Table 1. Mini games, their medical rationale and the MoCap data used

Game name	Mini games overview		
	Game description	***Clinical goal***	***Input data***
Temple of Magupta	The player runs through an ancient temple, collects artifacts and avoids obstacles.	Physical reconditioning, increase walking speed and walking time	Movement rate
Face of Chronos	The patient climbs a mountain by extending the arms upwards until the next hold is reached and collects artifacts placed on holds.	Increase reaching ability, velocity and smoothness of the motion, relaxation of the trapezius muscle after reaching	Position of the hand, movement characteristics of the arm (path, velocity), muscle activity of the left and the right trapezius muscles
Three Wind Gods	The player imitates a series of head movements executed by fictive characters.	Increase cervical ROM, velocity and smoothness of cervical motion	Measures of cervical ROM and current rotation (Flexion/extension, Right/left bending, Left/right rotation), movement velocities, movement acceleration

usage, distance values are discretized with step sizes of multiple millimeters. Using the distance lookup tables described above, we iteratively inspect the distance relationships between markers on adjacent bones. This allows for significant improvements in marker labeling accuracy, with minimal computational overhead.

5.5 External Interfaces

In order to make use of the generated body posture, interfaces have been implemented to external tools. This way, data from our system can be used for character animation (*Autodesk MotionBuilder*), medical evaluation (*C-Motion Visual3d*) and a game engine (*Unity3d*). For all three tools we have implemented plugins that can be used to utilize the data. In *Unity3d* and *Visual3d* the plugins are communicating with the tracker over a network interface utilizing a customized XML protocol, while *MotionBuilder* is connected to the iotracker using VRPN [RUSSELL et al. 2001]. To transform and extract data (e.g. information about velocities, specific positions etc.) from the skeleton pose data produced by the iotracker server, we are using an additional software layer. For this layer OpenTracker [Reitmayr et al. 2001] is used, which is a multi-modal data flow framework. It can serve as a center piece between the plugins and the iotracker, by implementing the required communication protocols. Figure 7 shows screenshots of the first two applications receiving the tracking data from our system in real time.

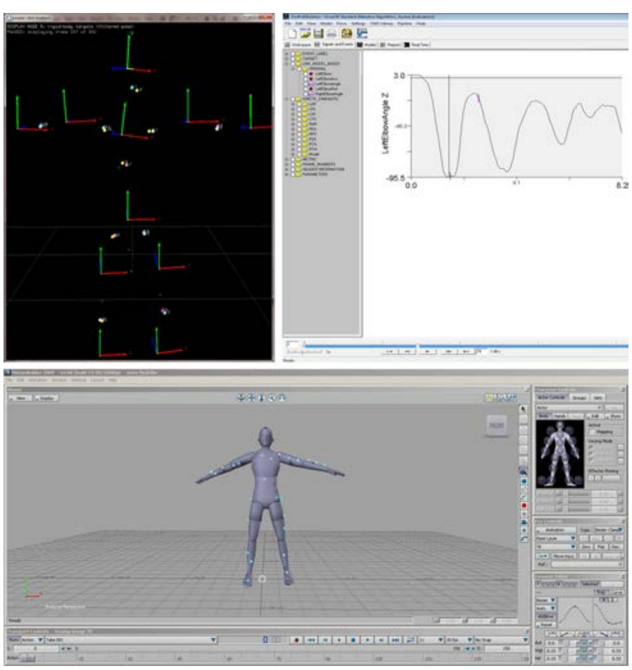

Figure 7. Visualization of the skeleton model's local coordinate systems (upper left), joint angle curve after the data was streamed into Visual3d (upper right), Motion Builder (bottom) showing animated avatar with marker positions.

6 A Serious game for chronic pain rehabilitation

6.1 The Game

Finally, we want to introduce the prototype of a serious game that has been implemented within the project PLAYMANCER to assist rehabilitation of patients with chronic pain of the lower back and the neck. An overview of the work done within the project can be seen in [Euronews 2011]. Also a video showing our system and game in action is provided there. Chronic pain patients are in a vicious circle of maladaptive pain-related cognitions (i.e. fear of movement), coping strategies (i.e. avoiding physical activities) and physical disuse. Therefore, therapeutic activities performed in pain rehabilitation practice, focus on changing these cognitions and increasing physical functioning. An important way to do this is by letting patients experience and execute physical exercises. Two important aspects that exercises commonly used in chronic pain rehabilitation focus on:

- Mobility and coordination by activities that focus on increased range of motion, increased velocity and smoothness of the motion.
- Improving a patient’s physical conditioning by endurance exercises like walking.

Our full body MoCap system is employed to track these exercises and works as main source of input data for the serious game. To incorporate these exercises into the game three separate mini games have been developed. An overview of the mini games, their clinical goals and input data used is listed in Table 1. They are embedded within an adventure setting, linking the games with a common story line. In that story the player arrives with his ship at a deserted island and discovers the remains of an ancient civilization. Pictures of test users playing the mini games can be seen in Figure 8.

The ship is the base of the patient. While on the ship, the game can be configured individually to each patient's needs and abilities by calibrating goals and baselines for the mini games. During the mini games the player can collect items, which can be seen in an inventory. When the player has collected enough items, he is rewarded by unlocking the next part of the story, which should provide additional motivation.

During game play the three mini games provide game feedback (scores, collected items) as well as visual, auditory and textual feedback on the patient's performance and results. Furthermore, after every session, therapist and patient view the patient’s progress, by having a look at the patient's profile. In this profile

Figure 8. Our MoCap system and two of the mini games during the preliminary testing. "Three Wind Gods" (left), "Temple of Magupta" (center), "Face of Chronos" (right).

objective data, recorded during gaming, is presented (e.g. reaching ability, cervical range of movement.

