# The Sorcerer's Apprentice

## A serious game aiding rehabilitation in the context of Subacromial Impingement Syndrome

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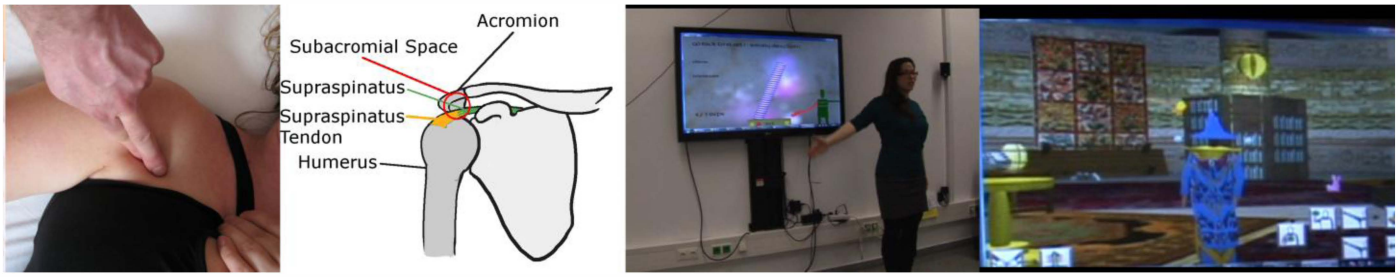


Fig. 1. Manual therapy a), the subacromial space and supraspinatus (a rotator cuff muscle) b), exercises incorporated in the game c), free play mode in the game d)

*Abstract*—**Serious games can help to improve efficacy of motor rehabilitation especially in a home environment. We introduce "The Sorcerer's Apprentice", a serious game improving strength and mobility of the shoulder area targeting support of supervised physiotherapy. It proposes a customizable environment for supplementary exercises in the context of rehabilitation for a one-sided Shoulder-Impingement-Syndrome. We introduce the medical background of the shoulder impingement syndrome, how the game aims to improve the health status of the patients through several options of exercises and how these exercises are embedded into the flow of game play. We will further explain how motivational factors are implemented and which additional factors were relevant in the design process. As the game makes use of motion tracking for input, we utilized Microsoft Kinect as a low-cost IO device suitable for a home-environment use case.**

***Index Terms***—Serious Game, Motor Rehabilitation, Motion Tracking, Shoulder Impingement Syndrome.

### I. Introduction

Serious games have become increasingly important as a field of research and have been utilized to fulfill their specific purposes in multiple yet very different fields of interest, for example in the educational, health or military sector [1]. The health sector offers several opportunities to deploy such games. Examples presented in literature have shown that there are many diseases and health conditions which are suitable application areas. Serious games have aided stroke therapy, balance restoration, orthopedic therapy, training functional activities of everyday life and others. Hence they have shown potential in cognitive as well as motor rehabilitation, as described by Rego et al. [2]. As physical exercises with therapeutic effects often rely on repetition of redundant movement patterns, the motivation of the patient to fulfill such tasks can be affected in a negative way. Serious games can improve motivation of the patient and hence boost motivation to engage in exercise [2]. Compared to e.g. stroke rehabilitation, which too requires intense exercise to achieve improvement [3], Subacromial Impingement Syndrome (SIS) has not been as prominently in the spotlight of attention yet. SIS is a widespread cause for shoulder pain, which is among the most common musculoskeletal reasons for seeking medical attention [4]. This condition heavily influences the daily lives of the persons concerned, as it causes pain in the shoulder, for example when combing hair, and may lead to loss of strength [5]. Physical exercises play an important role in the course of rehabilitation for SIS patients. They are part of a conservative therapy meant to strengthen the affected shoulder muscles to counteract the cause of SIS as well as post-surgical aftercare [6]. Roy et al. also state that movement training is effective to improve movement and reduce pain [7]. It is further suggested by them that home-based exercises including feedback can be assumed to effectively increase training time, which is beneficial for training success. The medium of video games offers many interesting mechanisms regarding the factors mentioned above.

