

The game has been developed as a fun and possible therapeutic tool that aims to be easily followed and efficient to use for people with upper limb deficiencies. It includes three modes, each targeting a different purpose: free game, training, questions answering. Each session will provide the creation of files with all the moves that the participant does, which can be used as analysis tool in behaviour observation. This process ensures both usefulness for the user and for the neuroinformatician that can further use the signal records.

The system includes as well the benefit of independent usage, as people who are autonomous can use the system without the help of a specialist, following the steps presented on starting the game. It also helps the caretakers in any moment they consider it is time to be used, as the system is portable, requiring only a Windows 10-compatible device on their laptop/ computer/ tablet, thus extending its usability beyond controlled lab environment.

4.3. Self review

The development of the process has been both challenging and ambitious. The obstacles encountered and milestones achieved have contributed to the clear representation of the final form of system as it stands today. On a personal level, working on this project has offered a valuable introduction to the structure and collaboration with the neuroinformatics projects. I came to appreciate how having a clear, well-defined goal can serve as a strong guiding force, even in the moments when the process of searching seems to stagnate.

One of the most significant lessons was the difference between working independently versus in a team in the neuroinformatics field. Collaborating within a group allowed for brainstorming different ideas that could shape better the goal of the project direction. I developed a stronger ability to filter and evaluate ideas, to be aware of the limitations of the project and remain committed to delivering the best possible version of the system. In terms of time management, as the project has been considered a complex one, the time that had to be invested has been estimated as a high workload. Frequent team meetings, feedback loops and code refactoring were necessary through the development cycle, all contributing to the project's refinement.

4.4. Future work

Integration with Different Devices

Given the discontinuation of the Myo armbands, a possible future step is to explore compatibility with other devices existing on the market. This could improve the stability of the connection, while ensuring the possibility of consulting more forums, discussion between users and possible errors that can be fixed along the development and last, but not least, it would represent a progressive development of the system.

Gameplay Adaptation to Signals

Enhancing the game features would include the integration of adaptive difficulty or special feedback in live time, while the user is playing the game. This feature would adjust the speed or even the thresholds based on muscle fatigue or gesture stability, giving the possibility to the user to experience a personalized environment and even more effective rehabilitation process.

Multiple User Interaction

The possibility of playing the game together with a friend or a relative might improve their engagement in the rehabilitation and boost their interactivity.

Mobile Version

An idea that might grow the efficiency and improve the users' interest rely on a mobile version. This would ensure accessibility and ease of usage in home-based rehabilitation. Reducing reliance on hardware, besides the phone, support remote monitoring in any moment of the day.

4.5. Broader implications

The project proved its usability and reliability for users, such as it can be considered as a sustainable contributor to neuroinformatics and Human-Computer Interaction (HCI) fields.

When discussing about HCI, the design is centered on the user, as it implies an intuitive interaction with a minimal luggage of technical skills, thus reflecting an important principle that HCI holds, where designing the application relies in ensuring natural interaction and usability. Moreover, the game defines itself as a tool that people with motor impairments can use to interact easier with the digital systems, benefit that argues that an assistive technology while using an universal design defined by HCI. While the UI is already assessing some of the HCI benefits, the Myo armband captures EMG and gesture input, enabling a non-keyboard or mouse control, which represents itself a known and common trend in HCI research.

Other key concerns that the HCI rely on the structure of the game which enhances the motivation of the user, also the creation of the system outside of the lab, serves as a reliable proof of a situated system defined by HCI. Nevertheless, the logging of the interaction data suggests the inspiration of adaptive interfaces and user modeling, all relating to the contributions in HCI area. (34) (1)

The system developed contributes also to the field of neuroinformatics, as the use of Myo armband includes the collection of EMG signals, perfectly fitting the concerns of the domain by including data that can be integrated into broader multimodal datasets. The signal-behavior correlation which researches the relationship between muscle activation and movements patterns is essential to be mentioned for the integration in neuroinformatics field, while the data logging comes in place, similar to the HCI motivation, as a providing tool for annotated behavioral data that can be also used for inference of cognitive workload, analysis of the motor learning and observation of the response to feedback. Nevertheless, the system acts as a platform for data collection to reproduce EMG-based datasets creation, as the events and actions are synchronized, while supporting open science and cross-lab sharing. (20)(61)

Besides the implications in the computer science field, it is highly important to mention the implications brought to the patients that this system is designed for. Their impairments and the possibility of a better recovery represent the base and a milestone for such a project, which transforms the repetitive rehabilitation exercises in a rewarding and satisfying experience, through the gamified structure. The possibility of motivation increase and adherence to therapy are solid ideas that rely as a viable base for the system. Independently to be used, the system is designed to include an easy use, allowing the patients to ask for limited supervision. This supports the patient autonomy and ensures a self-paced rehabilitation outside of the rehabilitation center or laboratory. Logging the EMG signals comes as a helpful process when considering the individualized tracking of motor function over time, as it offers valuable insights for clinicians and help at rehabilitation strategies adjustment for the progress of each patient.