6.2 Results

The "iotracker server" application runs on a quad-core CPU (Intel Core2Quad Q9300 with 2,5 GHz with around 75% CPU load). The skeleton tracking is implemented in a highly parallelized way using OpenMP and utilizes all cores. Especially step 2, which is the most computationally intensive, is well suited for parallelization. During our evaluations we were running the iotracker server and the game (developed in Unity3D) along with other input modalities (automatic speech recognition and electromyography) on the same PC. Therefore, we used a Workstation with two Intel Xeon DP X5355 processors (a total of 8 cores). CPU load was at around 85% during active gameplay.

The latency of the MoCap system consists of Firewire data transfer latency of 18ms (in case of 60 Hz tracking), since all camera images are transferred to the PC for processing. Additionally, overall latency is determined by the time needed for skeleton tracking, which is typically between 5 and 10ms for one skeleton on the above CPUs.

An evaluation of the serious game with eight patients has been conducted. Each patient was participating in the game interventions in a period of four weeks with one or two game sessions per week. During the evaluation the usability of the skeleton calibration procedure was rated good. All patients were capable to perform the requested skeleton calibration exercise and the calibration assistant produced and selected a functional skeleton model for each individual in almost all cases. Furthermore, the MoCap system was working stable and produced robust tracking data throughout the evaluation. Due to the lack of ground truth no absolute measurements of the system's accuracy have been made. Measuring human motion data with non-intrusive means (e.g. a goniometer) is usually highly inaccurate and depends on the tester and articulation used. Acquiring kinematic data of a human body by intrusive means on the other hand requires an enormous effort (e.g. radiostereometry [Tranberg et al. 2011] or bone pins [Andersen et al. 2010]) for which we lack the means. However, in the future we plan to compare our system's accuracy with that of another commercially available MoCap system. Nevertheless, visual inspection and subjective evaluation of the motion data showed smooth movements with little jitter. Evaluation of the joint angles showed also little jitter and high relative accuracy (smooth curves of angles and graduation in the sub-degree domain). Plots of unfiltered tracking data produced by our system can be seen in Figure 9. We have measured the rotation of the head relative to the torso on the up-axis. Even during fast motions like shaking of the head our system produced a smooth curve of measurements and even the inferred rotation-velocity introduced little jitter. When looking at slower motions our system produces values with sub-angular accuracy, which exhibit high plausibility. In addition, movement parameters calculated from positional information show little jitter in position and velocity. Finally, measurements regarding range of motion of assessed exercises show good repeatability.

The clinical changes induced by the gaming interventions are promising. The pain intensity measured on a visual analogue

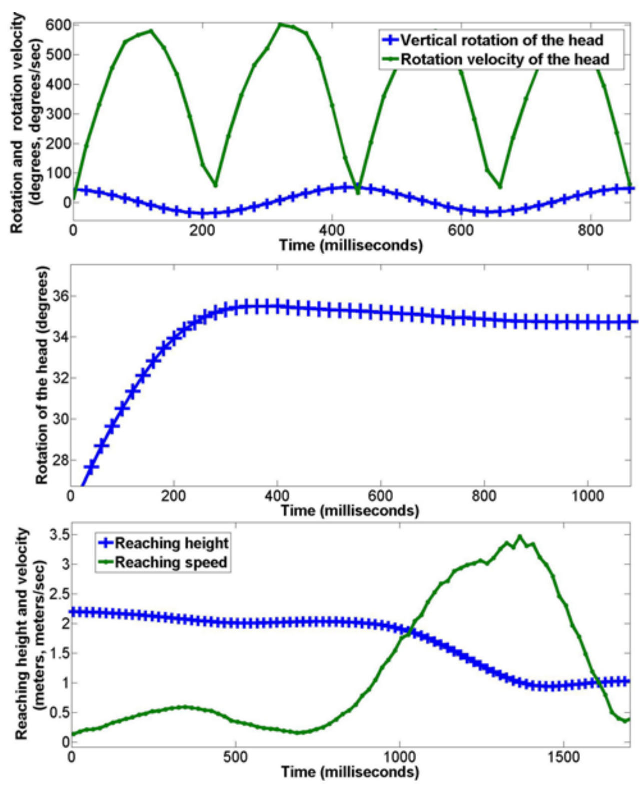

Figure 9. Rotation angle and velocity of the head relative to the torso around the up-axis during fast movement, i.e. head shaking (top), rotation of the head in the sub millimeter domain (middle), reaching height and velocity of a hand (bottom)

score decreased after gaming by an average of 11 millimeters. Also, physical fitness increased for many patients, especially for subjects with low exercise capacity. Furthermore, an increase of cervical range of motion of 7-10% for all three degrees of freedom has been determined. In addition a small increase in the patients reaching height has been observed. Also, usability was rated good. Finally, the patients were positive about the Playmancer game and enjoyed playing.

7 CONCLUSION AND FUTURE WORK

We have implemented a system for full body motion capture. Its high flexibility, accuracy and a moderate price makes it suitable for a large number of applications. We have introduced the applied algorithms and software components of the system. In addition, a serious game for the rehabilitation of patients suffering from chronic pain has been developed and evaluated in a clinical setting. Tests have shown promising results for our system and the game.

Patients suffering from chronic pain are a group that has previously been neglected by serious games. Therefore, the study had an experimental character, but the results could be very well used to define a test protocol for a controlled clinical trial, which might be conducted in the future. The evaluation has shown that patients suffering from chronic pain are a very heterogeneous group. Therefore, in future studies more mini-games and more specific inclusion criteria have to be employed. Furthermore, it is assumed that an increase in intensity, frequency and duration would have a positive effect on the outcome.

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