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MASTER THESIS

**CTS PHYSIOTHERAPY USING EXERGAMES AND THE LEAP
MOTION SENSOR**

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Abstract

There has been extended research regarding the negative effect of using computers and playing video games, but in recent years researchers suggest that video games, that motivate players to move, especially the games that require the use of sensors and generally motion sensing input devices, can be useful tools for encouraging healthy physical activity. The goal of the current thesis is to study new ways to exploit the advances of the technology and especially the progress made in the field of motion sensing input devices for the development of therapeutic physiotherapy applications. Additionally, the thesis includes an implementation of physical therapy exercises for the treatment of the Carpal Tunnel Syndrome (CTS) in the form of Unity3D games. CTS is a condition, afflicting a high percent of the population, that affects the functionality of the wrist and the fingers. The motion sensor that was chosen for the development of the games is the Leap Motion sensor, as its accuracy makes it the most appropriate tool for the tracking of hands and fingers.

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I. Introduction

Carpal tunnel syndrome (CTS) is associated with obesity, hypothyroidism, arthritis, diabetes and trauma among others. It is a medical condition in which the median nerve is compressed as it travels through the wrist's carpal tunnel and causes pain, numbness and tingling in parts of the hand that receive sensation from the median nerve. [1]

The treatment of the syndrome aims at (a) returning normal functionality of the hand, allowing patients to resume their usual daily activities and (b) preventing further/additional nerve damage and muscle loss in the fingers and hands. Mainstream treatment options include wrist splinting and immobilization, medicine (e.g., corticosteroids and anti-inflammatory drugs that relieve pain and reduce inflammation), physical therapy and, finally, surgery (a last resort measure, when other treatments are not effective).

Many CTS patients opt for physiotherapy, which involves tendon gliding of the finger flexor tendons and nerve gliding of the median nerve, thereby helping to reduce pain and increase mobility and strength. Additional exercises may be included, depending on the individual case, to increase muscle strength in the hand, fingers and forearm as well as in the trunk and postural back muscles, combined with stretching exercises to improve flexibility in the wrist, hand and fingers. Physiotherapy mainly aims at moderating the symptoms of the syndrome, allow the patient to maintain the functionality of his hands in everyday activities and obviate the need for surgery. Even if surgery cannot be prevented, post-surgery physical therapy helps to restore strength and full functionality to the hand.

However, the benefits of physical therapy are not instant, but are rather felt in the long-term (many weeks or months). It is understood that daily repetition of the prescribed exercises are required to have a partial recovery of impaired movements. These sessions tend to be long, tiresome and tedious and also it may be difficult to schedule frequent sessions because of healthcare costs. [2] Outpatient therapy gives a solution to this problem, as the patients may perform the exercises at home on a regular basis, while communicating remotely with the therapist, so that a physical therapist may not be required to be present after the first few sessions.

Even at home, treatment requires time-consuming and repetitive exercises that are not very pleasant for the patients and end up monotonous and boring, resulting in only 31% of people performing them as recommended [3]. Also, since the presence of the physical therapist is not necessary for the performance of the exercises, it is natural for the patients to lose their motivation and confidence, while doing them alone at home, especially when there is no significant improvement to be observed over a long period of time. Thus, these factors affect the results of the treatment and compel many patients to neglect the performance of the exercises on a regular basis and abandon the treatment before it is completed.

It is important to provide patients who suffer from motor disabilities rooted in neurological and musculoskeletal conditions appropriate rehabilitation programs designed to improve their quality of life. There are many studies [4] [3] [5] [6], which have come to the conclusion that interactive games have the potential, through several of their elements, to enhance the results of rehabilitation and therapy.

The idea of converting boring physical exercises into interesting and fun games is promising, since it can provide a motivation for patients to continue therapy at home, even when they are not under therapist supervision. Serious games have started to be used in physiotherapy and rehabilitation, as they can promote healthy habits and exercise, while entertaining and rewarding the players. [7] Motivation and immersion in the game scenario also helps patients forget that they are performing exercises as a part of their therapy.

The fact that games often use repetitive actions to get players into a rhythm is what makes them appropriate to be used as physical therapy exercises, since they contain a lot of repetition. Especially when the games are goal-oriented and highly interactive, they can provide patients the motivation they need to perform and complete their exercises at home. Additionally, typical features of games, like controlling 3D worlds or elements like high scores, achievements, rewards and positive feedback can make therapy incredibly fun and addictive and help maintain interest and, as a result, play more and help to speed up their recovery. It creates an environment where the repetition becomes an advantage, and something to be enjoyed rather than dreaded. [8]

One of the most popular trends in current game industry is to abandon conventional devices, such as keyboards, mice and joysticks in favor of mechanisms that detect the natural body motion, such as those employed by Nintendo's Wii and Microsoft's Kinect sensors. The purpose of these systems is to create the illusion to the user of being a part of the virtual environment by translating natural body movements to game movements according to the game scenario.

Interactive technologies like video games with motion-based input devices create an interesting alternative way to perform prescribed exercises at home via rich graphical and multimodal game contexts used to motivate players. As a result of streaming the required exercises into meaningful game contexts the quality of home-based self-initiated therapy is expected to improve. It is mainly for this reason that games must be customizable to suit individual patients and their particular therapy needs.

Rehabilitation and treatment can be more fun, and provide important quantitative measurable results by designing data-collection modules that measure useful data in the duration of game sessions that can be used to assess long-term patient progress. In addition, the therapist can analyze the data on a per-patient basis to be able to provide with help and advice tailored to the individual patient. Patients on the other hand experience the feeling of accomplishment. Naturally, such behavior should be calibrated to the abilities of each patient, so that no patient will become frustrated with a lack of progress or progress too quickly.

The present work discusses the key advantages of the Leap Motion sensor over other popular sensors and what makes it a promising tool on which to base the creation of CTS-oriented serious games. In particular, the advantages of the Leap Motion sensor that are relevant to CTS have been explored through custom 3D CTS-oriented serious games which require users to perform CTS-specific exercises (extension/flexion and radial/ulnar deviation) to successfully complete the game objectives.

II. Carpal tunnel syndrome

Carpal tunnel syndrome (CTS) is a very common and frequent focal peripheral neuropathy in which the median nerve is compressed where it passes through the wrist. CTS commonly causes swelling, pain, tingling and loss of strength in the wrist and hand. Usually the tendons of the wrist become swollen and press the nerve. The functionality of the median nerve is to control some of the muscles that make the thumb move and transfer the information about the feeling in the thumb and fingers back to the brain [9].

At times that the nerve is compressed it may feel painful, aching, tingling or it may cause numbness in the hand that is affected. The night hours often affect negatively the symptoms and may deteriorate the quality of the sleep of the patient, but may become more obtrusive in the morning, after sleep. Aching and tingling can be temporarily relieved by hanging the hand out of bed or shaking it around.

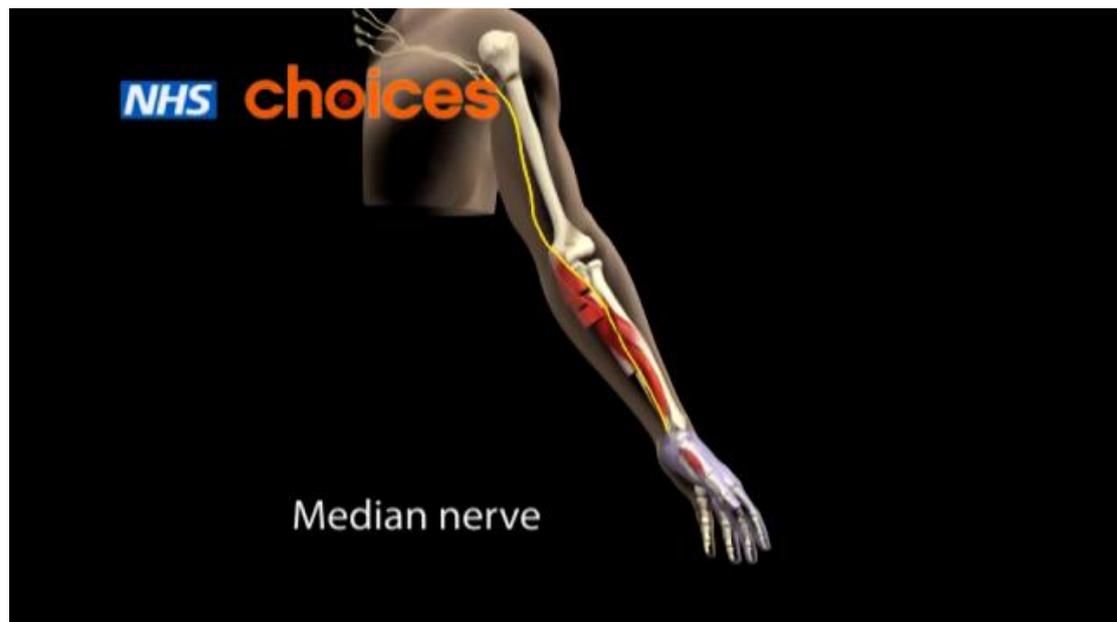


Figure 1 – The median nerve (adopted from [10])

Activities like typing on the computer, handwriting or some types of housework may intensify the symptoms, even if the problem is not so perceptible during the day. In some cases the symptoms of CTS may confuse and resemble other conditions with similar symptoms, such as arthritis or disc problems. [11] In case of such confusion the diagnosis can be more accurate with the help of a nerve conduction test.

The syndrome is three times more common in women with respect to men, while it affects almost 3 percent of adult population. Especially persons who tend to perform repetitive

movements of the wrist usually are more likely to develop the syndrome. CTS becomes more and more common in the developed countries. For example, in the U.S. it is reported to cost over 2 billion annually, partially due to the high cost of the medical treatment for roughly 3.7% of the general public who suffer from it but also on the average number of the missed working days for CTS patients. By comparison, in France, 127,269 patients over 20 years old were operated to treat CTS in 2008. The syndrome is reported to affect more frequently mostly females between 45 and 59 years old, and also mostly females between 75 and 84 years old. [9]

Many people, who use a computer frequently, for work, education or entertainment, complain about hand paresthesia, a superficial sensation of tingling, burning or numbness of the hand. [12] However, a small percent of these computer users actually meet the clinical criteria for carpal tunnel syndrome.

The syndrome was at first described by Sir James Paget, after a case of medial nerve compression at the wrist following a fracture of the distal radius. The principles of CTS were established in 1950, when George Phalen reported for the very first time this relatively unknown condition at the 99th Annual Meeting of the American Medical Association.

To comprehend CTS, one must first get familiarized with the relevant wrist anatomy and the tunnel that is shaped by the carpal bones. The wrist has an incurved contour that consists of eight bones, forming the joint, on the surface of the flexor, the muscle which bends the limb by its contraction, and is covered by the flexor retinaculum or transverse carpal ligament, a fibrous band on the palmar side of the hand. [9]

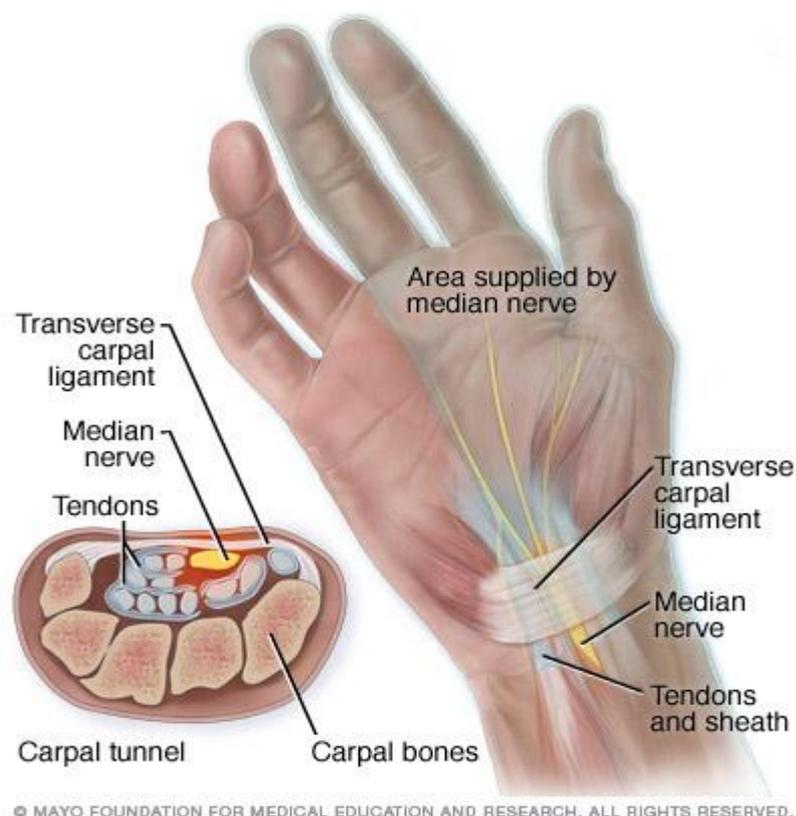


Figure 2 - Wrist anatomy(adopted from [13])

So, the carpal tunnel is confined by the bony carpus and the transverse carpal ligament (flexor retinaculum). The latter connected to the tubercle of the scaphoid carpal bone, the ridge of the trapezium carpal bone and the ulnar side of the hook (small projection of the bone) of the hamate and pisiform carpal bones. The flexor muscles of the fingers pass through the carpal tunnel, while the median nerve is located under the transverse carpal ligament. [9]

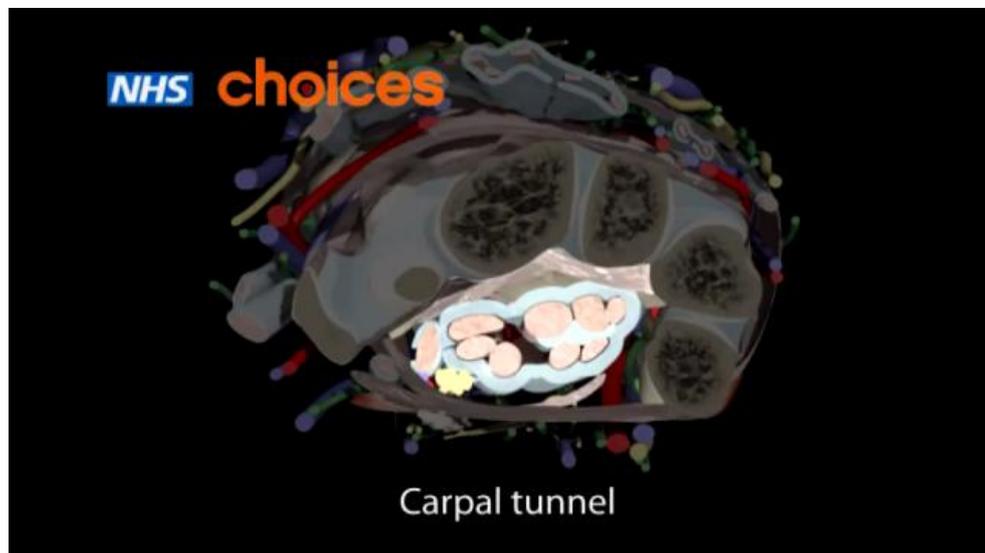


Figure 3 - Carpal tunnel image (adopted from [10])

In conclusion, the wrist consists of small bones, the carpal bones, which form the carpal tunnel. The median nerve, which controls the sensations in the palm and fingers, as well as the tendons pass through this tunnel from the forearm into the hand. The pressure on the median nerve can be sometimes caused by swelling and irritation of the tendons, thus producing the symptoms of the CTS. The affected hand is usually the dominant hand of the patient, although it is also quite possible to observe symptoms of carpal tunnel syndrome in both hands. [9]

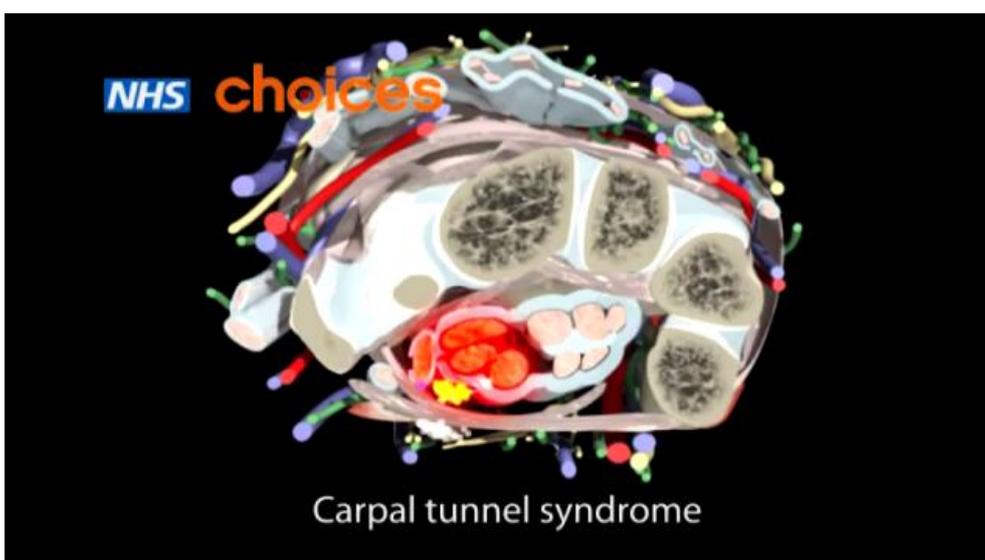


Figure 4 - Carpal tunnel syndrome image (adopted from [10])

i. Causes

The compression of the median nerve occurs at the carpal tunnel as the result of an incompatibility between the relative size of the canal and the volume of its content, the space occupied by the transit tendons and the median nerve. Studies, including the measurement of the inter-carpal canal pressure of CTS patients, have shown significantly increased mean pressure in the carpal canal. The most significant mean carpal canal pressure increment was observed during the wrist extension and slightly less, when wrist flexion was performed, while an immediate pressure decrease was observed during carpal tunnel release. Therefore, the syndrome is usually caused by several different conditions. The space inside the carpal canal can be reduced by processes including tenosynovitis of the flexor tendons, fracture or dislocation of the carpus and carpometacarpal joints and Colles' fracture. In addition, the conditions mentioned above, may also cause posttraumatic scarring or fibrosis inside the carpal tunnel. Rheumatoid arthritis, amyloid deposition, granulomatous infection and gout are some of the inflammatory processes that contribute to reduced volume inside the carpal tunnel and produce a proliferative tenosynovitis with hyperplastic synovium. [9]

Another cause of decreased space within the carpal canal can be tumors of the median nerve, disorders like acromegaly or hypothyroidism, pregnancy, diabetes mellitus, and lupus erythematosus. Some processes like the mentioned above, may increment the extracapsular fluid retention and produce swelling of the soft tissue.