To fit in a home environment we utilized the Microsoft Kinect for tracking, integrated by the ARTIFICE [8] framework. This low-cost tracking component can capture the chosen exercises with sufficient accuracy, while it might not be so well suited for others [9]. We explored SIS and its opportunities for physical exercises. Our serious game aims to provide therapists with a flexible instrument supporting individual patients` needs and capabilities by:

- Definition of exercises, aiming to provide additional physical training for rehabilitation in that context
- Design of a serious game **integrating these exercises into meaningful play** for the patient
- Implementation of the game, ensuring customizability and recording and monitoring of therapeutic progress

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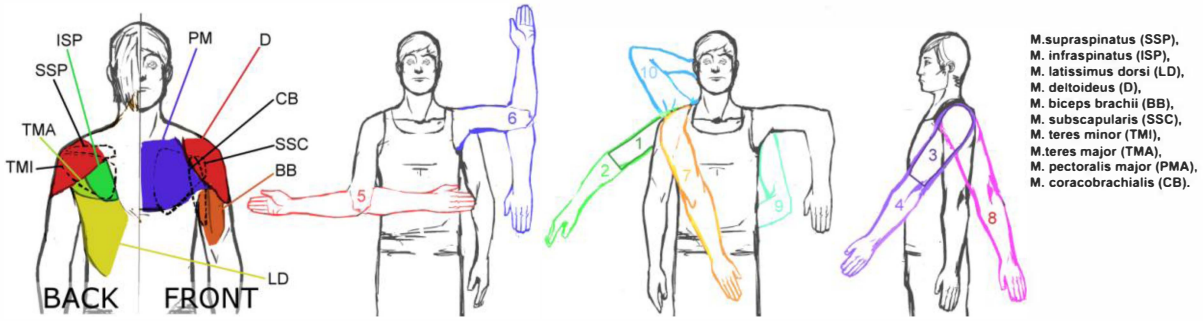


Fig. 2. Relevant muscles of the shoulder region (left) and exercises targeting rehabilitation of SIS implemented in our serious game (right).

## II. Related Work & Medical Background

Rego et al. [2] state that games are applied within the health sector to support certain aspects relevant for rehabilitation. Furthermore they have formulated criteria (e.g. adaptability, performance feedback, progress monitoring) for making such games more functional tools. We have considered these criteria throughout our design as described in the following sections.

Motivation is one of the obvious reasons for using games in serious applications. Patients are encouraged to exercise because the medium of computer games has been described as having the potential for being very engaging, even addictive for users [3]. Thus games can help to transform an often repetitive, monotone training task into a more engaging experience [10]. Therefore, serious games are interesting for rehabilitation, because the proposed exercises should be done frequently and on an intense level, which can be supported very well by the motivating nature of game media [3]. Furthermore, Roy et al. emphasize the importance of feedback especially for effective unsupervised home training [7].

A very prominent reason for seeking medical care is shoulder pain, often caused by shoulder impingement syndrome, which decreases the quality of life for patients [4]. SIS can be induced by multiple factors like continuous overexertion by working overhead with the upper limbs. It can be caused by pathological factors, which lead to a narrowing of the space between the acromion and the head of the humerus (Fig.1) [11]. This leads to pain by impingement of the rotator cuff tendons [4]. SIS patients often receive conservative treatment also consisting of physical exercises with the goal of strengthening the shoulder's rotator cuff and other important affiliated muscles, like the biceps or muscles related to the shoulder blade. If conservative therapy fails, surgery is an effective way of treating SIS. After surgical treatment, strengthening exercises are applied to support the rehabilitation process [6]. A physiotherapist was consulted to develop the basis for the implemented exercises which are available in the game. They provide a widespread selection of movement varieties, because in related work heterogeneous exercise interventions and protocols are used [4]. The exercises are meant to provide a way to train at home for patients who are able to do unsupervised training. They could also be easily combined with weights or with resistive exercise bands, as long as they do not affect correct tracking of the Kinect system. A graphical description of relevant muscles and implemented exercises can be found in Fig. 2. The list in Table 1 describes movements of the shoulder joint relating them to responsible muscle groups according to [12] and corresponding exercises.

| Movement | Muscles | Ex. |
|---|---|---|
| Abduction | *SSP*, D (Pars acromialis, Pars clavicularis(Abd.>60°), Pars spinalis (Abd.>60°)), BB (Caput longum) | 1,2,6*, 9,10 |
| Adduction | *SSC, TMI,* TMA, LD, PMA (Pars clavicularis), D (Pars clavicularis, Pars spinalis), CB, BB (Caput breve) | 7 |
| Inner Rotation | *SSC,* TMA, LD, PMA (Pars clavicularis), D (Pars clavicularis), CB, BB (Caput breve) | 5,6,9* |
| Outer Rot. | *ISP, TMI, SSP*, D (Pars spinalis) | 5,6 |
| Anteversion | PMA (Pars clavicularis), D (Pars clavicularis, Pars arcromialis), CB, BB (Caput longum, Caput breve) | 3,4,7~ |
| Retroversion | TMA, LD, D (Pars spinalis) | 8,9~ |
| Note: italic = muscles of the rotator cuff, ~ = specific movement is not focus of the (~) marked exercise, but is necessary to fulfill it, * = specific movement is necessary to move the limb into position where it is kept throughout the process of the exercise | | |