5. Conclusion

5.1. Concluding words

The previous chapters represent a detailed description of a process that constitutes not only a project that has been planned, organized, refined, tested and deployed, but it represent the implementation of helping a cause, the contribution to ensuring the possibility of living a better life. Disabilities should be understood as a tool to refer to the world in a beautiful manner, not as a difficulty that is damaging someone's life. Scientists can study cases, which come with a different challenges, thus arising innovative ideas that can be experimented to be able to support these. Living with paralysis and having difficulties in communication is a challenge for an adult, but especially for a child. Creating a game that is fun and easy to play has been the goal of the project, by becoming later on a possible tool used as rehabilitation for people with motor impairments. As the game has three modes and includes an easy UI, it can be observed how the game implies the combination of efficiency and responsiveness for a user to be engaged to play it on a prolonged period of time. It includes auditive feedback, records data that can give insights at future analysis, and can be easily used outside of a center or laboratory, also including minimal assistance for the patients that show less trauma in their upper limbs. I consider that the development of the game and the findings contribute to the neuroinformatics and HCI field, highlighting the processing of EMG signals, data logging and process of analysing the muscle activity. There have been also some limitations, from which we can remind of testing the game with the participant who lives in a different location than the development of the system, how the Myo armbands provide some outdatings and setting up the stable connection came with more challenges than expected. These, of course, can contribute to the setting for future work, stressing the usage of improved different devices, also a possible improved feedback system, even a multiple user interaction and the deployment of the game in a mobile version. This system represents a solid base of putting in practice an idea that can be developed and improved to reach a great community of people who need technology to complete itself with challenging medical situations in order to live their life in better conditions.

5.2. Personal touch

I am privileged to be able to write this section, as being part of the Neuroinformatics team from University of Vienna represented a very significant part of my Master studying years. For me, this project does not represent only the tool that could be used to change in better people's life, it represents the seed that has been planted right when the subject has been proposed. It has been growing, slowly, only in the ground, when research of good tools has been conducted, meetings have been set to discuss how to plan the project, questions has arisen which needed responses in detail. The flower was staring catching a form, the project now being put into test. Rain has came many times, with storms, and as a tornado impacts, so did the obstacles create confusion, fog, reschedule, but sun has always appeared with a solution and a way to make the flower continue to grow. Just like a flower with smaller buds, each represented a feature and a milestone that has successfully been reached, till a beautiful plant with bloomed flowers has been created, in the end.

This project has been going on for a long time and I can say that the experience that this project helped me achieve is not comparable to any other projects I have worked so far on. Working for a cause, for people who need technology to be used not only in social interaction, but in real therapy and overcoming their difficulties, has been and still is a work that requires patience, dedication, resilience and most importantly, hope. Having these ingredients, along with good research of tools and participants willing to try a new system, leads undoubtedly to the transformation of a general idea into reality.

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A. Appendix

A.1. Github Repositories

A.1.1. Happy Football

All the code used for the development of this thesis can be found https://github.com/AlexiaTheodora/happy-football/tree/football-mio-executable. This is the final version, based on which the executable is created in the end.

A.1.2. MioConnect

The setup that helped and represent a solid base for the connection between the Myo Armbands and the software can be found at the following address https://github.com/francocruces/MioConnect. This code has been used totally and significant adaptations has been made to the code in order to create a suitable environment for the system.

A.2. Pictures Licences

Visual assets have been used from the https://canva.com and they are used under the terms of their Free media licence agreement https://www.canva.com/policies/free-media-license-agreement-2022-01-03/. Moreover, the next websites have been used to gather the pictures observed in the software: arrow - https://www.freeiconspng.com/img/36981, ball-https://es.pinterest.com/pin/657947826843666293/, background- https://in.pinterest.com/pin/349169777372622693/, gate- https://www.pngaaa.com/detail/500450, smile face- https://www.pinterest.com/pin/355362845527689911/, sad face- https://www.onlinewebfonts.com/icon/424001 congratulations, intro page - https://www.canva.com https://www.pngegg.com/en/.

A.3. Publication

I had the great privilege to work for the publication "An EMG-based Brain Computer Interface for communication-impaired patients: A case study", together with Philipp Raggam, Manuel Eder, Peter Fugger and Moritz Grosse-Wentrup. The results of the publications appear mentioned in the present paper and they represent the significant base of the creation of a more complex and serious system which aims to help the motor impaired patients. The paper can be found here: https://eprints.cs.univie.ac.at/8210/.