It has been observed that women are three times more likely to have carpal tunnel syndrome than men. However, the reason for this increased frequency in women population is not known yet. Some of the theories mention that it may be caused by the difference in the size of the wrist bones, which are naturally smaller in most women. This means that the space that is formed by the carpal bones, through which the nerves and tendons pass, is tighter. Other factors that are considered by the scientists are the genetic links that make it more likely for women to have musculoskeletal injuries and the strong hormonal changes.

Certain health problems can be the cause of CTS, but sometimes the cause is unknown. Factors that raise the chances of developing CTS may be genetic predisposition, as mentioned above some people have smaller carpal tunnel than others, wrist injury causing swelling and pressure on the nerve or repetitive movements of the hands (computer users, assembly line workers, carpenters, musicians, athletes etc.). Some other factors contributing to the development of carpal tunnel syndrome, concerning women that have to do with hormonal changes are pregnancy and menopause. In these cases the wrist structure may become enlarged and add pressure on the nerve, but in many cases the symptoms fade after the completion of this special condition.

Another rare cause of carpal tunnel syndrome can be breast cancer, since often after mastectomy the build-up of fluids raises beyond the ability of lymph system to drain it and this causes pain and swelling of the arm and pressures the nerve.

In detail, the most significant and usual medical conditions that lead to CTS can be classified into the groups mentioned below:

- Swelling-tenosynovitis of the flexor tendons of the hand, because of extensive use of the hand, often happens to individuals such as farmers, builders, hairdressers, drivers or wheeled machine operators.
- Swelling of the tendon due to hormonal disorders such as disorders of the thyroid gland and ovarian (menopause or pregnancy).
- All of the above conditions, causing swelling of the sheaths and tendons within the carpal tunnel leading to an increase of pressure within. Initially the pressure affects small vessels of perineural and then the whole nerve that results to conduction disorder. The nerve swells and presents dotted macroscopic bleeding. In chronic cases of this neglected condition of the wrist the median nerve presents intraneural fibrosis and permanent functional impairment.
- Rarely the syndrome is caused by diabetes or a congenital narrowing of the carpal tunnel.
- In many cases CTS is a result of incorrect positioning of the wrist when typing on a computer. That is why the new keyboards have a new wrist support extension. The disease has been called journalistic and "typists disease" or "disease of the computer operator."
- In recent years it has been discovered that the intake of the drug Tamoxifen and Arimidex may also lead to Carpal Tunnel Syndrome.
- Also, rarely carpal tunnel syndrome coexists with median nerve pressure on the forearm, by the round pronator muscle.
- They have been reported rare cases of carpal tunnel syndrome caused by tumors, and carpal tunnel syndrome amyloidosis of histological lesions.

Aberrant anatomy	Infections	Inflammatory conditions	Metabolic conditions	Increased canal volume
Anomalous flexor tendons	Lyme disease	Connective tissue disease	Acromegaly	Congestive heart failure
Congenitally small carpal canal	Mycobacterial infection	Gout or pseudogout	Amyloidosis	Edema
Ganglionic cysts	Septic arthritis	Nonspecific flexor tenosynovitis*	Diabetes	Obesity
Lipoma		Rheumatoid arthritis	Hypothyroidism or hyperthyroidism	Pregnancy
Proximal lumbrical muscle insertion				
Thrombosed artery				

Table 1 – Associated conditions that may cause Carpal Tunnel Syndrome(adopted from [14])

Also, it has been observed that smokers with carpal tunnel syndrome have worse symptoms and usually recover more slowly than nonsmokers.

ii. Symptoms

To properly define the presence or absence of carpal tunnel syndrome it is required to observe both appropriate symptoms and abnormal nerve conduction studies for the diagnosis. The usual symptoms of CTS, that can be considered appropriate for the diagnosis of the condition, are burning pain in the volar aspects of both hands, numbness in the fingers, and tingling, which often become worse after work and at night and awaken patients from sleep. Symptoms expressed at night are prominent in 50-70% of patients. Shaking the wrist down may relieve the symptoms. Symptoms are commonly localized to the thumb and first two or three fingers often accompanied by burning pain in the palm side of the wrist (although this sensation of pain, numbness and tingling may also expand to the forearm, elbow, and especially the shoulder in the form of aching pain. In severe cases of the syndrome the patient may lose the dexterity of the hand because of decreased grip strength and thenar muscle atrophy.

A different diagnosis, such as ulnar neuropathy or C-8 radiculopathy should be considered, in case the nerve symptoms are observed only in the fourth and fifth fingers, while proximal symptoms, especially tingling in the radial hand combined with elbow side pain may warn about a possible C-6 radiculopathy.

Signs and symptoms observed during the physical examinations may often be negligible or confusing. Some of the diagnosis methods, like Hoffmann-Tinel's sign, which is described as paresthesias expanding in the median nerve distribution with tapping on the wrist or over the median nerve, and Phalen's sign, which is also paresthesias radiating in a median nerve distribution, but within 60 seconds of sustained flexion of the wrist, are frequently described, though are not specific enough for the diagnosis of carpal tunnel syndrome. The presence of these signs reinforces the existence of other specific neurologic symptoms. In addition, non-specific symptoms, like pain without numbness, tingling and burning cannot be considered as diagnostic of carpal tunnel syndrome by themselves.

When carpal tunnel syndrome becomes more severe some new symptoms may be observed, including decreased sensation to pin or light touch in the first three digits or weakness or atrophy of the muscles of the thenar eminence, especially the abductor pollicis brevis. Thenar weakness or atrophy may reveal more acute or advanced nerve injury, in contrast with Hoffmann-Tinel's sign or Phalen's sign, and in this case possibly creates the need for more aggressive treatment.

It is important to exhaust every possible effort to objectively verify the diagnosis of carpal tunnel syndrome before considering surgery. It has been showed that patients who have undergone carpal tunnel surgery with normal or near normal pre-surgical nerve conduction test results have worse outcomes than those with electrodiagnostic evidence of median nerve entrapment across the carpal tunnel, even though some evidence disaccord. A rare method of therapeutic and diagnostic challenge test can be a steroid injection performed into the carpal canal. In case the patients experience improvement in symptoms for weeks or months after the injection, but then having recurrence of symptoms, surgery may be

considered as a solution for carpal tunnel release. Also, further diagnostic evaluation can be performed by an appropriate specialist for the patients with a negative response. [9]

The therapists should also investigate other clinical problems that may be possibly related to work exposures [12], such as tendonitis, in case carpal tunnel syndrome is not defined by clinical criteria and nerve conduction velocity testing. In addition, the patient should be referred to an appropriate specialist to eliminate the possibility of having other neurologic causes of tingling in the hands.

iii. Associated conditions

Because of the functional and structural changes caused by carpal tunnel syndrome or other forms of polyneuropathy that lead to the syndrome, the median nerve becomes very sensitive to different compressive conditions.

One of the associated conditions is hereditary neuropathy with hypersensitivity to pressure, which is a hereditary sensory-motor form of neuropathy that is central and repetitive. The symptoms of the particular neuropathy, which include paralysis and paresthesias of the nerve trunk, usually appear after the age of 20. The symptoms, which usually occur after an injury or extended compression, often deteriorate and become more frequent. The condition is characterized by a disorder affecting the myelin of peripheral nerve fibers with stretching of the distal motor latency, which cause focal thickening of myelin in some zones of the nerve.

Another associated condition is the double constriction syndrome, which is based on the evidence that direct compression on the path of a nerve makes it more vulnerable than if the compression was located more peripherally. An appropriate clinical examination in addition with an electrophysiological study can determine whether the compression location is direct or peripheral and thus the treatment can be applied to the main compression location. [14]

iv. Diagnosis

The diagnosis for the patients with the condition, described as abnormal sensation like tingling or numbness of the hand and fingers, should include several steps, described below. At first, the appropriate specialist should have the initial discussion with the patient regarding the symptoms and consider possible pathological conditions associated with the described symptoms. At this phase of the diagnosis it is important to conduct challenge tests, to be able to determine the etiology of the condition.

Some of the most common challenge tests are the following:

- Tinel sign -this test shows whether the patient feels tingling and numbness of the hands and fingers, when the specialist manually taps the palmar side of the wrist at the level of the median nerve. In that case the test is positive.
- Phalen sign –during this test the patient must perform maximum active flexion of the wrist for 1 minute, while having the elbow extended. If paresthesia appears in the area of the median nerve, the test is considered positive.

- Paley and McMurphy test – the particular test shows the presence or absence of paresthesia or pain triggered by the manual pressure about 1 centimeter from the median nerve.
- Compression test with wrist flexed – during this test the specialist uses his two fingers to apply pressure on the median region of the carpal tunnel, while the wrist is being flexed at 60 degrees, the elbow is extended and the forearm is supinated. In case of the appearance of paresthesia in the area of the median nerve, the test is positive. [1]

Also, the presence of acroparesthesia at night, which includes tingling, numbness, swelling or pain, perceptible in the first three fingers, is considered one of the most sensitive symptoms.

The next step is to perform Weber test, which evaluates the severity of the nerve compression, and analyze the strength of the thenar muscles innervated by the median nerve. The specialist then has to decide if additional examinations, such as nerve conduction velocity test, are necessary. It is especially important to perform the nerve conduction velocity test, in case of carpal tunnel decompression surgery request. [15]

Sensory Nerve Conduction Studies (Electrodiagnosis) of the Median Nerve Across the Carpal Tunnel

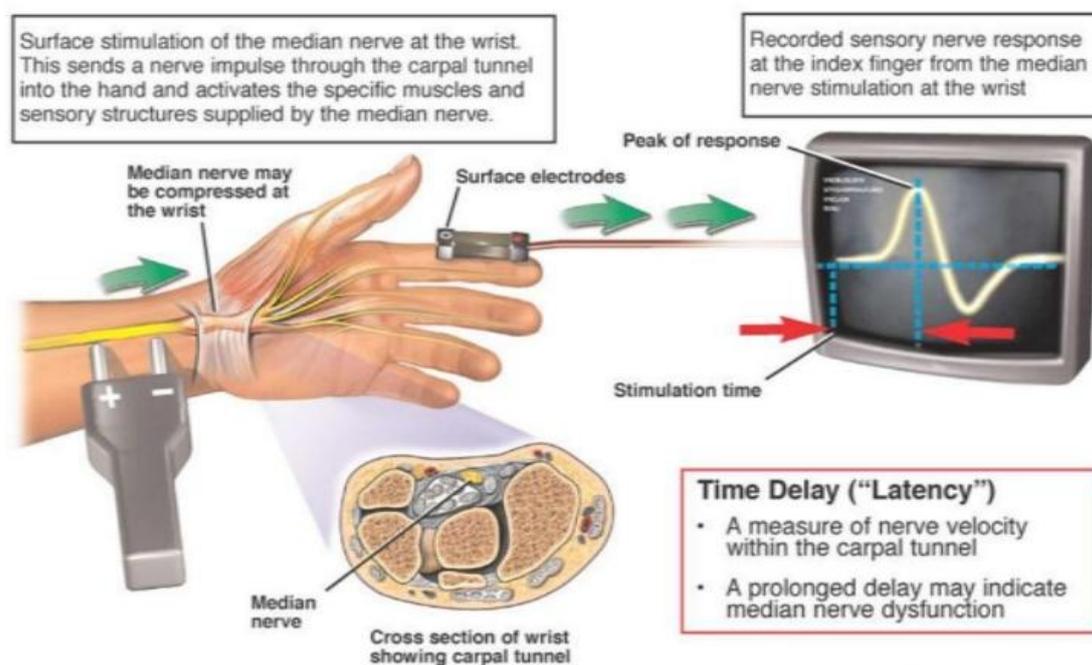


Figure 5 - Nerve conduction study (adopted from [16])

The clinical diagnosis of CTS is validated by the nerve conduction study with high degree of reliability, when there is evidence of slowing of sensory and motor fibers of the median nerve across the carpal tunnel. In case all the symptoms of the patient indicate a positive clinical picture of carpal tunnel syndrome, while the nerve conduction test results are

negative, the physician should consider other clinical diagnoses like tendonitis, pronator syndrome or cervical radiculopathy.

The final step of the diagnosis procedure is to propose an appropriate treatment adjusted to the location, the cause and the severity of the condition.

v. Treatment

There are some general guidelines for the carpal tunnel syndrome patients that help the treatment to be more effective and relieve the symptoms quickly. One of the most important guidelines is to avoid repetitive wrist and hand motions if possible and stop using vibratory tools that cause deterioration of the symptoms, such as jackhammers, floor sanders etc. Also, the patients have to consider changing their work conditions, like changing the position of the wrists while working on the computer or starting the use of wrist supports.

➤ Prevention

It is often to obtain musculoskeletal injuries that lead to carpal tunnel syndrome during work if the workplace conditions are not adjusted correctly to the needs of the workers. In order to prevent such injuries, the workspace and the equipment that is being used have to be at the right height and distance for the hands, so that the work is done without having to strain the wrists. The computer users have to make sure that the keyboard position allows the wrist to lay comfortably without bending and keep a correct posture. Also, it is important to have regular breaks to lower the risk of swelling.

Other ways to prevent carpal tunnel syndrome is to perform tasks that use different muscle movements and try to do the hand and wrist motions without unnecessary tension. Exercise, like flexing and bending the wrists, after tasks demanding repetitive movements can reduce the negative effects of these tasks. Keeping the muscles warm makes them less likely to get hurt, so it is important to keep the hands warm at work, sometimes by wearing gloves.

➤ Splints

Splints are being used to support and brace the wrist, so it is kept in a neutral position and the nerves and the tendons can recover. They reduce repetitive flexion and rotation of the wrist and relieve mild swelling of the soft tissue or tenosynovitis. Splinting the wrist is usually more effective when it is performed within three months of the manifestation of the symptoms and when it is adjusted to the symptoms and the preferences of the patient. In addition, it has been proven that wearing the splints full time is providing more effective improvement of the symptoms and electrophysiologic measurements.

➤ Surgery

The surgery is the last solution for the carpal tunnel syndrome and it should be only considered in severe cases, only when the symptoms don't respond to conservative measures and other types of treatment didn't have the expected result within at least six months of therapy. [17] The outpatient procedure of the surgery includes a regional

anesthesia that causes numbness to the wrist and hand area and a small incision in the palm that facilitates a division of the transverse carpal ligament and its overlying structures and enlarges the carpal tunnel. After the procedure the wrist needs to be splinted for three to four weeks. There can be complications after the surgery, which include injury to the palmar cutaneous or recurrent motor branch of the median nerve, tendon adhesion, hypertrophic scarring and laceration of the superficial palmar arch. Some other possible complications may be post-operative infection, hematoma, arterial injury, stiffness, and reflex sympathetic dystrophy. Recurrence of the symptoms has been observed, in cases that the carpal tunnel release was unsuccessful, which can be a result of incorrect or incomplete diagnosis.

➤ **Medication**

Non-steroidal anti-inflammatory drugs (NSAIDs), such as aspirin, ibuprofen and other pain relievers, are being used to relieve the symptoms of carpal tunnel syndrome and to control the pain. Also, for the reduction of the swelling caused by the severe cases of the syndrome, an injection of cortisone or corticosteroids in a pill form may be helpful. [14]

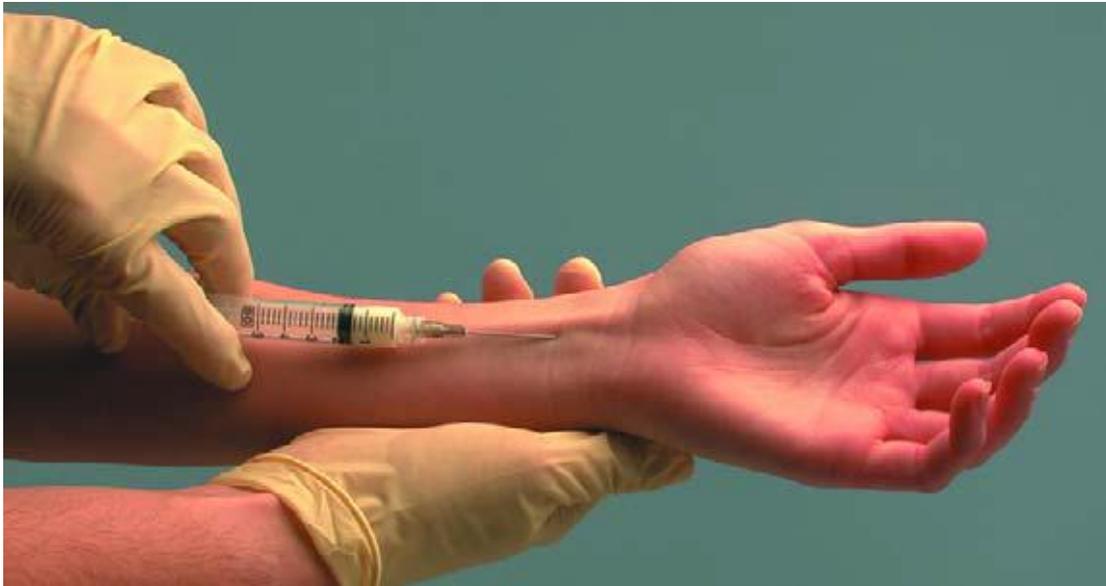


Figure 6- Corticosteroids injection (adopted from [14])

The injections of anesthetic combined with a corticosteroid into or near the carpal tunnel can be used for diagnosis and therapy. There is the risk of injuring the median nerve with the needle by performing a direct injection into the carpal tunnel. Other risks are to cause intratendinous injection and tendon rupture, or dysesthesias. Like in the case of surgery, also with the injections, wrist splinting is recommended after the procedure. In case the first injection is successful, a second injection can be performed after a few months, although if another injection is needed, surgery should be considered as the next option.