TABLE I. Movement types, Involved muscles & Exercises

## III. Design Guidelines & Decisions

As mentioned above, feedback, motivation, repetition, configurability and progress monitoring can be assumed key factors when designing serious games with a rehabilitation background. We aim to provide extrinsic feedback for the patient to ensure that she or he is capable to fulfill the exercise tasks correctly and to support motor learning effects (see also Schönauer et al [9]). Careful consideration in the game design has to ensure motivation is maintained throughout the game, e.g. through meaningful play and rewards [13]. In order to make the outcome of training traceable for the therapist it is also suggested that a record of training performance should be made available. We have derived certain design criteria from the above factors and requirements to be imposed on game play and elements interconnecting them with game aspects:

- The game provides an overall gaming experience integrating the exercises containing the therapeutic core. (Motivation, Repetition)
- Exercises and other actions in the game have a comprehensible and unified outcome in the game creating meaningful play [13]. (Motivation)
- Exercises and training units are represented by the game structure or elements in it, to not disturb the flow of the game (Motivation, Feedback, Repetition)
- Transitions between exercises and other game phases should not interrupt the game experience. (Motivation)
- Exercise related feedback is visualized in GUI elements and in-game representation. (Feedback, Motivation)

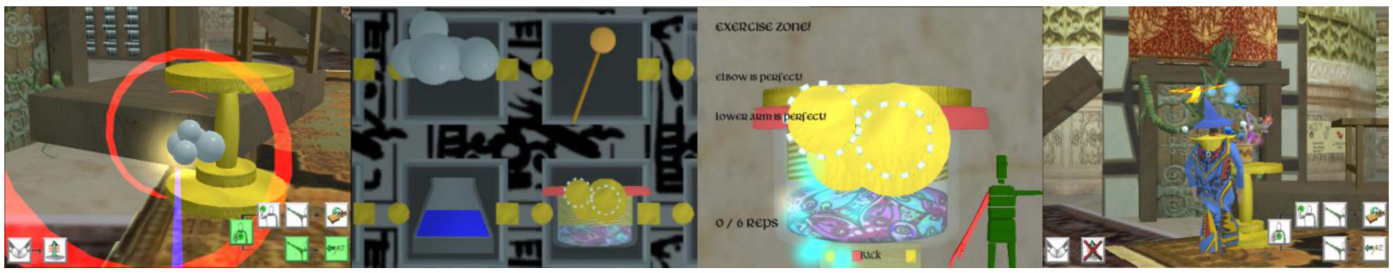

Fig. 3. Picking up primary-artifact a), artifacts in the inventory b), exercising manipulates primary-artifact c), finish the level upon completion of exercises d)

- The elements, interactions and game flow suit the background storyline of the game. (Motivation)
- Support of the individual character of the patients' handicap by selection of the affected limb, exercises and their parameters of success (Exercise, Configurability)
- Inability to fulfill the exercise goal does not get punished by demoralizing consequences (Motivation)
- Record of training progress for the therapist, so he can adjust exercise parameters to the progression of the patient. (Progress monitoring)
- Rewards for well-performed exercise. (Motivation)
- Coherent gaming experience by unobtrusive access to the last achieved game state, easy to learn game play mechanisms and in-game instructions. (Motivation)

## IV. Game Design & Implementation

The background theme provides an encapsulated logic behind game mechanics that fits the game interaction.

### *A. Background*

The game‘s underlying storyline is placed in the genre of fantasy. The game interactions are based on the concept of magical spells triggered by gestures, needed for game play and exercises. Hence the patient’s in-game character is empowered with magical skills beyond the abilities of healthy humans in reality. We hypothesize that this approach of avoiding a virtual representation of the patient’s deficiencies might help to form a positive attitude towards the game.

### *B. Game Concept*

After starting the game through a menu, the player can begin to explore the level. During this phase of the game, further referred to as the free play mode, the player is challenged to look for items – so called primary-artifacts – representing the exercises. They are randomly put into a set of possible locations within the level, which should provide replayability to some degree. Picking up those items can be done by touching them, as well as by executing a gesture activating a magical beam and pointing at them. This action pulls the corresponding item to the player over a distance (Fig.3a). Furthermore, another spell can be triggered in a similar manner, to shoot a glowing projectile, moving certain objects away which might block the line of sight to an item. A menu provides easy access to statistics presented in game, or manipulation of exercise parameters. All interactions which are not taking place in the exercise mode are handled by movement of the healthy arm.

