















**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).

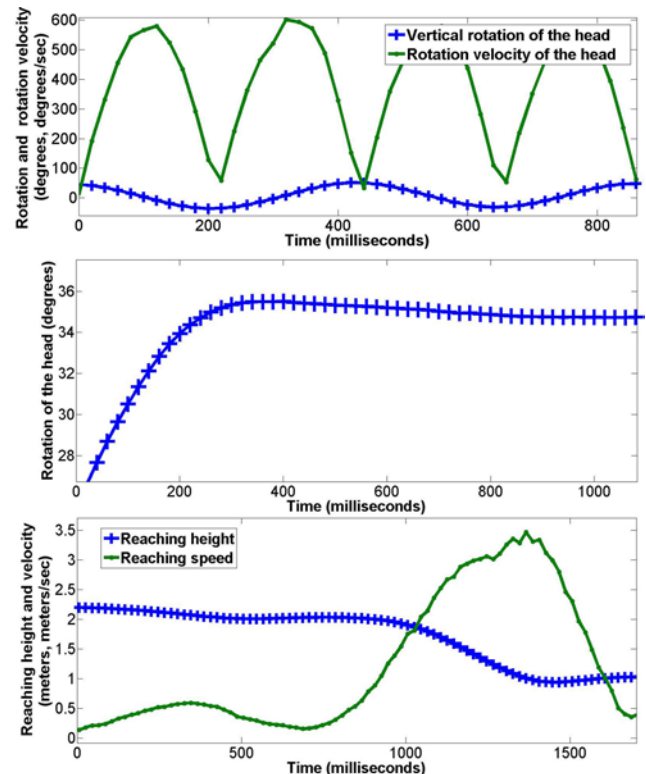
## 6.2 Results

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 do-

main). 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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