➤ **Ultrasound therapy**

Ultrasound therapy is possibly beneficial for the management of carpal tunnel syndrome, although more studies are needed to confirm that. Some studies have shown that twenty sessions of carpal tunnel ultrasound therapy administered over approximately seven weeks contributed in significantly greater reduction of symptoms at two weeks, seven weeks, and

six months. [18] On the other hand, other studies doubt the benefit of the particular treatment for the carpal tunnel syndrome.

➤ **Physical therapy**

A physical therapist can help you do special exercises to make your wrist and hand stronger. There are also many different kinds of treatments that can make CTS better and help relieve symptoms. Massage, yoga, ultrasound, chiropractic manipulation, and acupuncture are just a few such options that have been found to be helpful. You should talk with your doctor before trying these alternative treatments.

vi. Physical therapy traditional treatment

Carpal tunnel syndrome has reached epidemic proportions as, according to estimations, the surgical release of the transverse carpal ligament is included in the top ten most common operations, which significantly affects the national health care costs. Additionally there are of course other costs to be considered, including time off work, lost wages, and diminished workplace productivity. As was mentioned previously there also are different options for a non-surgical management of the carpal tunnel syndrome that include splinting, non-steroidal anti-inflammatory medication, steroid injections, and ergonomic modification of the workstation, but these current non-surgical treatment methods are frequently ineffective, often leading to recommendation for surgical treatment. Even after the surgery, the results might not be satisfactory, because of the presence of significant postoperative dysphoria as a result of enervating pain in the thenar and hypothenar eminences, a scar, the extended loss of grip strength and recurrence of symptoms on return to work. [17]

Dividing the transverse carpal ligament alters the mechanism of the thenar and hypothenar muscles and may cause bow-stringing of the flexor tendons. Even in case of the endoscopic carpal tunnel release, that was developed in order to reduce the abovementioned effects, the results are controversial and require further study. Thus, it was considered necessary to develop an auxiliary approach towards current conservative methods of carpal tunnel syndrome treatment and review the traditional compression neuropathy static model to enhance their efficiency. Some older studies have depicted the normal longitudinal movement of the median nerve through the carpal tunnel, where the median nerve slides proximally into the forearm with digital flexion, and slides distally toward the hand on extension of the fingers.

When the wrist and the fingers are extended the median nerve is displaced farthest under the transverse carpal ligament into the hand. The study of McLellan and Swash [19] also described how the median nerve slides distally by 10-15 mm relatively to a fixed bony landmark in the carpal tunnel, when the wrist is hyper-extended, while the displacement mentioned above, which occurs during the flexion of the wrist and the fingers, is often four times greater at the wrist than in the arm. Additionally, the nerve is getting displaced 11 mm distally during the active and passive extension of the wrist and the fingers and 4 mm proximally during the flexion. Local stretching of the median nerve, that would normally occur, is prevented by the longitudinal sliding. Studies of Szabo [20] have shown the differences between median nerve and digital flexor tendon excursion in the carpal tunnel

and the linear relationship that exists between median nerve movement and that of the flexor tendons.

Another study described that recurrent active wrist and digital flexion and extension exercises reduce the pressure within the carpal tunnel. Thus, it is possible to affect the clinical course of Carpal Tunnel Syndrome of some patients by using a specific series of exercises. A systematic procedure, which actively forces the median nerve and the flexor tendons to their maximal excursion through the carpal tunnel, is proposed in case that the attachment to the median nerve exists preoperatively. Certain studies have also proposed a regimen suitable for postoperative nerve gliding that is used to minimize scar adhesions and maximize nerve excursion through the carpal canal, which is reported to be effective in the management of postoperative carpal tunnel syndrome, with relief of pain and low recurrence rates. The performance of these nerve and tendon gliding exercises significantly affects symptom resolution by stretching the adhesions in the carpal canal, broadening the longitudinal area of contact between the median nerve and the transverse carpal ligament, also by reducing tenosynovial edema by a "milking action" , thus improving venous return from the nerve bundles and finally reducing pressure inside the carpal tunnel. This alternative conservative method of carpal tunnel syndrome management reduces the need for a surgical intervention.

These neuromobilization techniques may be applied, when there is certain evidence of an entrapment of the median nerve at the wrist and the neurodynamic test is positive. These techniques combine repetitive movements of the hand that provoke the symptoms, movements in the more distal and proximal segments. The position and the movements necessary for the neurodynamic test are similar to those needed for the treatment exercises, which usually include movements performed in a moderate pace divided in 3 sets of 10 repetitions in each set and a 3 second hold at the final stretched position. The therapist can decide to focus on a specific part of the nerve, if the test shows that this part is responsible for the symptoms, but without abandoning the exercises for the other parts of the nerve. Especially in the first few sessions the patients may experience a feeling of "stretching", tissue tension, light numbness, even a slight increase of pain symptoms during the technique; however the symptoms decrease or completely stop immediately after the procedure. The patient has to perform daily home exercise program including self-mobilization techniques for the median nerve, which can be performed in standing or sitting position.

Determining whether the condition of CTS is mild, moderate, or severe can provide clarity with respect to the intervention choices. Before applying the specific therapy it is important to assess the severity of the carpal tunnel syndrome of the patient, as a patient with a mild CTS condition may have a successful symptom reduction by only using splints at night and by altering the activities during the day, while a patient with moderate or severe CTS will not usually benefit so much from splint usage. According to recent studies the individual differences in CTS symptoms or the results of therapy may be linked to a genetic predisposition for developing the syndrome, so people with the same activity or the same treatment might have different symptoms and treatment results.

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Exercises for mobility and grip strength and pain reduction are the first two steps for a patient with reported loss of functionality because of CTS. The most common exercises recommended for the conservative management of the symptoms of CTS are tendon gliding of the finger flexor tendons and nerve gliding of the median nerve. [21] Studies that included measurements of the carpal tunnel pressure have shown that occasional exercise of active wrist and finger motion lasting about one minute lowers the pressure within the carpal tunnel. [22]

The gliding exercises include moving the fingers in a specified pattern of exercises and help the tendons and nerves glide more smoothly through the carpal tunnel. While there's some evidence that gliding exercises can help relieve symptoms when used alone, these exercises appear to work better in combination with other treatments -such as splinting.





Figure 7 - Common physiotherapy exercises for CTS treatment (adopted from [21])

Also manual therapy integrates a patented form of instrument-assisted soft tissue mobilization that gives the opportunity to the therapists to accurately detect and treat scar tissue and restrictions that effect normal function. Manual therapy techniques like active release technique and myofascial release are hands-on techniques that release tight tendons and musculature.

In the aggregate, physiotherapy is responsible for:

- Reducing pressure or inflammation, pain and loss of strength in your hand, wrist or arm
- Deciding whether a wrist splint is appropriate for the specific case
- Providing an individual program to improve functionality and increase the mobility of the wrist
- Instructing the patient to perform effective stretching exercises to prevent or minimize future symptoms appearance
- Providing specific advice on returning to work or normal everyday activities

vii. Game based therapy approach

Video games are commonly considered as a form of entertainment for young people, but their primary purpose can be much more than just pure entertainment. The process of memorizing the rules of the game, of developing the tactics and making quick decisions helps the players to improve their learning abilities, to advance their discipline, attention, self-control, the self-perceptual and also their motor abilities. [5]

A special category of games, the serious games, can be used mostly as training simulation for professionals in the field of the military, health care or engineering, but it can be also a very useful tool for education. Since the games usually involve challenges and rewarding system, they can motivate the users to learn or perform different tasks for the purpose of the game that wouldn't be normally so interesting to engage with.

Thus, the serious games can easily find application in the field of health care and help resolve or at least mitigate frequent health problems, such as severe mobility impairments, especially those that occur due to neurological and musculoskeletal problems. An example of such condition that causes deficiencies leading to mobility impairment and limitations in everyday activities is the multiple sclerosis, a chronic progressive neurological disease that affects the communication capacity of nerve cells in the brain and the spinal cord. Another example of such condition, which often creates similar difficulties in the movement and also usually contributes in the loss of balance, is the stroke. It develops disorders of the blood supply to the brain and subsequently leads to a partial loss of brain functionalities, since the affected area of the brain stops functioning. The aftermath of such condition can be decreased reaction time, the loss of range of motion, disordered movement organization and impaired force generation, thus affecting the patient's ability for self sufficient and independent existing. [23]

Additionally, an important benefit of the game-based physical therapy is that the technology allows the patients that require regular physical therapy sessions to perform prescribed exercises at home, so that they can avoid tiresome travels to treatment centers. Furthermore, the patients don't usually feel attached to the rehabilitation exercise program and lose their interest easily, especially when the results are not prompt, since the exercises consist of repetitive and monotonous tasks. Accordingly, it is very important to configure an appropriate environment for the performance of the physical therapy exercises that will be able to motivate the patients [24] and facilitate the completion of repetitive, tedious tasks efficiently, so that the patients will stay dedicated to the program and have a better recovery curve. [25]

In the case of Carpal Tunnel Syndrome, the gliding exercises, which are also repetitive movements of the wrist and fingers that are commonly prescribed, can be successfully implemented in an engaging game environment with many interesting features keeping the patient amused, while performing therapy, and stimulate the patient to keep going with the elements of reward.

III. Background technology and tools

i. Leap motion sensor

Recently the variety and the number of different applications have been significantly increased due to the development of several optical sensors detecting and acquiring 3D objects. The accuracy of such systems and their robustness makes them more and more appealing to the developers and the users, especially with their prices decreasing. Different ideas now have the possibility to be implemented with such sensors, including industrial tasks, users and objects tracking, motion analysis, character animation, 3D scene reconstruction and gesture-based user interfaces. Of course, there is still a long way to go considering the requirements in terms of resolution, speed, distance and target characteristics.

The Leap Motion controller presents a new gesture and position tracking system with accuracy that reaches a sub-millimeter. This sensor is a small USB peripheral device which is designed to be placed on a table, facing upward. The device observes an approximately hemispherical area to a distance of about 1 meter (3.28084 feet), by using two monochromatic IR cameras and three infrared LEDs. The LEDs generate IR light and the cameras generate almost 300 frames per second of reflected data, which is afterwards sent through a USB cable to the host computer, where it is analyzed by the Leap Motion controller software using mathematical calculations in a way that has not been published by the company, in some way integrating 3D position data by comparing the 2D frames that are generated by the two IR cameras.

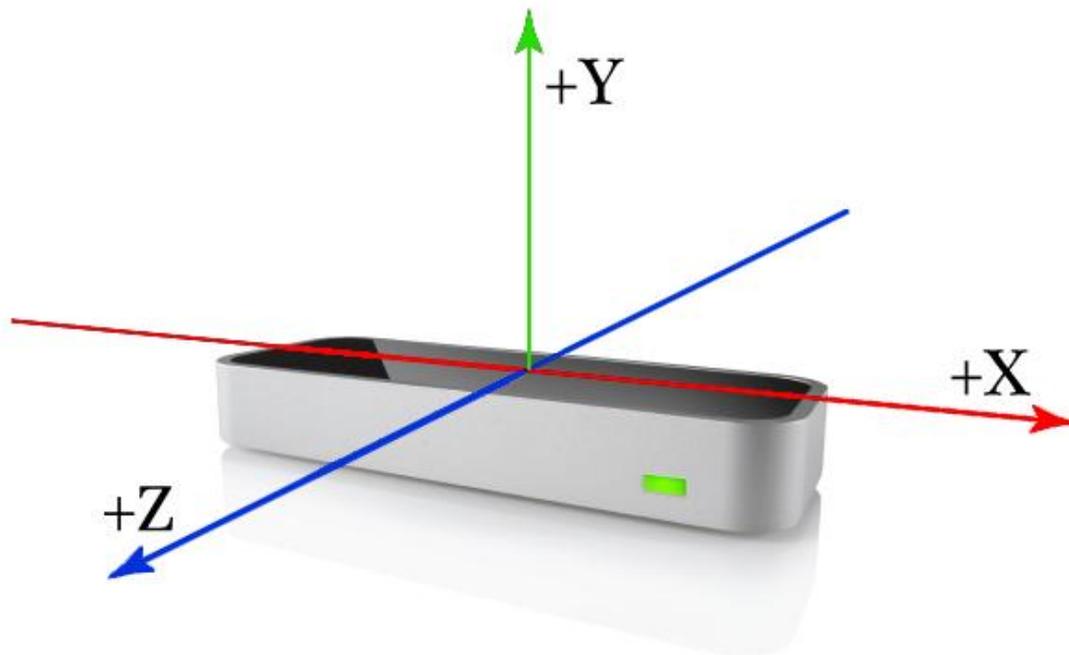


Figure 8 - Leap motion sensor(adopted from [26])

Unlike other common multi-touch devices, this table-top sensor is appropriate for use in realistic stereo 3D interaction systems, particularly those that have to do with direct selection of stereoscopically displayed objects. An interesting study of Weichert, Bachmann, Rudak and Fisseler [27] measures Leap Motion controller's accuracy and repeatability abilities. The major contributions of the study is the analysis of the accuracy and robustness of the device, the specification of an objective test setup for 3D sensors by using an industrial robot system and the definition of the quality criteria for industrial specifications.

The assessment of optical 3D sensors usually depends on their stereo vision cameras, the structured light sensors and the time of flight cameras. The stereo vision cameras that are formed by two 2D optical cameras determine the depth of the environment by comparing and combining the points extracted by the two cameras. Structured light sensors inspect the distortion of a noted design to an unfamiliar area to ascertain the shape of the objects in the three dimensional space, while the so called time of flight(TOF) 3D cameras resolve the distance of the target object by measuring the time of flight of a light signal emitted by the device. Also, the devices can be divided into photonic mixer devices, which measure the

frames of data. Further data of the frame class can be accessed through several functions defined by the frame class.

The data of a detected hand of a user can include information about the position, the rotation, the direction and the motion of the hand:

- `isRight`, `isLeft` — Describes which of the two hands was detected, the left or the right hand.
- `Palm Position` — Calculates the center of the palm in millimeters relatively to the Leap Motion origin.
- `Palm Velocity` — The velocity and direction of the palm movement in millimeters per second.
- `Palm Normal` — Represents a vector perpendicular to the plane formed by the palm of the hand, while the vector points downward out of the palm.
- `Direction` — A vector pointing from the center of the palm toward the fingers.
- `grabStrength`, `pinchStrength` — Describe the posture of the hand.

The motion factors provide relative translation, rotation and scale differentiations in movement between different frames. Additionally, the vector class includes methods that retrieve the pitch (rotation around the x-axis), yaw (rotation around the y-axis), and roll (rotation around the z-axis) rotations of the detected entity. [26]

ii. Unity 3D

Unity3D is a popular cross-platform game development tool created by Unity Technologies and is commonly used for the development of PC, consoles, mobile devices video games and applications. This game engine focuses on portability, while it targets APIs, such as Direct3D, Xbox 360, OpenGL, OpenGL ES and APIs on video game consoles. Furthermore, it gives the possibility to publish the applications for Android, Apple TV, BlackBerry 10, iOS, Linux, Nintendo 3DS, OS X, PlayStation 4, PlayStation Vita, Unity Web Player, Wii, Wii U, Windows Phone 8, Windows, Xbox 360 and Xbox One. [28]

Unity's versatility includes the ability to determine the appropriate texture compression and resolution settings for each platform that it supports. Additionally, the game engine provides reflection mapping, bump mapping, parallax mapping, screen space ambient occlusion (SSAO), dynamic shadows using shadow maps, render-to-texture and full-screen post-processing effects. The graphics engine platform of Unity3D recognizes the most compatible modification of the shader regarding the video hardware of the system, since it allows alternative specifications for the shader [29], while it includes an asset server and Nvidia's PhysX physics engine.

One of the most usable features of Unity3D is the integrated editor, which within a simple user interface combines external editors for scripting, texturing and model editing, while it also provides a convenient asset and file organization system. The graphical power of the

game engine is also highly optimized, since it can support high resolution meshes without significant frame rate decrease. As for the importing of assets and different files like textures, models and scripts, all common file formats are being supported by Unity and the procedure is very simple.