### *C. Goal*

One training unit (as configured by a therapist) is represented by one level within the game. By completing all exercises defined for one training unit the player completes one level and is provided with one or more items, which represent the key to the next level, hence the next training unit (Fig.3d).

### *D. Integration of Exercises*

The mentioned primary-artifacts are stored in an inventory after pickup and can be accessed there (Fig.3b). Selecting one of them brings the player into the exercise mode of the game and the item representing the chosen exercise appears on screen. By starting the exercise, items are being manipulated (Fig.3c). The tracking data of the arm associated with the handicapped shoulder is processed according to the exercise the player is required to perform. To ensure that the exercise movement is executed correctly the following quality criteria are checked:

- Continuity of the movement performed
- Speed and timing of the movement
- Correct execution of movement within defined boundaries. (Exceeding these boundaries triggers a warning or resets the current repetition of the exercise in severe cases).
- Goal of the exercise is defined as goal angle and repetition count. Items reach visual goal state after all repetitions.

These criteria are also relevant for bonus behavior, explained in the according section below.

### *E. Integration Of Feedback*

Feedback ensures the patient’s awareness of his or her actions in unsupervised training and provides information regarding the success of an exercise and overall performance.

#### *1) Real-time feedback*

While performing in exercise mode, the player is provided visual feedback on several occasions. The progress of movement while exercising is mapped to the visual transformation of the primary-artifact displayed in real-time, if the exercise is done correctly (e.g. transformation of a cooking pot into a diving helmet). A textual instruction gets displayed informing the patient about the correct position of a limb, if the player’s corresponding movement is out of bounds. Furthermore the player gets textually informed, if the movement significantly deviates from the boundaries, to return to the starting position. The visual progress of the artifact is reset to the state before the beginning of the attempted current

repetition. The primary-artifact displayed has a sparkling aura of a white-yellowish hue. If the patient manages to elevate the distinct limb above the goal angle the color turns blue to indicate that the training goal angle has been exceeded.

*2) Accumulative Exercise Feedback*

The overall performance of exercise success throughout the training units gets represented by an in game element, the *familiar*. The *familiar* is a birdlike creature, accompanying the player's character, representing the access point to the inventory. The appearance and the behavior of the *familiar* are influenced by overall performance of the player, not only providing feedback about performance in general, but also for motivational reasons.

### *F. Integration Of Motivational Factors*

Many of the game mechanisms stated above are meant to be motivating through the course of the game. The graphical transformation of the primary artifact should invite the player to explore what is happening when an exercise is performed well, hence is meant to trigger curiosity. Also if the performance is within boundaries but the goal angle could not be reached by the patient because of the inability to fulfill the task, the current repetition gets completed automatically, but results in a reduced bonus behavior. The player gets bonus points when the exercise performance is sufficient or above. Besides the quality criteria mentioned in subsection D, performing more repetitions than required also results in bonus points. Bonus points are an indicator for overall performance and are accumulated throughout all training sessions. The *familiar* has a leveling systematic, influenced by the bonus points. As it proceeds through levels, it changes looks and has an increasing chance of triggering a glowing white bird. This bird flies towards remaining primary artifacts of the stage, pointing them out to the player. As the game proceeds, finding the items may become a redundant task for the player. Thus this mechanism reduces the time needed for finding the primary artifacts. We believe that having the progress of performance represented in game and by game mechanics can further encourage the player to perform well, in order to be able to experience the advancement of the *familiar*.

## V. CONCLUSION

In this work we propose a serious game aiding supervised physical therapy for patients suffering from SIS. It can be applied in addition to conservative therapy or rehabilitation after surgical treatment in a home environment. The game relies on the support of motivation, is providing feedback and records training progress. We believe these factors are positively influencing the course of the patient's rehabilitation process. Mechanics derived from entertainment video games, such as collecting items, combining them, proceeding through levels and others, are directly connected to the requirements related to physical exercises. This includes definition of training units, timing, repetition and correct execution of the movements. We believe that the implemented factors can help the patient to keep motivated to perform unsupervised training in addition to guided physiotherapy and therefore extend the training time, thus improving effectiveness of the rehabilitation progress. In future work we want to evaluate the game with patients towards usability, emotional engagement and efficacy. In addition, we want to increase flexibility to allow easy integration of expert knowledge in future customization iterations, e.g. through adjustable boundaries for the exercises.

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