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Analysis of wheelchair rugby accelerations with fractal dimensions

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Abstract

The Hausdorff dimension and the average amplitude of the acceleration signal of a rugby wheelchair during a match quarter were calculated in order to determine which method is suitable for distinguishing between the different activities of a rugby wheelchair athlete. The activities were analysed on the match video and identified on the corresponding acceleration signal, measured with an Apple 4G iPod Touch which was connected to the frame of the wheelchair. The following activities were identified: collisions, high speed pushing, high speed coasting, low level activities, and no activity. The Hausdorff dimension values of high speed pushing and high speed coasting were similar. The average amplitude values of collisions and high speed pushing were similar, as were the values of high speed coasting and low level activities. Both methods combined provide a 2D map for distinguishing between all five activities, however, the standard deviation of the average amplitude is too high for clearly separating the activities on the amplitude scale.

Keywords: Wheelchair rugby; accelerations; fractal dimension; Hausdorff dimension; iPhone; activities; activity classification

1. Introduction

Wheelchair rugby is a standard discipline of the Paralympic Games, and is characterized by fast play with frequent collisions and blocking of opponents. A match is played with up to 12 players per team, four of which play on the indoor court at any time, in four periods of eight minutes. The main aim of the game is to carry the ball across the opponent’s goal line as in rugby, and likewise to prevent the other team from getting the ball or scoring. Like the game of rugby, wheelchair rugby requires the athletes to

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turn and accelerate quickly to avoid their opponents and to score. In contrast to rugby, however, the game is played with a volley ball.

Chua et al. [1] performed a wheelchair activity analysis with accelerometer data collected with Apple 3G iPhones, connected to the frame of the rugby wheelchair. The purpose of this study was to find a method for distinguishing between combinations of acceleration magnitude and push frequency. They calculated the fractal dimensions of the acceleration signal with the method developed by Kulish et al. [2], from probability distributions based on Renyi's entropy [3]. The fractal dimensions calculated with this algorithm strongly depend on the signal amplitude and impulse [4]. The reason for this is that the method counts the number of bins occupied by data, with a bin size corresponding to the resolution of the sensing device. The fractal dimension according to Hausdorff [5], however, is the ratio of the logarithm of the number of circles required to cover a curve to the logarithm of the circle's radius, if the radius approaches zero.

The aim of this study is to explore the fractal dimensions of acceleration signals by a method, closer related to Hausdorff's [5] procedure, and to assess different actions of a wheelchair rugby athlete during a match.

2. Experiment and data analysis

An Apple 4G iPod Touch (Apple Inc., Cupertino CA, USA) was attached to the frame of a rugby wheelchair and the forward/backward acceleration was collected at 60 Hz for one match quarter. The athlete was a paralympian. The match quarter was videotaped for identification of activity types. The original unit of the acceleration signal, g, was kept for the calculation of fractal dimensions. The acceleration signal was processed with a method developed by Fuss [6], which combines Katz' [7] (Euclidean length of a signal) and Higuchi's [8] (rate of change of log length with respect to log frequency) methods and has the same accuracy of Higuchi's method in standard EEG signals. However, for extreme sport signals, Higuchi's method is impracticable as it assumes maximal amplitude throughout the signal [6]. The new method [6], however, optimizes the signal amplitude such that the maximal possible range of the Hausdorff dimension is obtained, which allows distinguishing between different events embedded in the signal. The Hausdorff dimension was obtained with this method from the acceleration signal through a running average procedure with a window width of 2.5 s. In addition to that, the average amplitude of signal's absolute value was calculated and processed with the same running average procedure. The Hausdorff dimension of different activities was then compared to the average amplitude of signal's absolute value in order to determine which method is able to classify and distinguish between the different activities.

3. Results

Five different activities were identified from the video and the acceleration signal (Figure 1):

1) no activity;
2) low level activities (low speed pushing and coasting, turns);
3) high speed coasting;
4) high speed pushing; and
5) collisions.

The acceleration signal during zero activity corresponds to the noise of the iPhone accelerometer (Figure 1, "**1**"). The acceleration of low level unspecific activities is characterized by an irregular signal of smaller amplitude (Figure 1, "**2**"). The acceleration of high-speed coasting is expected to be negative and its amplitude to decrease with speed due to energy losses from aerodynamic drag and rolling resistance. Instead the signal shows pronounced noise at a high frequency (Figure 1, “3”), which comes from the fact that the wheelchair is not rolling entirely in a smooth fashion. The average acceleration signal, however, is negative. The acceleration during high speed pushing shows the typical pattern of alternate positive (torque produced by the athlete) and negative (coast down) acceleration of push and recovery phases with high amplitudes (Figure 1, “4”). Collisions are characterized by sharp acceleration spikes (Figure 1, “**5**”).