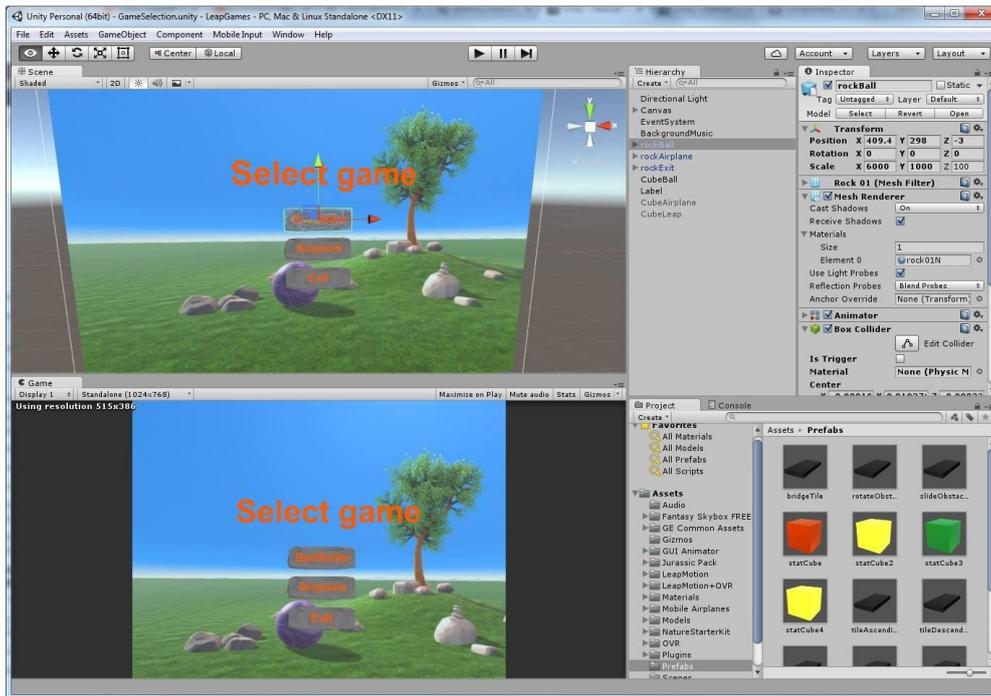


Figure 2 - Unity3D environment

Unity's shader system is usable and flexible; it includes different shaders from the simple like Diffuse or Glossy, to more advanced, like self illuminated bumped specular etc. The built-in shaders can be successfully combined with any type of light. On the other hand it is possible to create custom shaders by using ShaderLab language with Cg and GLSL. The terrains of Unity are not very demanding regarding the hardware and can perform uncomplicatedly on low-end hardware, as long as the models contain a reasonable amount of polygons. The lights and the shadows available in Unity3D include realtime soft-shadows, baked lightmaps, halos and lens flares.

Unity3D also contains a network system that allows the development of full featured real-time multiplayer games, since it is able to access HTTP servers and establish connection with PHP websites. As for the physics, the game engine includes a built-in physics engine Ageia PhysX™, which supports rigidbody that reacts to the forces being applied, creates collisions and does not require scripting to work. Unity3D provides rich libraries and thorough documentation regarding the .NET-based C# and JavaScript scripting. In addition to the native Unity editor, the users may utilize Visual Studio editor and also compile the scenes in Unity3D with Visual Studio by adding UnityEngine.dll.

iii. C# (sharp)

C# is an object-oriented, modern and general-purpose programming language that was created and developed by Microsoft. The combination of C# and the Microsoft's .NET platform gives the possibility to develop various applications, such as web applications, websites, desktop applications, office applications, mobile applications, video games and

others. C# has some resemblance with other high level languages like Java and C++, and a little bit less to languages like Delphi, VB.NET and C, which as well contain sets of definitions in classes that include methods and the methods hold the whole program logic.

Lately C# is being commonly used by the majority of the developers around the world and has become one of the most popular programming languages. Of course the language is more extensively spread among organizations, companies and individual programmers that are supporters of Microsoft, since C# is created by Microsoft as part of the .NET Framework. Also, it is worth to be mentioned that the C# programming language and the .NET platform are not open to third parties and are both maintained and managed entirely by Microsoft, while the Java platform is an open source project.

The C# language is being distributed with the Common Language Runtime (CLR), a component of .NET Framework that manages the execution of the C# program, contains standard libraries and provides basic functionality, compilers, debuggers and other development tools. The C# program is versatile and operates appropriately on diverse operating systems and hardware platforms. This versatility is provided by the .NET Framework and the CLR and it allows the execution of the C# programs on Windows Phones, Windows Mobile and other portable devices, while it is usual for the C# programs to be executed on Microsoft Windows. Of course the C# programs can also operate on Linux, FreeBSD, iOS, Android, MacOS X and other operating systems thanks to the free .NET Framework implementation Mono, which is not officially supported by Microsoft [30].

Within the Unity3D game engine environment the programmer has the possibility to select among three different languages to use for the development, C#, JavaScript and Boo (available until 2014 releases of Unity). The selection of the appropriate language for each developer is rather personal, since it strongly depends on his experience with these languages. The developers experienced in C++ or Java would probably select C# as the most convenient choice among the other languages, while someone that has a background in dynamically typed languages like JavaScript, Basic or PHP are likely to choose JavaScript.

On the other hand, a beginner developer without specific experience in programming would probably try out JavaScript, since the language does not concern the users with variable types, castings or memory allocations. Additionally, it is worth to mention that the JavaScript language within the Unity3D environment is a slightly different version of the popular JavaScript used for Web development and is called Unity Script among the members of the community, thus before selecting it for the development of an application, even an experienced in JavaScript programmer should take a look at the specific version of JavaScript to be accustomed with it. [31]

IV. Other sensors used for rehabilitation and therapy



Figure 3 - Different motion sensing devices approximately scaled for their size comparison (from left to right Leap Motion Controller, Intel Creative Gesture Camera, Asus Xtion and Microsoft Kinect). The scale bar is 10 cm.(adopted from [32])

The Leap motion controller was selected from all currently popular motion sensors for the purposes of the current thesis because of its superior accuracy compared with other sensors in detecting hands and fingers [33], since carpal tunnel syndrome therapy requires execution of exercises mostly for wrists and fingers. Although, it is interesting to review the other motion sensors and discuss their capability to become rehabilitation tools.

i. Microsoft Kinect

Kinect is a motion sensing input device created by Microsoft, which was built for Xbox 360 and Xbox One video game consoles and, also, has a version suitable for Windows PC. Kinect enables users to control the applications through a Natural User Interface (NUI), where they can interact with the system wirelessly and without a game controller by using gestures, moving the body in the 3D space or by using spoken commands. The device contains an RGB camera, a depth sensor and a multi array microphone and its dimensions are approximately 25cm x 10cm x 6cm. Kinect is usually placed below the screen, where the user observes the feedback of his detected movement. [32] [34]

The depth sensor included within the device contains an infrared projector and a monochrome CMOS sensor, thus providing the users with the capability to track objects and movement in 3D space regardless of the lighting conditions.

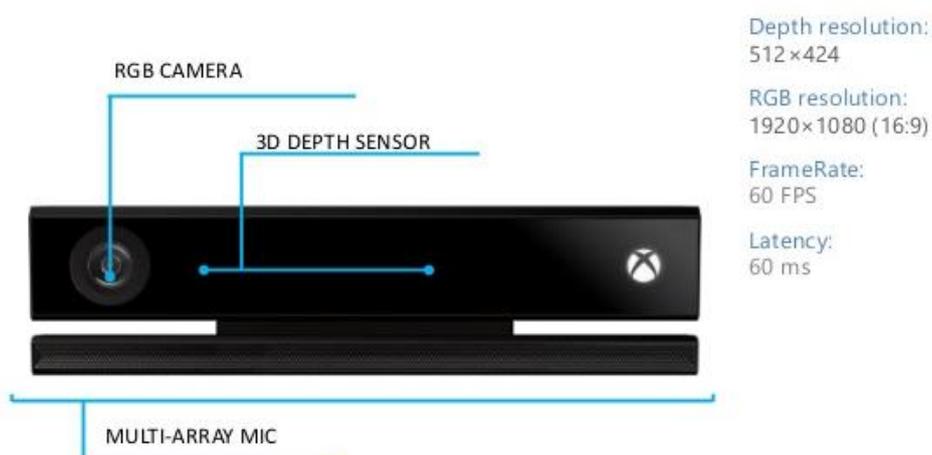


Figure 4 – Kinect sensor for Xbox One(adopted from [35])

The first version of Kinect sensor captures streams of RGB, depth, and infrared data with frame rate of 9–30Hz depending on resolution, while the default display resolution of these streams is 640 × 480 pixels and can be increased up to 1280 × 1024 with a lower frame rate. The default RGB stream uses 8bit VGA or UYVY color format resolution and depth stream of 11 bit, which provides 2048 different depth sensitivity levels. The space required for the appropriate use of Kinect sensor is on average 6 m² and the depth sensor can be adjusted to either near or far range mode, where in near range mode people the device detects users within the range of 0.4–3m and in far range mode within the range of 0.8 – 4 m. However, the detection functions better in the recommended range 0.8– 3.5m. Kinect’s angular field of view is 57°horizontally and 43° vertically, while the motorized pivot is able to tilt the sensor 27°up or down. The microphone array of the device can process 4 channels of16-bit audio with the four featured microphone capsules it contains at a sampling rate of 16 kHz.

The second version of the Kinect that was released in 2013 with the Xbox One console contains a time-of-flight sensor instead of the previous PrimeSense hardware and offers new features and optimization of the existing features. The detecting of the body is better than in the first version of Kinect, since the range of tracking is wider, the detected positions and the smaller object detection are more accurate and the number of users detected at the same time has been increased from 2 to 6.The new video resolution is 1080p and infrared now can be used at the same time as color. [32]

	Kinect	Kinect 2
Method to calculate depth of objects in scene	Structured light	Time of flight
Developed by	Microsoft + PrimeSense	Microsoft
Resolution	480P	1080P
Number of skeletons tracked	2	6
Bone orientations	No	Yes
Forces at body joints	No	Yes
Muscle simulation	No	Yes
Recognizing expressions	No (You can write your own algorithm if you want)	Yes
Face tracking	Yes	Yes
Measuring heart rate	No	Yes
SDKs available	Kinect for windows SDK v1.8	Kinect for Windows SDK v2.0

Table 2 – Comparison of Kinect 1 for Xbox 360 and Kinect 2 for Xbox One [36]

All these features of the Kinect sensor make it an appropriate, usable and affordable motion sensor for physical therapy and rehabilitation applications. Of course the conversion from a commercial game controlling device to a clinical therapeutic tool requires further study and research, so that the tracking of the patient, the monitoring of the exercise performance and their evaluation are not obstructed by occlusions in the image and noises in skeleton tracking. [37]

ii. Nintendo Wii

The Wii Balance Board is an accessory compatible with Wii and Wii U game consoles that was released in 2008 and has similar shape to the household body scale. It uses the

Bluetooth technology to exchange information with the Wii console, like the other wireless accessories and controllers of the console.

The device consists of multiple pressure sensors, which form a reliable and very accurate source of data for the calculation of the center of balance and weight of the user. The Balance Board is an isometric input device, so the users can't control the particular degrees of freedom precisely, even though the pressure sensors located in the corners of the board give it four degrees of freedom. Additionally, it is not possible to modify the amount of pressure that is being applied to one of the sensors, without altering the pressure on the other sensors, since the Balance Board supports the weight of the user. [38]

The movements and postures, like balancing on one leg, rotating or bending the body, sitting, kneeling and lean on the hands, supported by the software behind the Balance Board can also be used in therapeutic game systems for physiotherapy and rehabilitation [39].



Figure 5 – Wii Balance Board (adopted from [40])

One disadvantage of the Wii Balance Board system is that it is not possible to use multiple Balance Boards at the same time, because only one Balance Board can be connected with the system at a time and the board uses the connection of the fourth player controller, by replacing the Wii Remote that is occupying that connection at that moment. [9] [10]

iii. Playstation EyeToy

PlayStation EyeToy is a color digital camera device, which has a similar functionality with a web camera and is compatible with the Sony PlayStation 2 game console. The system behind the device processes images that are taken by a camera embedded in the device, by using computer vision and gesture recognition. The users can control the games with gestures and voice commands, since the device recognizes the gestures by detecting motion and color and the voice commands with the built-in microphone. [6] A second version of EyeToy was released in 2007 for PlayStation 3 with the name PlayStation Eye and has improved web camera resolution, frame rate and sensitivity.

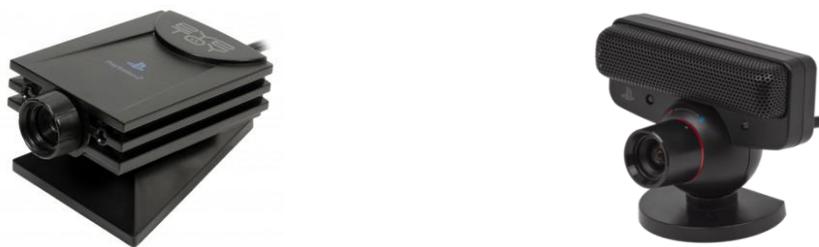


Figure 6 – Playstation EyeToy (left) and Playstation Eye (right) (adopted from [41])

A study by Yavuzer, Senel, Atay and and Stam [42] and another one by Neil, Ens, Pelletier, Jarus and Rand [4] contain research and clinical trials on using the EyeToy sensor for stroke rehabilitation and mention the benefits from using the device for home-based rehabilitation. The first study performed trials with twenty patients suffering from hemiparesis after they had stroke. The sample size was divided randomly into two groups of post-stroke patients, the first group used the EyeToy sensor for 4 weeks and the other group constituted the control group, which just watched the games for the same duration as the players group without physical participation. The results of the study showed that the combination of using the Playstation EyeToy games with the conventional treatment had a positive impact in terms of upper extremity-related motor functioning.

The second study also performed clinical study with two groups, the one with post-stroke participants and the other with healthy individuals. The participants tried two different gaming consoles, the Playstation EyeToy and Nintendo Wii. The study shows the assistance of the gaming consoles in the process of the rehabilitation, but also points out the limitations of such systems in terms of usability, monitoring and assessment.

iv. Playstation Move

PlayStation Move is a game controller device, compatible with the PlayStation 3, the PlayStation 4 gaming consoles and the PlayStation VR platform, initially released by Sony in 2010. The user controls the game by performing physical movements while holding the controller, similarly to Nintendo's Wii Remote and Microsoft's Kinect. PlayStation Move is used combined with the PlayStation Eye or PlayStation Camera, which track the position of the controller, while inertial sensors within the device detect motion.



Figure 7 – Playstation Move game controller(adopted from [41])

On the PlayStation 3 console it is possible to use four PlayStation Move controllers simultaneously. The controller contains a three axes angular rate sensor and a three axes accelerometer, similarly with the Nintendo Wii Remote controller, with the difference that the upper part of the PlayStation Move controller is a luminous sphere which can glow in different colors using RGB LEDs. The glowing sphere on top of the controller is used to facilitate the detection of motion and position of its origin, while the different colors are used to distinguish specific users by their controller's color. When the user performs left and right movements, while holding the controller, the system recognizes the axis of the motion, based on the light from the sphere. Also, the system can detect the position of the user in the Z axis, which means the distance of the user from the console, by comparing the size of the glowing sphere. [43]

V. Related work

The last decade there have been many attempts [44] [45] [46] to take advantage of the emerging motion sensor technology in the fields of physiotherapy and rehabilitation. The variety of the sensors and the constant optimization of their potentiality and features make them convenient for the therapy of different motor disabilities. Many of the attempts are mostly academic research [47] [48] that includes some prototypes of video games using sensors for physiotherapy treatment, but there are also commercial products developed by technological companies.

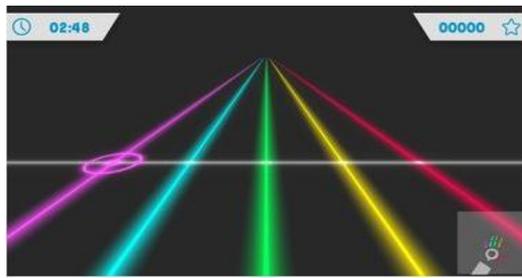
VirtualRehab Hands [23], a mini-gaming platform developed by Virtualware, is using the Leap Motion controller for recovery from various health problems, such as Parkinson's disease, stroke and other. The games that use Leap Motion sensor's hand detecting technology are easy and amusing. According to Virtualware, the platform they developed is among the first virtual rehabilitation software to be classified as a medical device, under the EU's Medical Device Directives.



Figure 8 - Virtual Rehab hand rehabilitation game (adopted from [23])

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At the moment the system is being used in the National Hospital for Neurology and Neurosurgery at Queen Square in London, while, according to the Director of International Business Development of the company, the platform has been tested by patients and physiotherapists in installations in Europe, Latin America and the Middle East. It is also scheduled to be installed in other hospitals and to be used by stroke patients during remote rehabilitation.



01 **Magic Chords:** The patient can touch the circle with the corresponding finger as soon as they move towards the end of each line. Every coloured line represents a different finger on the hand



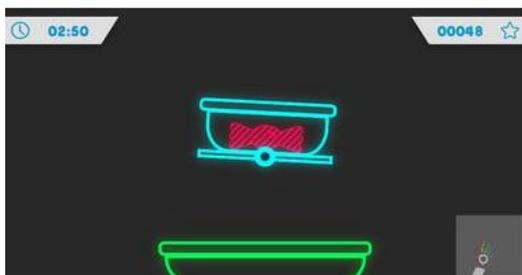
02 **Star Trap:** The patient places their hand flat, closing or spreading their fingers moving the pieces along the screen. When the star begins to descend from the top, the user has to move on of the semi circlus to trap it.



