iPod for Home Balance Rehabilitation Exercise Monitoring

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Abstract:
When people fall and experience problems of balance, physical therapists (PTs) often prescribe home balance exercises involving repetitive head movements. Currently, patients' compliance and performance of these home exercises are invisible to PTs, who need the data to make informed decisions for treatment adjustments. We present an easy-to-use tool that monitors patients' home balance exercises and provides PTs with accurate, quantitative patient data. The tool, Head Coach, is a wearable device implemented in an iPod, fitted in a pocket on a baseball cap, and worn by patients while doing their exercises. We tested the reliability of the system using a magnetic field tracking device (Polhemus) as the gold standard. The test showed that the iPod can be used to accurately track home balance exercises.

Each year, over two million nonfatal fall injuries among older adults are treated in emergency departments and over half of these patients are hospitalized. Many falls are caused by problems of balance and vestibular dysfunction [1]. For these vestibular patients, physical therapists (PTs) commonly prescribe home rehabilitation exercises. After interviewing three PTs at the balance clinic of the University of Pittsburgh Medical Center, we found that a significant problem is the inability to know what patients do at home. The invisibility of home exercise compliance and performance hinders decision making regarding treatment refinements. Relying on recall during weekly checkup visits can be vague and erroneous, especially among elderly and concussion patients. The PTs expressed a need for objective, accurate information regarding home exercises.

SECTION 1.
Introduction

We present HeadCoach which was designed in collaboration with PTs. As depicted in Figure 1, it has three components: An iPod Touch 4G, a baseball cap with a pocket to hold the iPod and a custom software application.

SECTION 2.
HeadCoach

Patients wear the cap when they begin an exercise. Upon a tap anywhere on the screen, HeadCoach gives an audio feedback, “begin”, and begins recording data on exercise start time, duration, and performance. Upon a tap anywhere on the screen again, HeadCoach gives an audio feedback, “finished”, and stops recording.

HeadCoach currently supports the Gaze Stabilization Exercise [2] which is commonly prescribed by balance PTs.

In this exercise, patients gaze at a target, such as a business card, placed three feet away. They then rotate their head side to side or up and down while keeping their eyes fixed on this target. Because the inner-ear helps to coordinate eye and head movements, this exercise improves function by adapting the vestibuloocular reflex (VOR) gain, or by symptom habituation. At home, patients are usually asked to do this exercise for 30 to 60 seconds several times each day.

Because the iPod has a gyroscope, it can give PTs performance metrics, such as the number of head turns and average turning speed. Number of head turns are calculated using pwelch function in Matlab to derive oscillating frequency (turns/sec). Multiplying frequency by exercise time gives total number of head turns. Inverting frequency gives the time window for each turn (sees/turn); average turning speed can then be derived by averaging the peak velocities of the time windows.

SECTION 3.
Accuracy Validation

To ensure that the iPod's motion sensors are accurate, we compared motion data registered by the iPod with a gold standard used by PTs in the lab, a magnetic field tracking device called the Polhemus.

3.1. Method

We recruited eight healthy participants (six male, two female, age 18–50) and asked them to do the gaze stabilization exercise while wearing a custom plastic helmet. The helmet contains the Polhemus receiver and a receptacle to hold the iPod at one of three orientations, 0, 45 and 90 degrees. We used a custom helmet to maintain distance between the magnetic field transmitter and the iPod to avoid interference.

We asked each participant to perform head movements for 30 seconds under varying conditions: orientation of iPod (0, 45, 90 degrees pitch with respect to horizontal), frequency of head turns (0.25, 0.5, 1 Hz), direction of turning (side-to-side or up-and-down), and different iPods (one of three) to test for consistency across iPods. The frequency of head turns was controlled by playing a metronome and asking the participants to move in synchrony with it. Each participant performed 18 trials to include all the combinations of the above. We randomized the order of conditions.

The Polhemus magnetic tracker provided angular position in yaw, pitch and roll relative to an earth-fixed transmitter. Data were differentiated to compute angular velocity. The iPod provided angular velocity using its internal gyroscope.

3.2. iPod Data Transformation

Because the angular velocity data of the iPod were about the iPod's axes (Figure 2) and not the user's head, we needed to transform the data to real-world yaw and pitch rates. Since the Polhemus provided the real-world yaw and pitch, its data did not need this transformation.

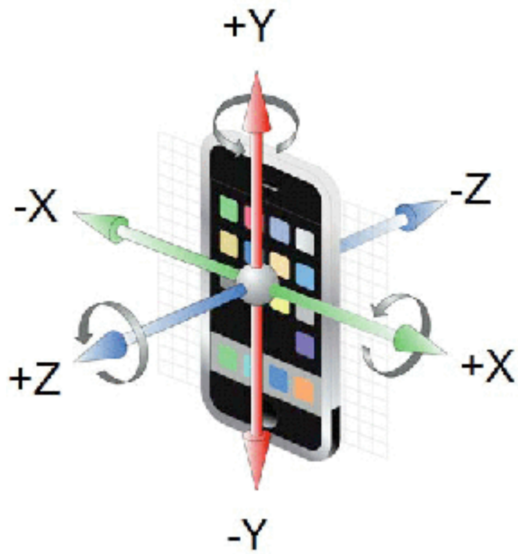

Figure 2. iPod rotational axes

The iPod rotation rate used was the rotationRate property of CMDeviceMotion in the iOS 4 SDK. To transform the rotation rate we calculate the pitch rate as the X-axis rate. For calculating the yaw rate, we had to incorporate both the Y and Z axes. This is because the iPod is usually resting at an angle naturally on the forehead, with the bottom protruding more than the top. Thus, side-to-side motions would cause both the Y and Z axes to register activity. The yaw rate was calculated using the formula: yaw–rate=sqrt(Z∧2+Y∧2)∗F(Z,Y), where F(Z,Y) is defined as follows: If abs(Y) >= abs(Z), then F(Y,Z) =sign(Y), else F(Y,Z) =sign(Z), where sign() is either +1 or -1 depending on if the value is >=0 or <0. When a trial included side-to-side movements, we compared the yaw values, and when a trial included up-and-down movements, we compared the pitch values.

3.3. Validation Results

To measure the correlation, we used Matlab to apply a filter (low pass Butterworth - 4th order, 4 Hz cutoff frequency) to the iPod and Polhemus data and then ran a cross correlation. We found that the correlation coefficient (r value) of the angular velocities of the Polhemus and the iPod were very high. Of the 142 trials (8 participants * 18 trials each - 2 mistrials), the lowest correlation coefficient was 0.92, with most being in the 0.95+ range.

SECTION 4.

Conclusion and Future Work

In conclusion, we believe that a mobile phone based system can be feasible for monitoring home balance rehabilitation exercises. The iPod was used as a less expensive testing surrogate for the iPhone. In the future, we plan to include new exercises, add real-time exercise feedback for guidance, and develop a visualization “dashboard” for PTs on the iPad so that they can sit beside patients and review their sessions. We plan to create a complete package for PTs to quickly see exact information regarding their patients' home rehabilitation exercises.

SECTION 5.

Acknowledgements

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Citation Map

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