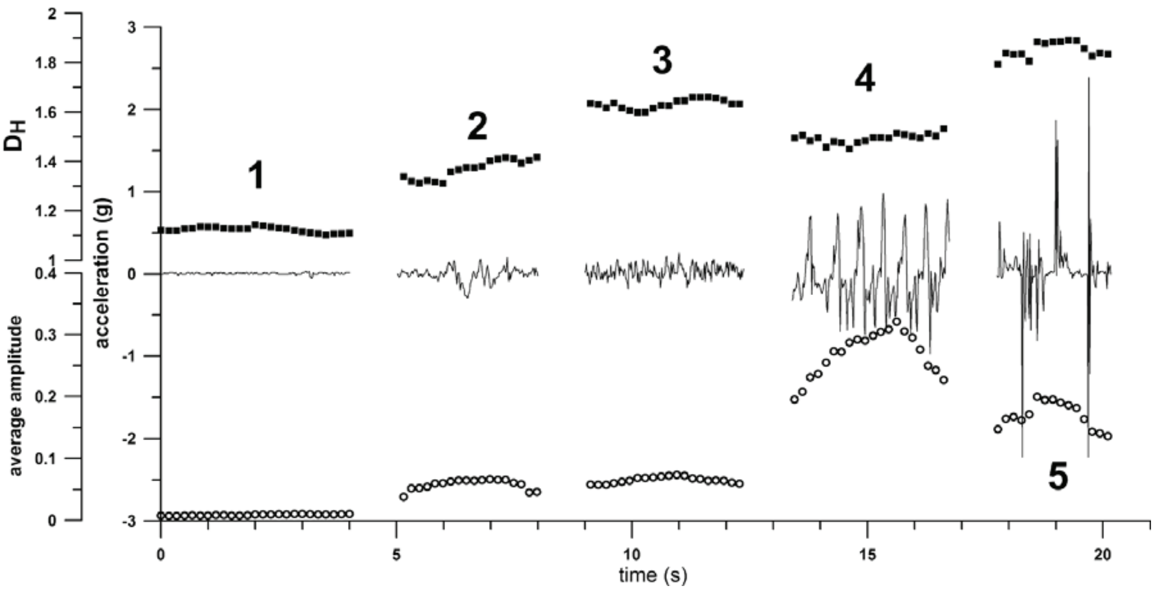

Fig. 1. examples of acceleration signals (in the middle), with average amplitude (bottom) and Hausdorff dimension (D_H; top); 1: no activity; 2: low level activities; 3: high speed coasting; 4: high speed pushing; 5: collisions

Figure 2 shows the mean signal amplitude and the Hausdorff dimension of different activities. The average amplitude does not allow distinguishing between activities 2 and 3, and activities 4 and 5 (Figure 2a). The Hausdorff dimension delivers comparable values for activities 3 and 4 (Figure 2b). The combination of both methods (Figure 2c) provides a 2D activity map which provides a good separation of all five activities. It has to be noted that Figure 2c shows the mean ± one standard deviation. Considering two standard deviations on either side of the mean does not significantly affect the Hausdorff dimension, however, the average amplitudes of activities 3 and 4 are clearly overlapping.

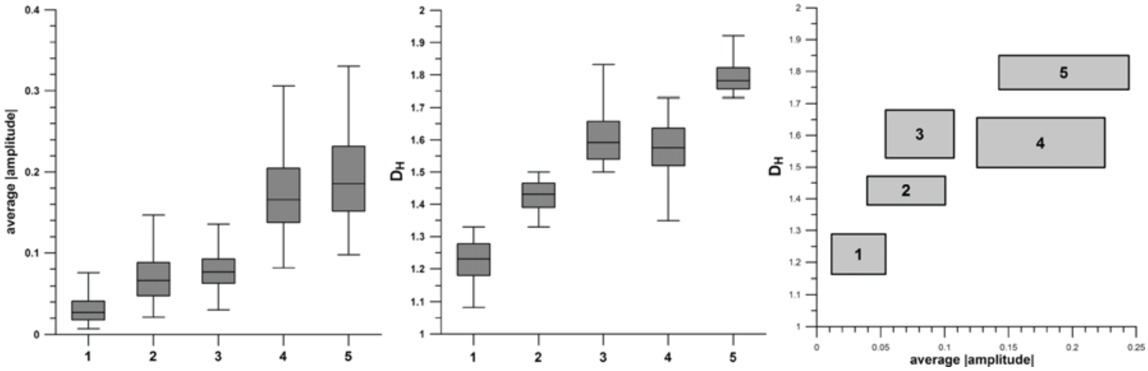

Fig. 2. average amplitude against activity class (left; Box-Whisker plot with median, quartiles and data range); Hausdorff dimension (D_H) against activity class (center; Box-Whisker plot); Hausdorff dimension (D_H) against average amplitude (activity class number at the mean; side lengths of boxes correspond to two standard deviations: one standard deviation on either side of the mean); 1: no activity; 2: low level activities; 3: high speed coasting; 4: high speed pushing; 5: collisions

4. Discussion

The Hausdorff dimensions of activities 1, 2 and 5 are different whereas the ones of activities 3 and 4 are basically identical, despite the clear difference in average amplitude. The comparable average amplitude of activities 4 and 5 seems surprising when considering that the deceleration of the wheelchair due to collisions is far higher than the acceleration produced by the athlete when pushing the chair. However, the 2.5 s window width of the running average procedure is considerably longer than the collision spikes so that pre- and post-collision activity affects the average amplitude. The window width could be reduced for more accurate collision results, but this would result in a noisier signal, thereby inflating the standard deviation. Combining the two parameters, the Hausdorff dimension and the average amplitude, provides a first step towards distinguishing between, and classification of, activities. However the average amplitude method is not ideal due to its high standard deviation. It has to be noted that calculating the level of significance via t-test is impractical in this study, as the number of data per activity is in excess of 3000 and all p-values turn out to be < 0.0001.

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