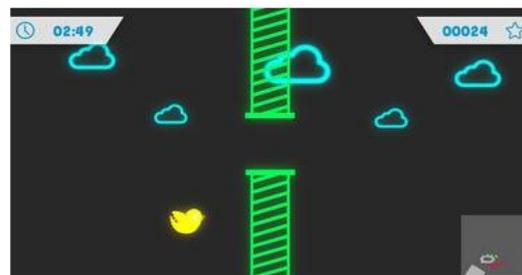
03 **Balloon Pop:** Balloons begin to move across the screen towards the dart. The patient can pop the balloon and gain points by moving the dart up by opening their hands and down to by closing their fingers into a fist.



04 **Blast off :** The objective of this game is to put out the fuse on the firecracker before it can take off, touching the tip of each finger, improving hand-eye coordination.



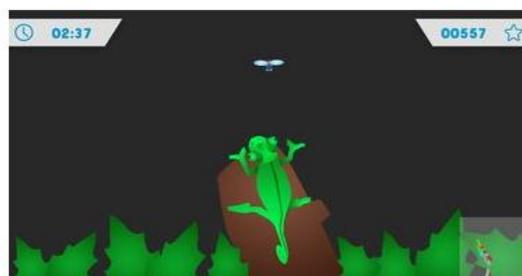
05 **Candy Toss:** The user needs to hold their hand in a supination position and then rotate it to a pronation position so as to drop the candy from their bowl to the next bowl.



06 **Birdy:** the user controls a small bird and has to help it fly through openings located at different heights in walls that appear onto the screen, moving the bird up or down to fly through the openings.



07 **Frog Jump:** the user controls a frog which must jump from one lily pad to another, moving their hand laterally through ulnar or radial deviation to coincide with the location of the lily pad.



08 **Hungry Chameleon:** The user controls the chameleon's head with flexion and extension movements of the hand in a horizontal plane in order to point it in the direction of the buzzing fly to shoot out its tongue to catch it.

Figure 9 – VirtualRehab Hand mini games(adopted from [23])

The same company developed the VirtualRehab Body platform that employs the skeletal tracking and motion detection technology of Microsoft Kinect to detect and capture the movements of the patients within a game environment. The games include exercises that help patients with motor disabilities and movement difficulties to preserve and regain upper and lower limb motor functionality. Additionally, the platform displays guidelines for the correct execution of the exercises and store the execution information or recording to provide feedback to the patient and allow the remote monitoring of the patients performance and progress by the therapist. The platform is suitable for home exercise program or for usage within clinics and hospitals.



Figure 10 - VirtualRehab Body platform mini games (adopted from [23])

The first game, shown in the figure below, promotes static and dynamic balance, as well as load transfer. In this game the user is catching the objects that appear on the screen with their hands and avoiding lower obstacles by raising their feet and step on specific tiles.

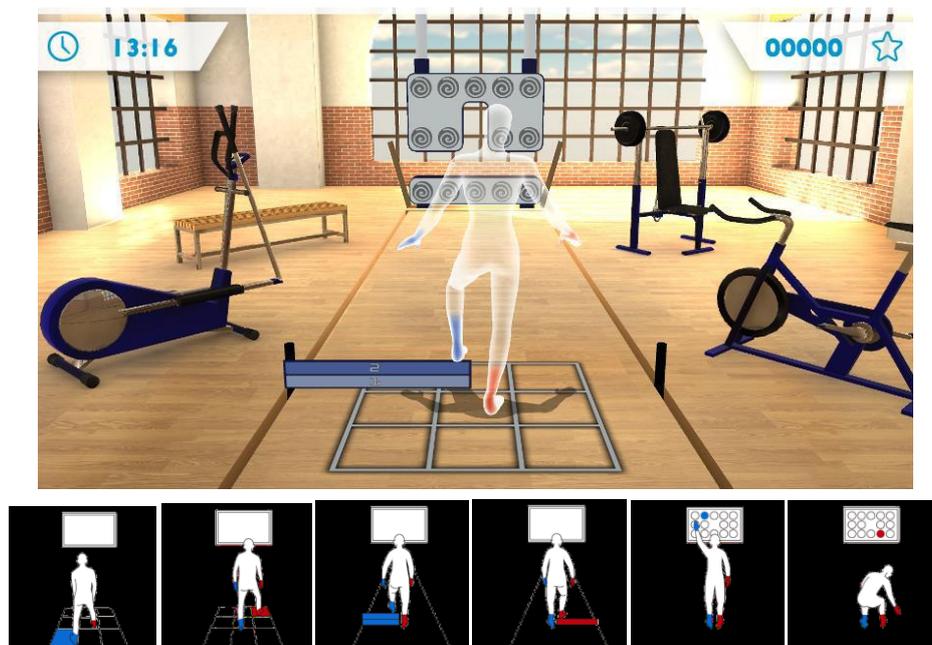


Figure 19 – VirtualRehab Body platform's "Bullseyes&Barriers" game (adopted from [23])

The next game's goal is for the user to take a shape with his body similar to the shape of the avatar that appears on the screen. This exercise helps the users to maintain and increase their flexibility and balance.

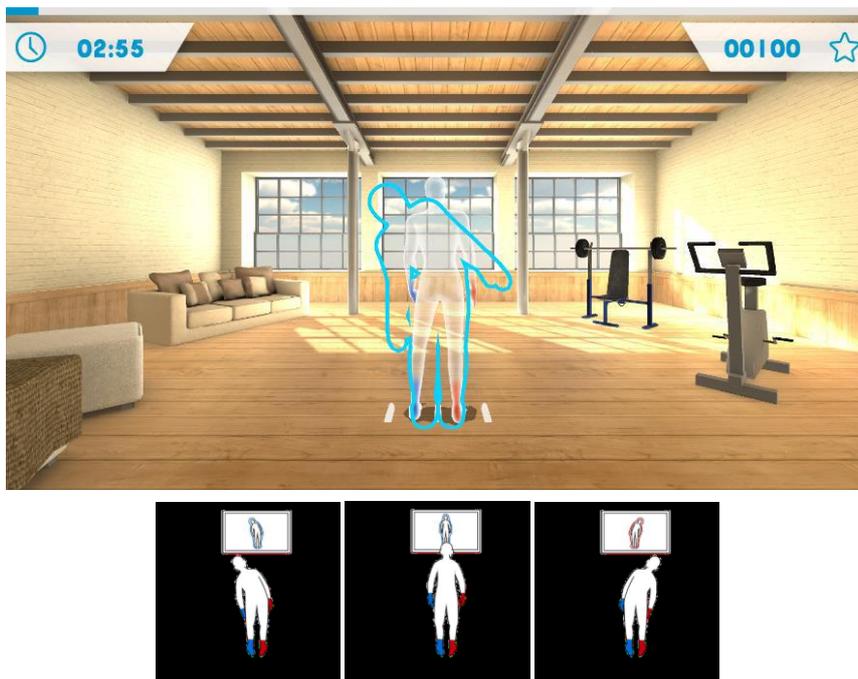


Figure 11 - VirtualRehab Body platform's "Fit in the figure" game(adopted from [23])

Another game that simulates the rowing in a boat urges the user to perform coordinated parallel movement of the hands, thus training the upper limbs.

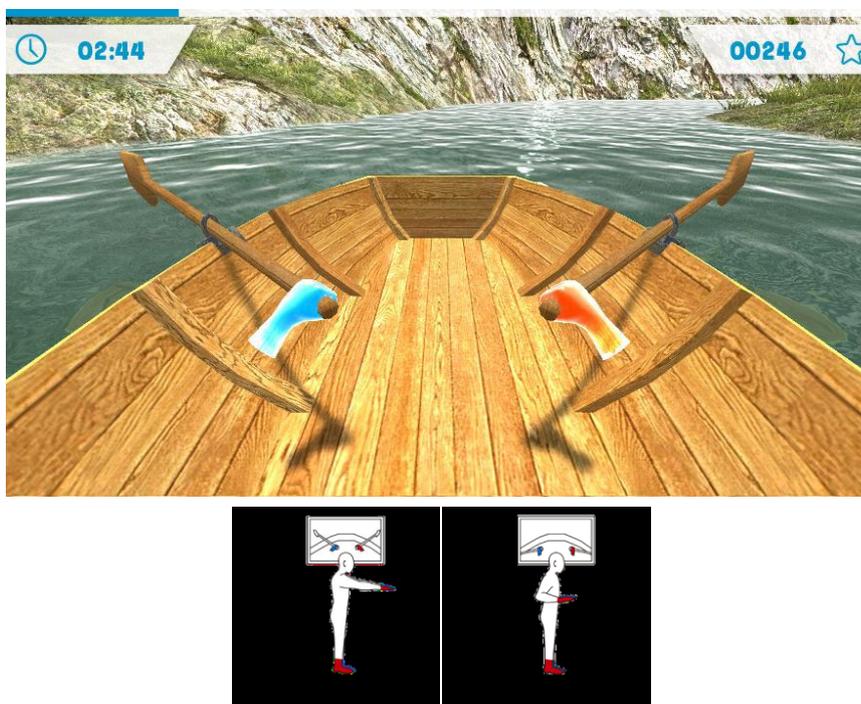


Figure 12 - VirtualRehab Body platform's "Row the boat" game(adopted from [23])

"Bail out the water" is a game affecting trunk control, body scheme and hand-eye coordination. The goal of the user is to bail the water out of a boat by using a pump, which is activated by performing a parallel, but inverted, movement of the hands.

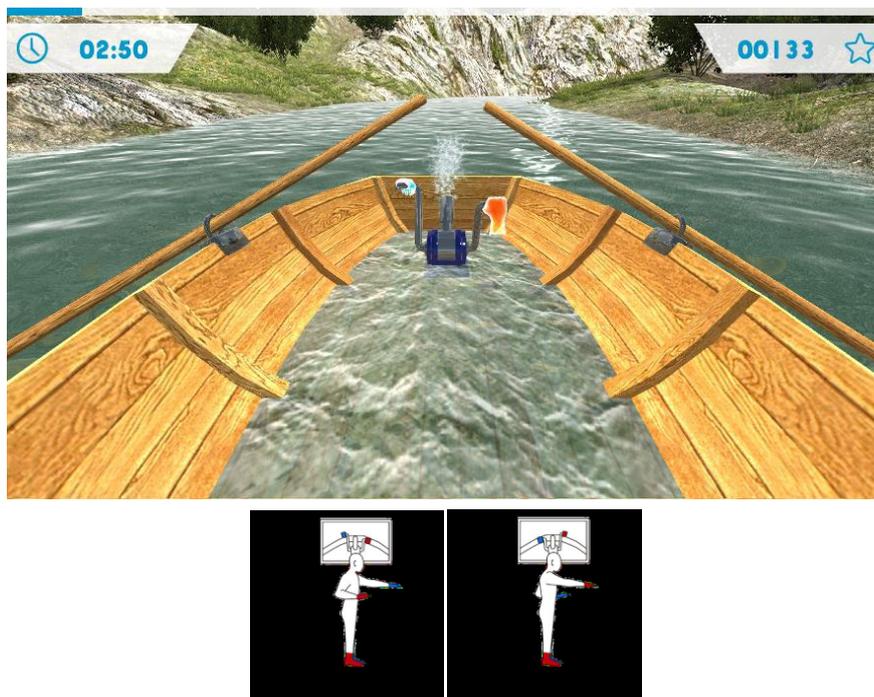


Figure 13 - VirtualRehab Body platform's "Row the boat" game(adopted from [23])

According to Virtualware, there are plans for the future to enhance the platform with additional games aiming different common neurological and physical disorders, based on research and consultation with the specialists. Furthermore, the company intends to develop an assessment module for the therapists.

Another example of sensors used for physical therapy is the serious game developed by X-TECH Games team [49]. The game utilizes the Kinect motion sensor to motivate the patients with different motor disabilities to perform their prescribed physical therapy exercises, but also urges casual users to get trained and gain body functionality improvement. The game, which is called "Kinect therapy – Boat Driving", involves the gathering of buoys in the sea by a boat driven by the user. The buoys score points and have to be gathered within certain time limits. These elements of time limit, score and rewarding instigate the users to execute the exercises often and for longer time. The user can operate the boat by performing rowing movements of the hands.

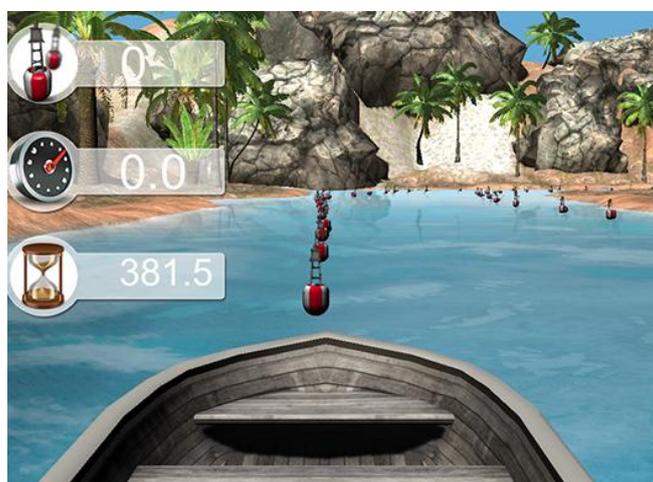


Figure 14 - "Kinect therapy – Boat Driving" game by X-TECH Games team(adopted from [49])

Another commercial game platform that utilizes the Leap Motion controller for the purpose of rehabilitation and physical therapy is Visual Touch Therapy software program by the company Ten Ton Raygun [7]. The platform aims to make the therapy fun and engaging, while allowing the monitoring and assessment by the therapists to be easier. The target group of these therapeutic games is mostly patients that had stroke, but also individuals with spinal cord injuries, head injuries and nerve damage.

The Leap Motion Controller supports various movements and gestures, like swipes, taps, pushes and pulls, grabbing, grasping and side to side arm movements. Therefore, it gives the opportunity to the developers to implement a wide range of exercises. The games combine typical video game visual style, rewarding system with prompt feedback and various exercises for stroke rehabilitation, including hand and eye coordination challenges. The game scenario involves the Rocket Dog avatar that advances through the game levels and gains new abilities, such as speed, strength and rocket pack.

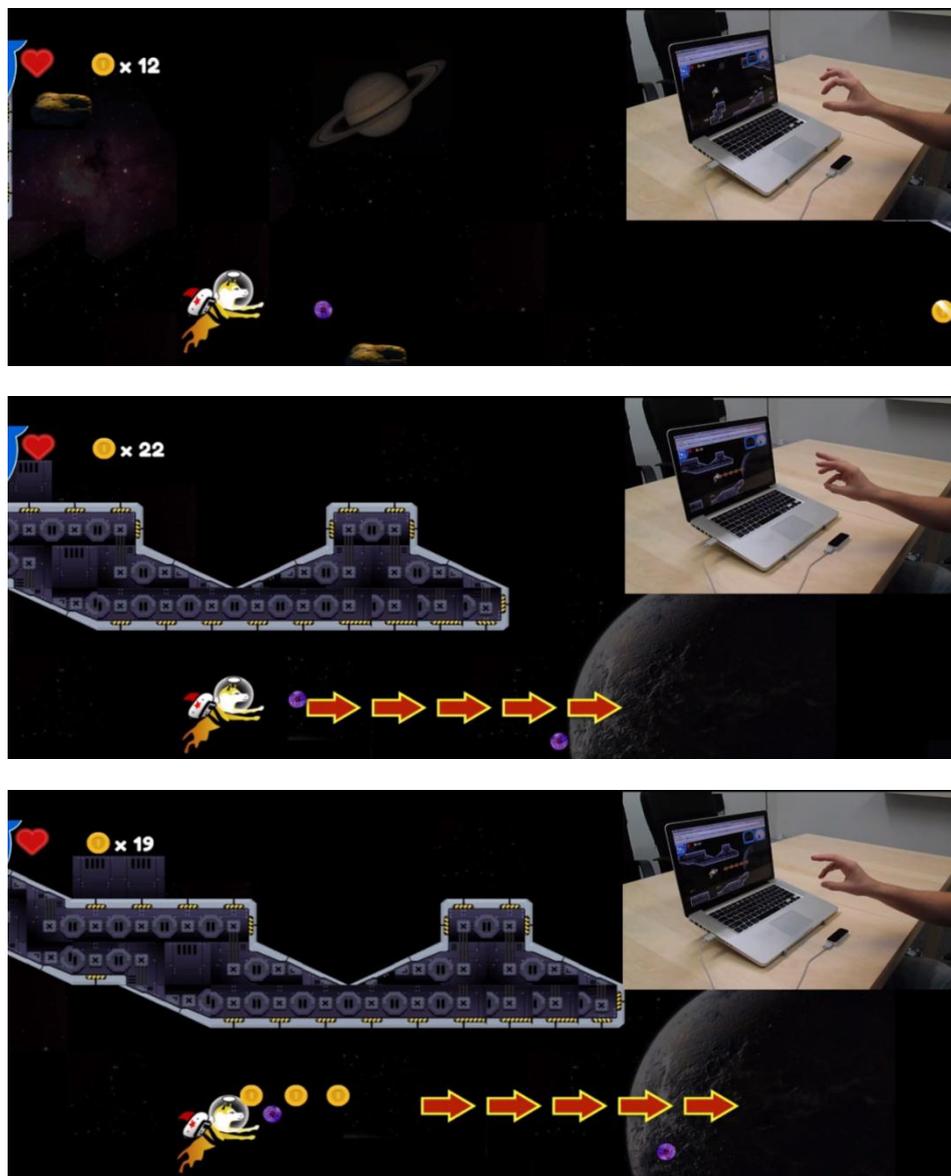


Figure 15–“Rocket dog” stroke rehabilitation game that utilizes the Leap Motion sensor(adopted from [7])

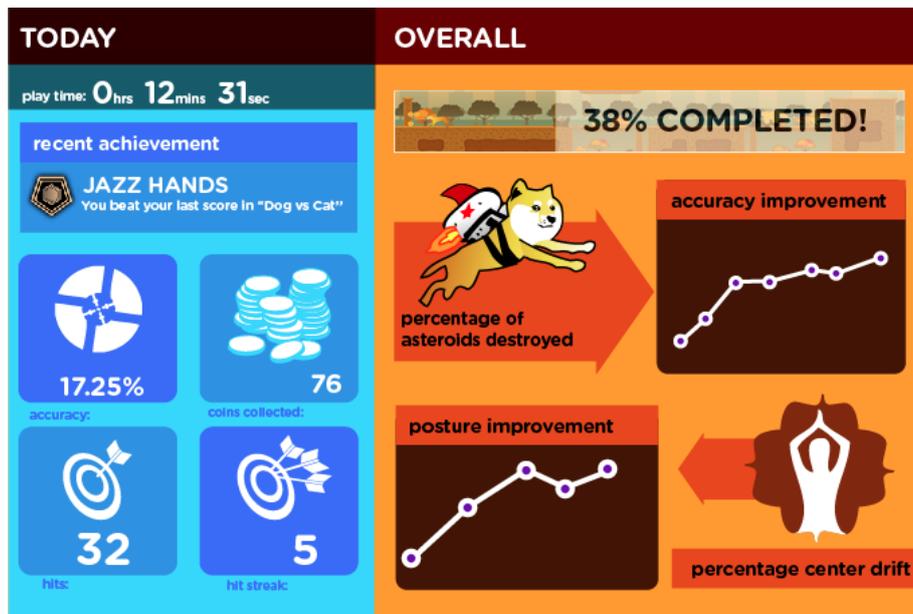


Figure 16 – Statistic data of the patient’s performance in the game(adopted from [7])

An interesting study by L. Geurts, V.Vanden Abeele, J. Husson, F. Windey, M. Van Overvelde, J. H. Annema and S. Desmet [48] describes in detail the whole iterative process of requirements specification, design, development and evaluation of four mini games for patients with spasticity. Patients with spasticity suffer from involuntary muscle contractions, which happen because of lesions in the central nervous system that regulates and coordinates muscle tone. Different conditions like cerebral palsy, multiple sclerosis, spinal cord injury and acquired brain injuries, including stroke, lead to spasticity and its consequences, such as uncoordinated gait, stiff body posture and decreased range of limb movement and functionality. These symptoms are usually treated with physical therapy that aims to increase the mobility of the patient through the stretching and the strengthening of the muscles.

For the purpose of the study the authors of the study organized several workshops with the participation of patients and therapists in order to specify the requirements of the games at first, and later to try the prototypes of the games. The physical therapy exercises that correspond to each game and the sensors used for the game play are displayed in the table below:

Game	Physical exercise	Sensors
Catching Dishes	Stretching and bending of the arms	Webcam
Collecting Eggs	Maintaining balance standing on one leg	Wii remote & MotionPlus
Preparing Recipes	Controlled head movements	Wii remote (IR camera)
Flying Dragons	Transfer of weight and balancing when seated	Balance board

Table 3 - The four minigames with corresponding physical exercises and used sensor technologies. (adopted from [48])

In the first mini game the user has to catch flying dishes that are being thrown by a non-player character by stretching the arms and put them in a pile in the middle of the screen by moving the hand to the middle. This way the patient performs extension of the elbow and exorotation of the shoulder.



Figure 17 - The mini game 'Catching Dishes' is controlled by the player's hand covered by a colored cloth. The player sees and controls a virtual hand on the screen (top left) to catch a dish (right to the virtual hand). (adopted from [48])

In the second mini game the user has to maintain his balance, while standing on one leg, so he can gather eggs by jumping from mountain top to mountain top in the game environment. The user has to raise his leg above a certain height in order to perform a jump in the game environment and keep flying; otherwise the avatar lands on the nearest mountain top.

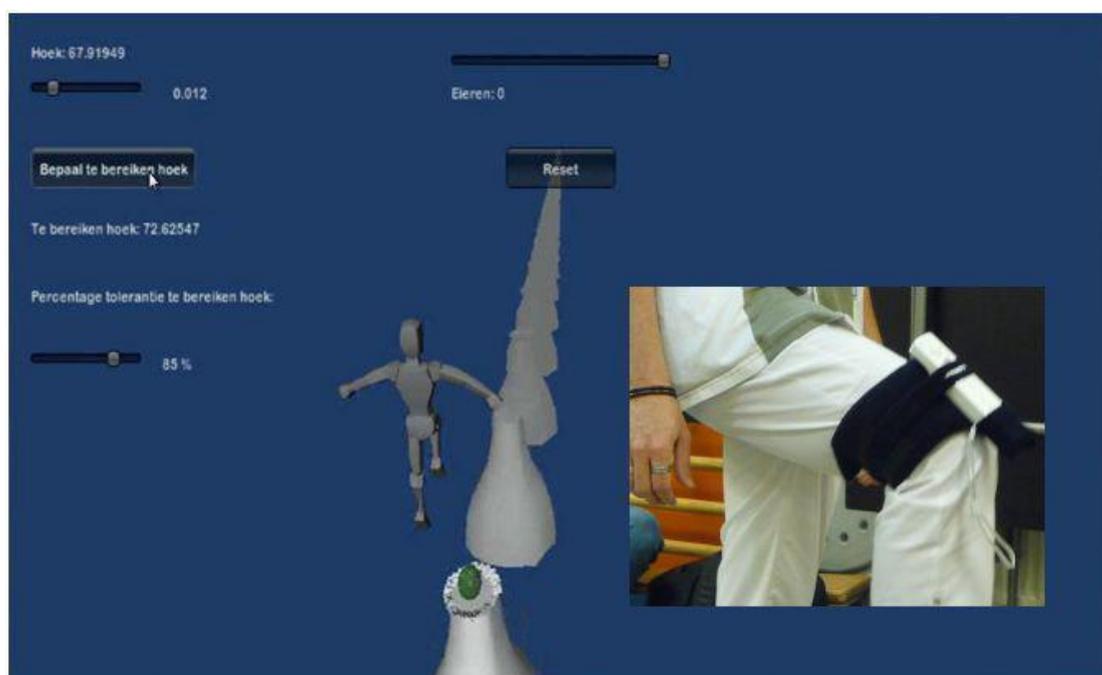


Figure 18 - The mini game Collecting Eggs is played with a Wii remote on the upper leg. When lifted high enough, the game character will jump from mountain top to mountain top. (adopted from [48])

In the third mini game the users have to sit still and select ingredients from the screen and throw them in a cooking pot by moving their head left and right. These rotations of the head
The physical exercise focuses on a rotation of the head horizontally and vertically constitute the physical therapy exercise.

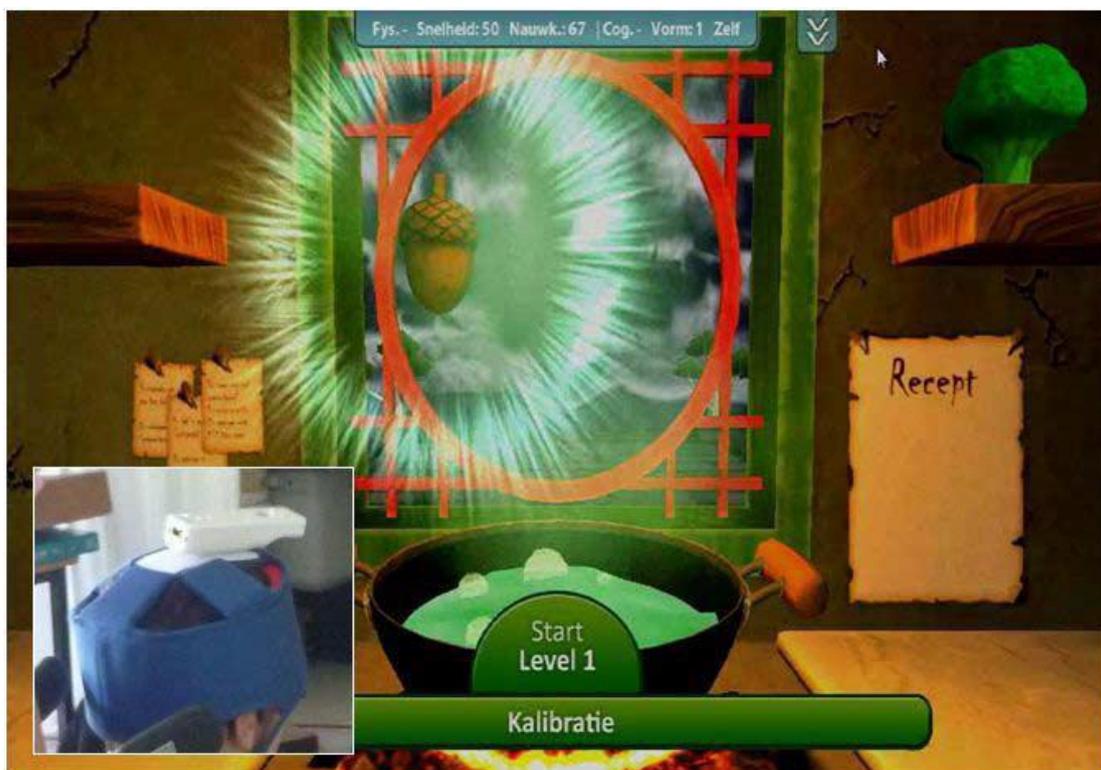


Figure 19 - Preparing Recipes is played with the Wii remote on the head. The player controls the magic selection circle to catch ingredients and put them in the cooking pot. (adopted from [48])

In the fourth mini game the users are trying to fly a dragon through rings, by changing their balance, while sitting. The weight transfers in this exercise strengthen the muscles of the back and the abdomen.

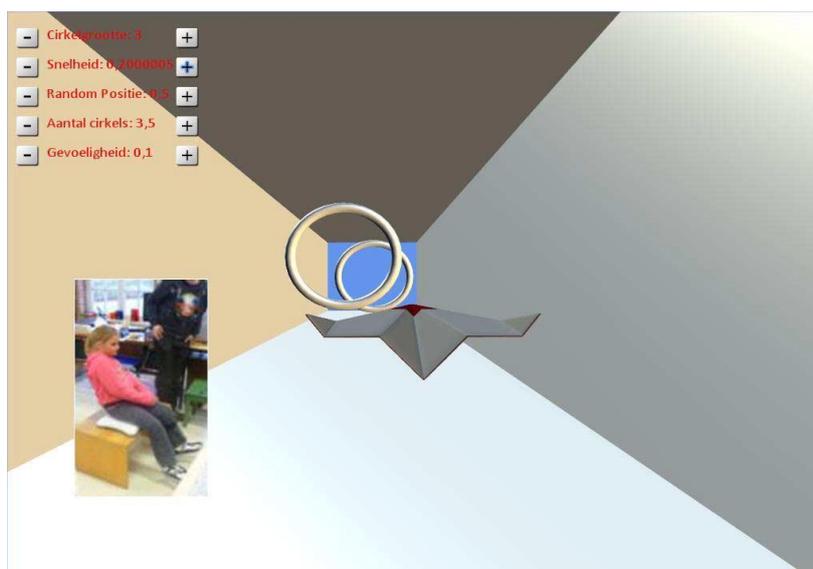


Figure 29 - Flying Dragons: By shifting weight on the Balance Board, the player controls the dragon that has to fly through the rings. (adopted from [48])

As can be seen in the examples above, there are many attempts to develop physical therapy and rehabilitation platforms with the use of Kinect and Wii sensors. However, the Leap Motion sensor, despite the potential it offers in accuracy and portability, is still new in game development industry and especially in the field of therapeutic applications. The idea of developing a physical therapy game platform for the carpal tunnel syndrome with usage of Leap Motion controller seems very promising, due to increased accuracy of the sensor compared to other sensors, and quite original, since similar application examples haven't been found in the literature research.

VI. Customized Exergames for CTS using the Leap Motion sensor

It is very important for the further development and progress of the therapeutic and rehabilitation systems with the use of the Leap Motion sensor, like the one that was attempted to be developed within the context of the current thesis, to conduct experimental studies involving a large sample of Carpal Tunnel Syndrome patients, in order to acquire valid clinical results, based on which such system can be adapted and improved. Different studies that concern a specific physical and mobility impairments would significantly contribute to the advancement of these treatment applications.

Another important step would be to create open source libraries of different sets of gestures that would be useful for the development of the therapeutic applications, since that at the present time the existing gestures sets are very limited and intended for simple application and game controlling. Specifically, for the Carpal Tunnel Syndrome there are more exercises that can be implemented and added to the existing therapeutic game platform. Additional movements can be seen in the figure below.

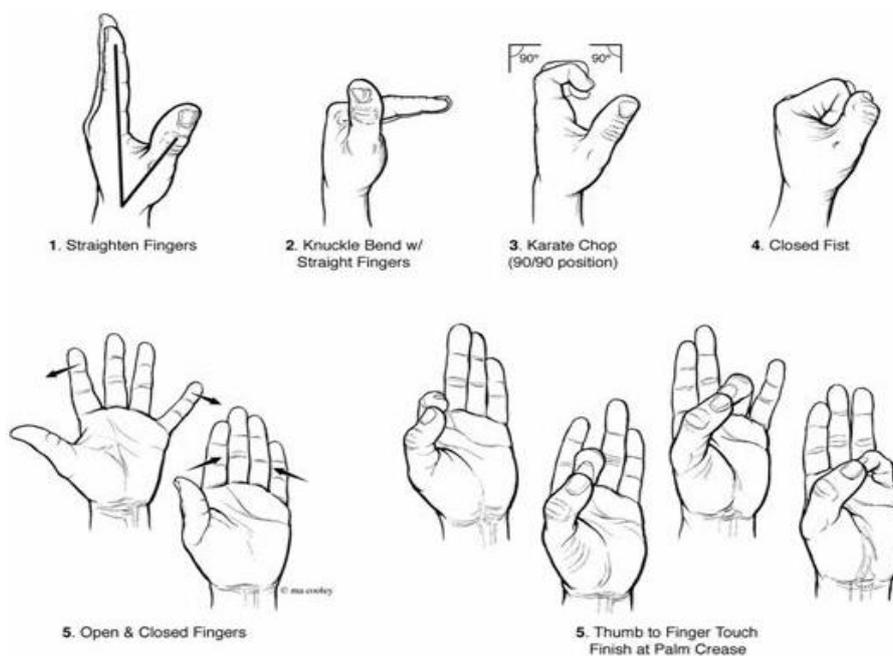


Figure 20 - Additional exercises for the Carpal Tunnel Syndrome treatment

Of course, the use of Leap Motion sensor in physical therapy and rehabilitation is limited, because it is only appropriate for the arm, hand and fingers tracking, so it can be used for specific therapeutic applications. However, it can be combined with other existing platforms to be able to calculate all the metrics and detect and track a rich set of body gestures. For example, Leap Motion sensor can compensate for the lack of precision of Microsoft Kinect in detecting hand gestures like pronation/supination and flexion/extension of metacarpophalangeal and the proximal interphalangeal joints of the hand, while Kinect is more appropriate for other body movements tracking. This combination of sensors would provide the therapist with sufficient data for the comprehensive assessment of the patient's condition and therapy progress.

Implementation

The initial idea of this master thesis was the implementation of a rehabilitation platform with the use of motion sensor technology, since it has a lot to offer in the field of physical therapy treatment and especially for home-based rehabilitation and remote patient monitoring. After research of the related work it has been determined that state-of-the-art prototypes usually implement such therapeutic platforms for stroke patients or the Parkinson's disease patients and that research has not been performed yet in the field of the carpal tunnel syndrome therapy with the use of motion sensors; notwithstanding that the particular syndrome has become very common, especially with individuals performing repetitive movements, like computer users and typists.

The implementation of the therapeutic games for the Carpal Tunnel Syndrome physical therapy treatment with the use of a motion sensor, described in this chapter of the master thesis, required several steps to advance from the phase of requirements analysis and selection of the appropriate tools to the final implementation and evaluation phase. The first step of the implementation included several meetings and discussions with a physiotherapist in order to acquire the necessary general knowledge about the syndrome, like simplified anatomy of the wrist and carpal tunnel area, the causes of the condition and mainly the treatment methods.

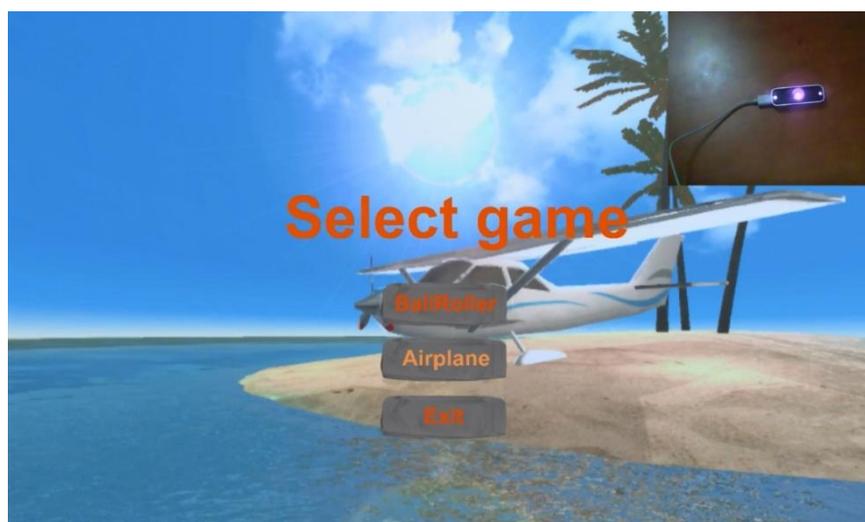


Figure 21 - Game selection scene and the Leap Motion sensor

After these meetings and the final definition of the system requirements, it was possible to select the appropriate motion sensor technology that could be used to detect the movements of the patients during the performance of the therapeutic physical therapy exercises with enough accuracy to be able to track fingers and even specific joints or fingertips. So, through the literature research, the Leap Motion sensor was found the most appropriate motion sensor controller for the desired application in terms of accuracy of hands, fingers and joints detection. Subsequently, the selection of the Unity game engine was based on a previous experience with the specific game engine, but also on the simplicity and usability of its environment.

When the goal was established and the tools were selected, it was possible to choose several physical therapy exercises, which would be performed by the users to control the 3D game environment. The initial exercise set, proposed by the physical therapist, contained ten distinct movements of the wrist and the fingers, including different rotations and postures of the wrist and the joints of the fingers. Finally, four exercises were selected to be used for the games. The first combines extension and flexion of the wrist, which means upward and downward rotation of the wrist, the second combines ulnar and radial deviation of the wrist, which means wrist rotation to the right and to the left, and the other exercises are variations of the first two with closed fist.

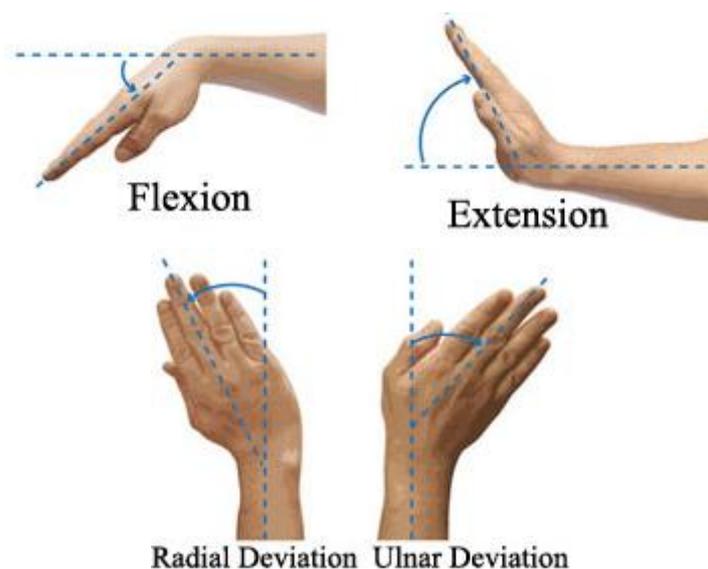


Figure 22 - Extension - flexion exercise (up) and ulnar-radial deviation exercise (down)(adopted from [50])

The concept of the games was based on these exercises, so that the movements of the exercises would be corresponding to the movements of the avatars in the game environment and the user would naturally perform the exercises without confusion. The basic idea of the first game is to use physical therapy exercises to move a ball avatar across the scene through a bridge, while trying to avoid different obstacles and stay on the bridge. The game is over, when the ball falls off the bridge or when the player reaches the winning point. The exercises, used for the navigation of the ball are ulnar deviation of the wrist to rotate the ball to the right, radial deviation to rotate it to the left, extension to stop the ball and flexion to move it backwards, while having a closed fist. The forward movement is constant for reasons of making the game more challenging for the user.

Physical therapy exercise movement	Game avatar movement
Wrist extension (upward rotation)	Stop the ball avatar
Wrist flexion (downward rotation)	Move the ball backwards
Wrist ulnar deviation (rotation to the right)	Turn the ball to the right
Wrist radial deviation (rotation to the left)	Turn the ball to the left

Table 4 - Correspondence between physical movements and game avatar movements in the first game

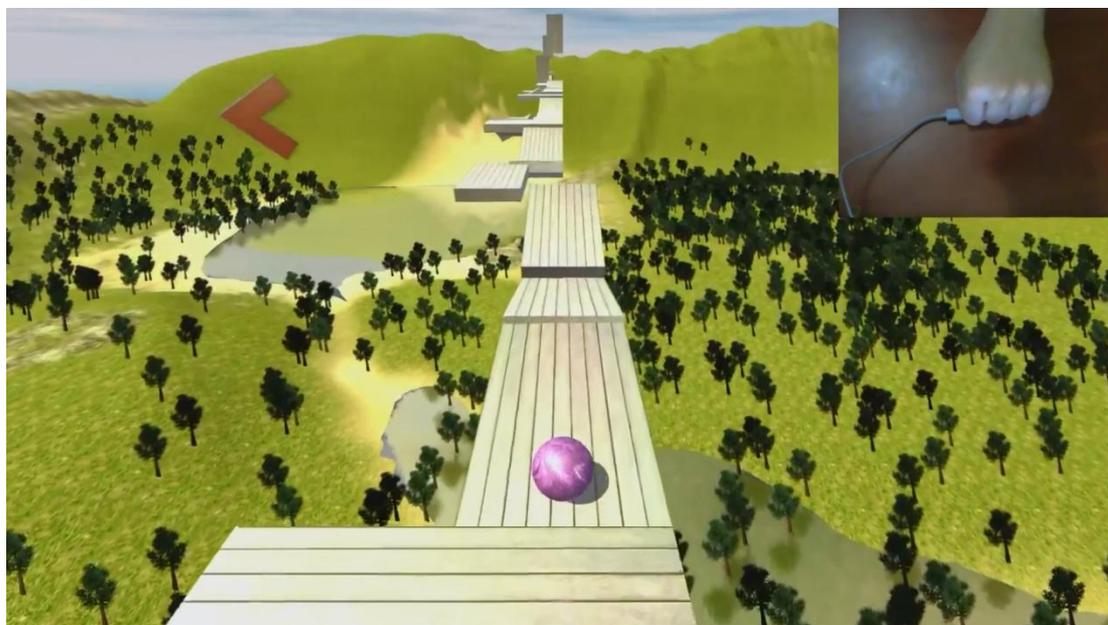


Figure 23 - The scene of the first game, the user performs the exercise with a closed fist

In order to motivate the user to perform these specific movements in many repetitions, but without making the whole procedure tiresome, the scene had to be designed in a certain way that would make these movements natural and necessary to be able to advance through the game environment. The scene of the first game is randomly generated every time it is being played by creating bridge tiles as instances of predefined game objects at runtime, while the tiles are being placed in the scene according to certain rules. The scene is created by combining nine different tile types, horizontal tiles, vertical tiles forming a right turn, vertical tiles forming a left turn, ascending tiles, descending tiles and obstacle tiles, which are rotating obstacle tiles, sliding obstacle tiles, descending door obstacle tiles and sliding door obstacle tiles.

Path tiles	Obstacles
Horizontal (Straight)	Rotating tile
Vertical (Right turn)	Sliding tile
Vertical (Left turn)	Descending door tile
Ascending	Sliding door tile
Descending	

Table 5 - All the types of the tiles that can be contained in the scene of the first game

One obstacle is being generated after every four path tiles, so that there can be a normal game flow. The path tiles all have the same probability to be generated; however there are extra rules for the turn tiles and the tiles that change altitude. When a right turn tile is generated, the next turn tile to be generated is the left turn tile, so that the patient does the

appropriate movements for the exercise, in this case the rotation of the hand to the right and to the left. Also, the presence of the obstacles makes the patient use the up and down rotation of the hand every four tiles. Thus, although the scene is generated randomly, we can still be sure that the patient will be forced by the game scene to do the exercise correctly.

```
change=(int)Random.Range(0,5);
...
//generate tileRotate
elseif(change==1){
  if(previous=="horizontal"){
    x = x +15;
    z=z+5;
  }
  elseif(previous=="vertical"){
    x = x +10;
  }
  elseif(previous=="verticalleft"){
    x = x +10;
  }
  elseif(previous=="up"){
    x = x +13;
    y=y+3;
    z=z+5;
  }
  elseif(previous=="down"){
    x = x +13;
    y=y-3;
    z=z+5;
  }
}
Instantiate (bridgeTile,new Vector3(x,y,z),Quaternion.Euler(0,90,0));
previous="vertical";
right=1;
left=0;}
```

Figure 24 - An example of random tile generating

In the code example above we can see the process of the determination of the position for the tile that is going to be instantiated. The position depends on the tile type, but also on the previous tile type.

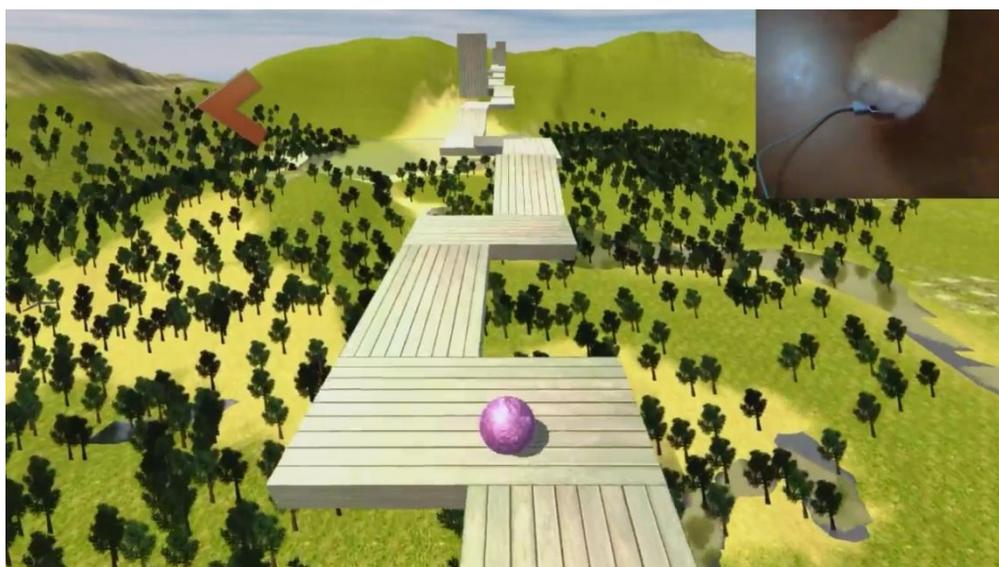


Figure 25 - Left turn in the game scene that requires wrist rotation to the left (radial deviation of the right hand or ulnar deviation of the left hand) - The hand image is a mirror image of the actual hand rotation

In the image above we can see a point of the game play where the player following the path of the scene has to guide the ball to a left turn by performing radial deviation of the wrist of the right hand or an ulnar deviation of the left hand, depending on the hand which he uses to perform the exercises. It is recommended to use one hand at a time for each session, so that both hands can perform the prescribed exercises correctly. The same applies to the right rotation of the ball, where the player must perform ulnar deviation of the right hand or radial deviation of the left hand, in other words turn the wrist to the right. This case in the game scene can be seen in the image below.

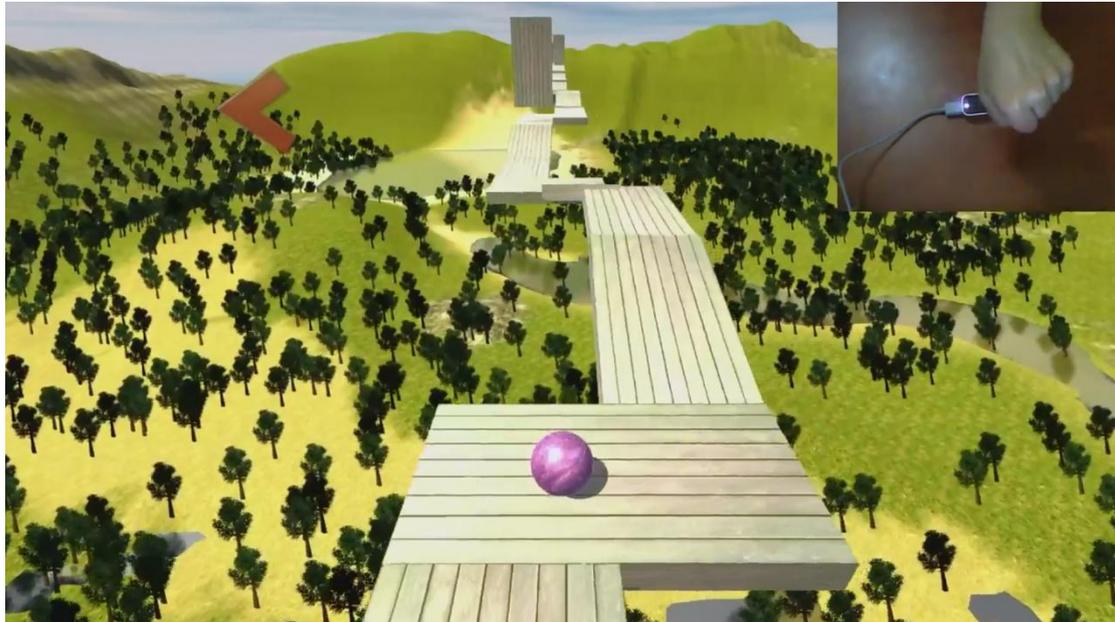


Figure 26 - Right turn in the game scene that requires wrist rotation to the right (ulnar deviation of the right hand or radial deviation of the left hand) - The hand image is a mirror image of the actual hand rotation

The obstacles situated in the game scene create more challenging game environment, but also urge the player to use flexion and extension of the wrist, i.e. rotation of the wrist downwards and upwards. Extension stops the movement of the ball, while flexion moves the ball backwards. In some cases the player can choose the movement he prefers to do, but in other cases, depending on the obstacle, the player has to use specific hand movement, as it will be more appropriate to avoid the particular obstacle. For example, when the obstacle follows a descending slope, the ball develops speed, because of the gravity and mass force that is applied to it, and it can be difficult to stop its movement with extension movement, so the user has to perform flexion, which will apply counter force to the ball.

```
controller=new Controller();Frame frame=controller.Frame();

yaw=frame.Hands[0].Direction.Yaw;
pitch=frame.Hands[0].Direction.Pitch;

if(!frame.Hands.IsEmpty&& pitch >minPitch){

    Vector3 movement =new Vector3 (0f,0f,0f);
    rb.AddForce(movement);}
elseif(!frame.Hands.IsEmpty&& pitch <-minPitch){
    Vector3 movement =new Vector3 (-1f,0f,0f);
    rb.AddForce(movement * speed);}

elseif(!frame.Hands.IsEmpty&& pitch <minPitch&& pitch >-minPitch){

    if(!frame.Hands.IsEmpty&& yaw >minYaw){
        Vector3 movement =new Vector3 (0f,0f,-1f);rb.AddForce(movement *speed);}
    elseif(!frame.Hands.IsEmpty&& yaw <-minLYaw){
        Vector3 movement =new Vector3 (0f,0f,1f);    rb.AddForce(movement *speed);}
    else{
        Vector3 movement =new Vector3 (1f,0f,0f);    rb.AddForce(movement *speed);}}
```

Figure 27 - Example of the ball movement controller

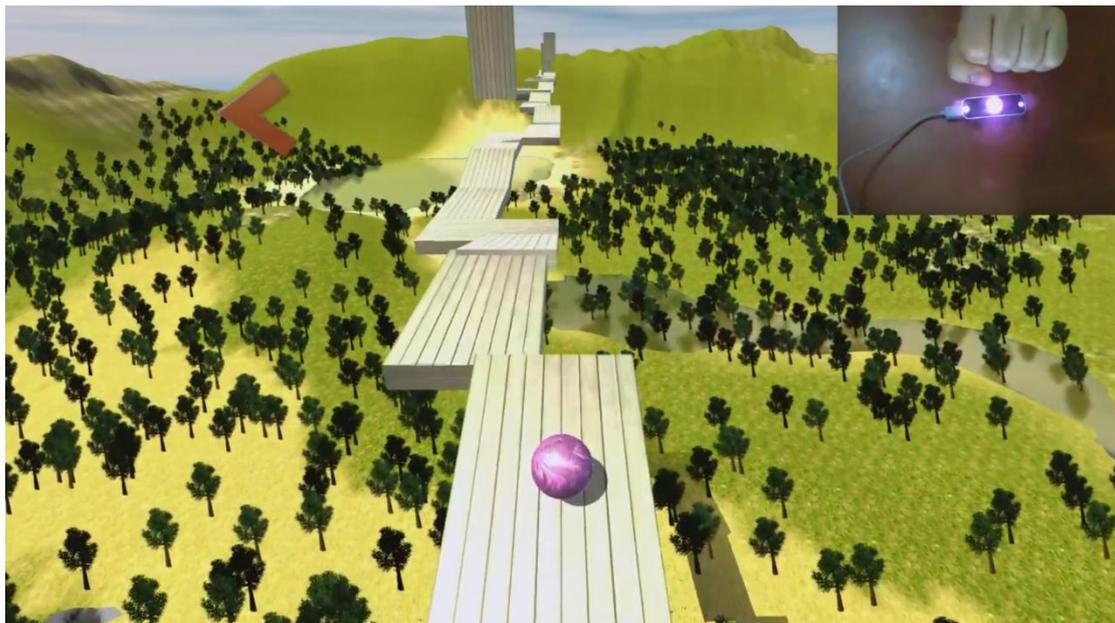


Figure 28 - An obstacle in the game scene that requires wrist flexion or extension (flexion will move the ball backwards, while extension will stop its movement)

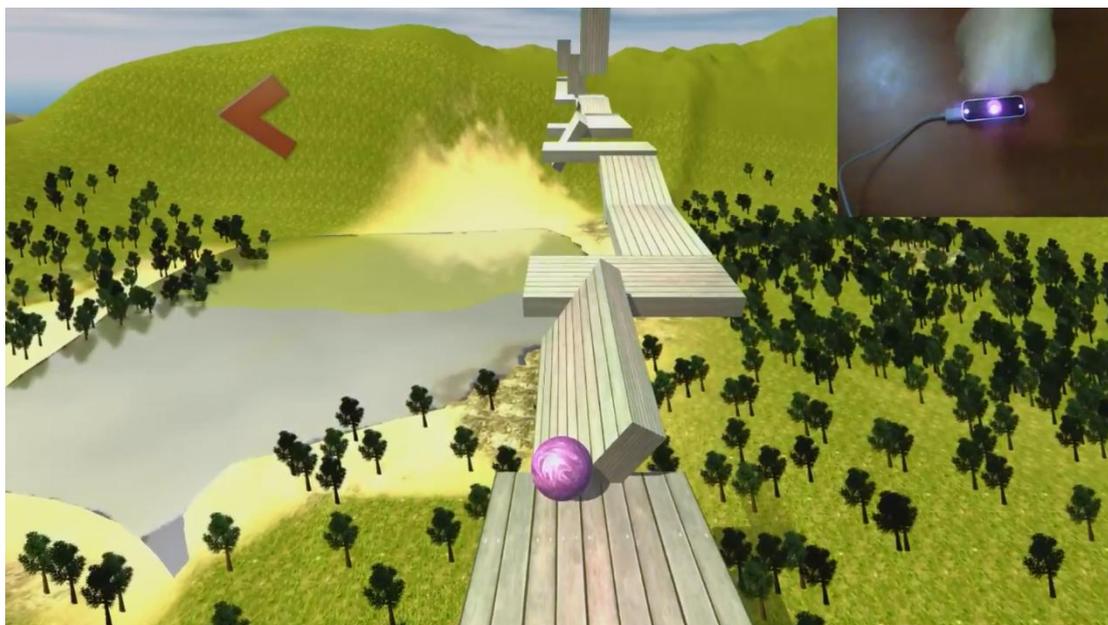


Figure 39 - Another obstacle in the game scene where the user performs wrist flexion to move the ball backwards and avoid falling off the bridge

The goal of the second game is to control an airplane and pass it through certain rings located in different positions in the game scene. Similarly with the first game, the user has to perform extension, flexion, ulnar and radial deviation of the wrist. In this game also, the physical movement corresponds very naturally to the game avatar movement, as the airplane performs exactly the same rotations with the hand, positive pitch angle rotation when the user performs wrist extension, negative pitch angle rotation when wrist flexion is performed, positive yaw angle rotation when the user performs ulnar deviation and negative yaw angle rotation when the radial deviation of the wrist is performed.

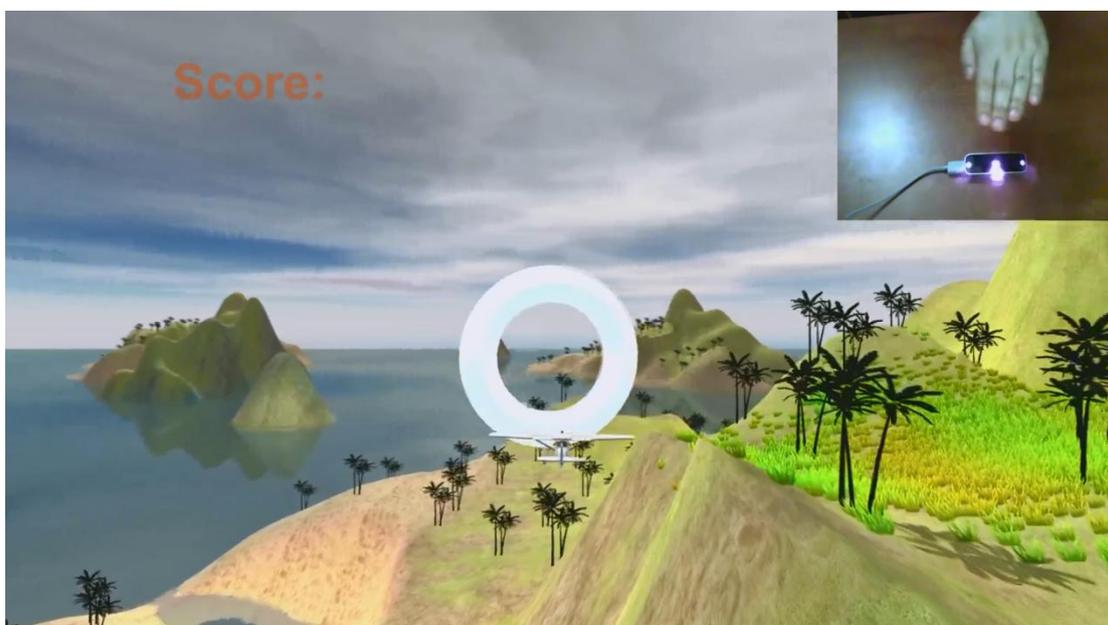


Figure 29 - The scene of the second game

Physical therapy exercise movement	Game avatar movement
Wrist extension (upward rotation)	Positive pitch angle rotation
Wrist flexion (downward rotation)	Negative pitch angle rotation
Wrist ulnar deviation (rotation to the right)	Positive yaw angle rotation
Wrist radial deviation (rotation to the left)	Negative yaw angle rotation

Table 5 - Correspondence between physical movements and game avatar movements in the second game

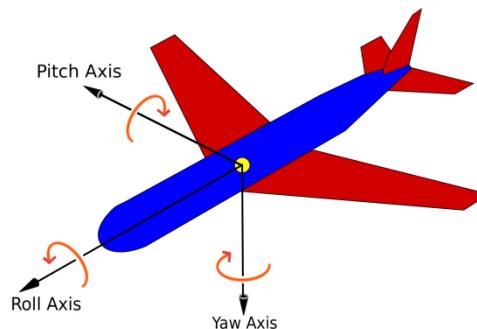


Figure 30 - Aircraft principal axes

The scene of the second game is also constantly generated as long as the airplane keeps moving in any direction. The scene is created by generating a 3x3 grid made of the initial terrain, containing exotic islands and sea environment, which is being repeated in a specific direction from the game starting point, whenever the airplane reaches that area. The need for the generating of the grid is being checked in every frame in the Update() method, while its position is being determined in the UpdateTerrainPositionsAndNeighbors() method.

```

void Start ()
{
    Terrain linkedTerrain=gameObject.GetComponent<Terrain>();

    _terrainGrid[0,0]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);
    _terrainGrid[0,1]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);
    _terrainGrid[0,2]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);
    _terrainGrid[1,0]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);
    _terrainGrid[1,1]=linkedTerrain;
    _terrainGrid[1,2]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);
    _terrainGrid[2,0]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);
    _terrainGrid[2,1]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);
    _terrainGrid[2,2]=
Terrain.CreateTerrainGameObject(linkedTerrain.terrainData).GetComponent<Terrain>(
);

    UpdateTerrainPositionsAndNeighbors();
}
    
```

Figure 31 - The creation of a 3x3 grid repeating the initial terrain object

```

controller=new Controller();

Frame frame=controller.Frame();
yaw=frame.Hands[0].Direction.Yaw;
pitch=frame.Hands[0].Direction.Pitch;

if(frame.Hands.IsEmpty){airplane.transform.Translate(0f,0f,-0.01f* speed);}
if(!frame.Hands.IsEmpty&& pitch >minPitch+0.3){
    Vector3 movementUp=new Vector3 (0f,-0.1f,0f);
    airplane.transform.Translate(movementUp);
    transform.eulerAngles=new Vector3
(Mathf.LerpAngle(transform.eulerAngles.x,30.0f,Time.deltaTime),transform.eulerAng
les.y,Mathf.LerpAngle(transform.eulerAngles.z,180.0f,Time.deltaTime));
    
```

Figure 32 - Example of the airplane movement controller code

Flying the airplane through the rings in the game environment is the main goal of this game, so the position of the rings is crucial for the correct execution of the physical therapy exercises. For that reason the rings are being instantiated according to the rules similar to the first game. When the user passes a ring, which urged him to perform ulnar deviation and turn the airplane to the right, the next ring object to be generated will be on his left, so the user will have to perform radial deviation and turn the airplane to the left. Similarly, when a ring is situated above the airplane, the user is forced to perform an extension of the wrist to reach the ring in the game scene, while the next ring will be positioned in lower altitude, in order to make the user perform flexion of the wrist to pass the airplane through the ring. Thus, the patient performs all the necessary movements for the physical therapy exercises.



Figure 33 - Left turn in the second game scene that requires wrist rotation to the left (radial deviation of the right hand or ulnar deviation of the left hand) - The hand image is a mirror image of the actual hand rotation

In the image above we can see that a ring that is located on the left side of the airplane forces the user to rotate the wrist to the left (we can see a mirrored image of the hand in the upper right corner of the game scene image) in order to collect it and raise the score. So, the user must perform radial deviation of the wrist, if he uses the right hand for the execution of the particular exercise, or ulnar deviation of the wrist, if he uses the left hand. The same applies to the right rotation of the airplane, where the player must perform ulnar deviation of the right hand or radial deviation of the left hand, in other words turn the wrist to the right. This case in the game scene can be seen in the image below.

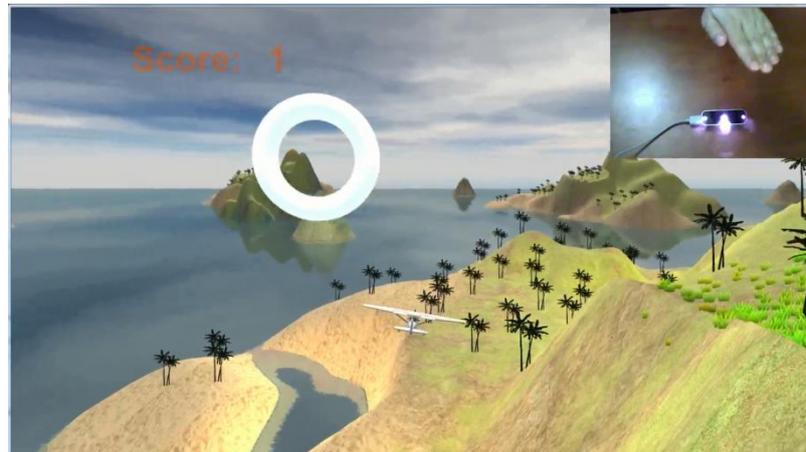


Figure 34 - Right turn in the second game scene that requires wrist rotation to the right (ulnar deviation of the right hand or radial deviation of the left hand) - The hand image is a mirror image of the actual hand rotation

Unlike the first game, the user is able to move the airplane avatar up and down and these movements in the game scene are being exploited in order to urge the player to use flexion and extension of the wrist, i.e. rotation of the wrist downwards and upwards. Extension rotated and moves the airplane up, similarly to the hand, while flexion rotates and moves it down. The airplane moves forward constantly, but with a slow speed, so that the game is more challenging, while the user still has enough time to perform the exercise at a normal pace. The following two images show the wrist extension and flexion exercises performed in order to rotate and move the airplane up and down.



Figure 35 - Execution of the wrist extension exercise to move and rotate the airplane down.



Figure 36 - Execution of the wrist flexion exercise to move and rotate the airplane up.

As can be seen in the Figure33 the degrees of normal hand rotation defer between the right (Ulnar deviation) and the left (Radial deviation) rotation of the hand, as the rotation to the left (of the right hand), and respectively the rotation of the left hand to the right, is much more limited. Thus, also the accepted values for the detection of hand rotation by the Leap motion sensor were set to lower values for the left rotation of the right hand. Additionally, since the carpal tunnel syndrome severity also defers among the patients, the system can be adapted to the needs of each patient to some degree by allowing the users to select the difficulty level of the game between easy, medium and hard. Each difficulty level determines different speed of movement for the avatar, but also the acceptable wrist rotation angles.

For example, if the user chooses to play in easy mode, the ball in the first game will be moving slower and will rotate even with a minimal angle of the wrist rotation, while in the difficult mode the speed of the ball will be faster and the user will have to perform wider rotation to be able to rotate the ball, otherwise it will not react to the gesture.



Figure 37 - Difficulty levels of the game

Furthermore, the game platform also provides the user with the opportunity to monitor the progress by observing the scores for every day of therapy in graph and details forms.

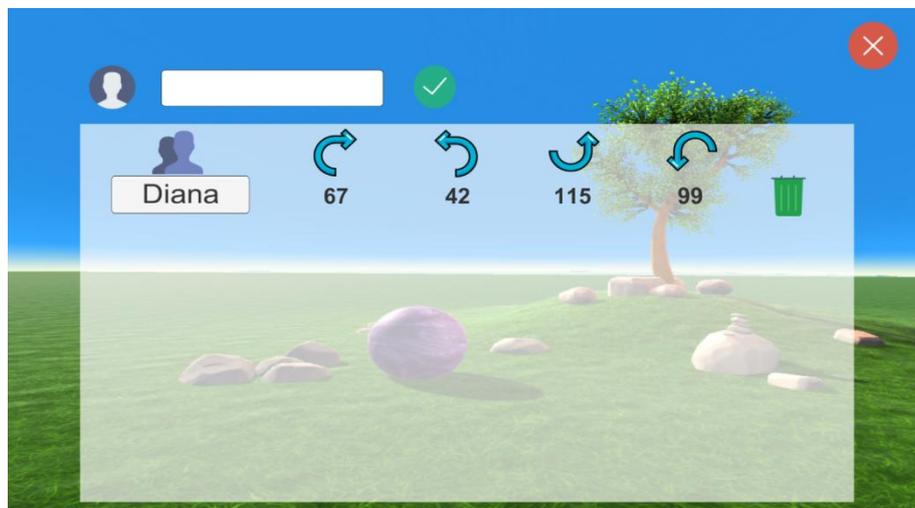


Figure 49 - Detailed score

The system stores the highest score for every hand rotation (right, left, up and down) for every user profile, but also sends data with JSON (JavaScript Object Notation) to a server, which displays the score graph for every user by the date of the game play.

```
public class LeaderBoardData
{
    public List<UserData> entries = new List<UserData>();
}
```

```
public class UserData
{
    public string username;
    public List<ProgressData> user_progress = new List<ProgressData> ();
}
}
```

```
public class ProgressData
{
    public string datetime;
    public int right_score;
    public int left_score;
    public int up_score;
    public int down_score;
}
}
```

Figure 50 - The three classes that define the JSON format that is being sent to the server

```
{
  "entries": [
    {
      "username": "Diana",
      "user_progress": [
        {
          "datetime": "6/28/2017 6:08:28 PM",
          "right_score": 42,
          "left_score": 36,
          "up_score": 115,
          "down_score": 95
        }
      ]
    }
  ]
}
```

Figure 51 - An object instance of JSON, including scores for the username "Diana" and date "6/28/2017"

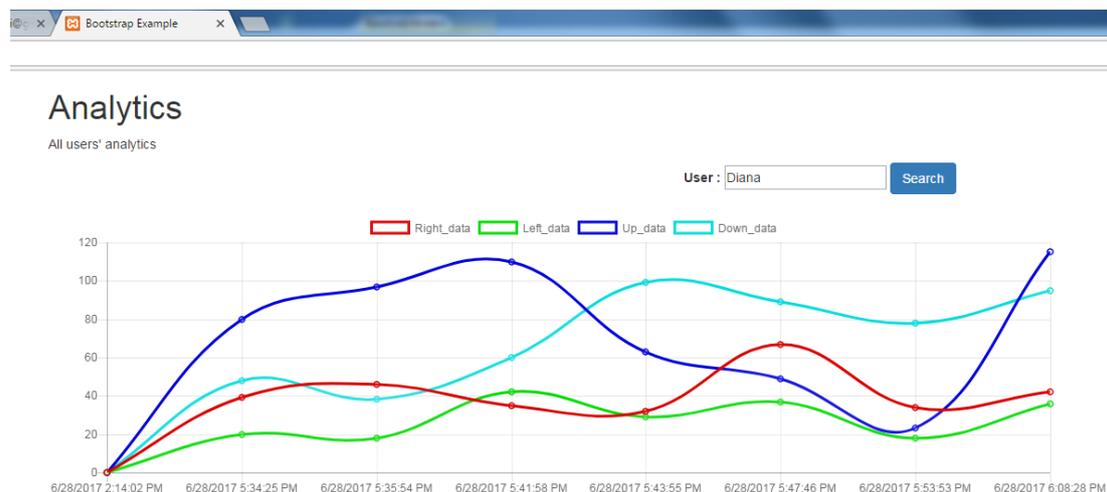


Figure 52 - Aggregate score graph

Future work

The work performed for the purposes of the present thesis included a contribution of physiotherapist expertise and the result was approved and acknowledged as important step for the future of physical therapy and the use of sensors as tools for rehabilitation. However, the research made for the writing of the thesis and the implementation of the therapeutic games have the potential to be further developed and enhanced in the future.

During the meetings with the advisor physiotherapist Mr. George Stratakis a set of several exercises appropriate for the treatment of the Carpal Tunnel Syndrome was proposed for the implementation of the games, but only four of them were finally selected as gestures for game controlling. A future enrichment of this work could introduce additional gestures integrating more physical therapy exercises for the CTS.

There are also future plans for further collaboration with Mr. Stratakis and other physiotherapists in order to conduct a pilot study involving the testing of the CTS treatment games by a sufficient number of CTS patients and obtaining valid clinical data. This pilot study will be an important step towards the assessment and enhancement of the system.

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