The Relationship between Maximum Movement Velocity in Postural and Gait Measured by an Accelerometer

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ABSTRACT

In this work, an inertial measurement unit (IMU) was developed and employed to study the lower limb kinematic measures during the gait and sitting postures. The tasks consisted of isotonic maximum velocity test and gait with maximum speed test to achieve similar conditions in both tests. Acceleration data of the right leg were captured and six temporal and spectral features were extracted. The results showed a considerable correspondence of these tests, suggesting that kinematics measured by the IMU at postural conditions have the potential to be used to evaluate gait kinematics. These results can be leveraged to predict kinematics in non-ambulatory patients.

KEYWORDS: kinematic, isokinetic, accelerometer, ankle, gait

I. INTRODUCTION

Gait analysis involves evaluation of the walking patterns, and is typically conducted by capturing the position of individual body parts during walking in a straight line. The normal gait cycle consists of two phases: the stance phase, during which one leg and foot are bearing most or all of the body weight, and the swing phase, when one foot is not in contact with the ground and the body weight is borne by the other leg and foot. In both phases, kinematic parameters are important for movement assessments [1-4].

Isotonic test is a static test in the sitting posture with a voluntary muscle shortening (concentric) or lengthening (eccentric) [5, 6]. Isotonic test is one of the most common tests used in evaluation of neuromuscular impaired patients to evaluate kinetic and kinematic performance [6-8].

There is an increasing need to examine the movement parameters to evaluate the treatment progress, particularly, in patients with neurological disorders such as stroke, spinal cord injury, multiple sclerosis and cerebral palsy [9]. Previous studies on motion camera-based gait recognition have shown promising results [10]. Motion capture systems can accurately measure the gait parameters [11]; however, gait test is not applicable for many patients with severe balance instability and gait impairments, as they cannot walk. Furthermore, data acquisition using such systems is expensive for clinical and research applications. To address this challenge, a portable compact setup such as an inertial measurement unit (IMU) can be employed for gait analyses [12, 13], prognosis of gait impairment, and monitoring the progress of therapeutic interventions in improving the posture and locomotion. This setup can also be employed for isotonic analyses. The advantage of this method is the use of a single device for data acquisition in both tests, which allows performance comparison between these two conditions.

The objectives of this study was to develop an IMU that contains a three-axis accelerometer and employ it to measure lower limb kinematics at sitting posture and gait, and also, to determine the relationship between the measures obtained at these two conditions. This relationship can be used to predict the patient's kinematics of the gait position from posture data, and vice versa. This allows to measure the training improvement of patients that cannot perform one of these tests, based on the results of the other test.

II. METHODS

A. Experiment Setup

Twelve healthy subjects; 8 male and 4 female (Table 1), aged 23 to 27 with no background of motor deficit and neurological disorders participated in this study. This study was approved by the ethics board of Tehran University of Medical Science. Before the experiment, all subjects provided written informed consent. All subjects performed both isotonic and gait tests.

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Table 1: Weight, Height and gender of the subjects

Subjects	Weight (Kg)	Height (Cm)	Gender
1	97	185	M
2	88	180	M
3	86	184	M
4	83	181	M
5	63	173	F
6	50	155	F
7	63	170	F
8	62	165	F
9	92	179	M
10	82	178	M
11	93	189	M
12	75	185	M

The IMU setup was designed to incorporate three sensors: ITG-3200 (MEMS triple-axis gyro), ADXL345 (triple-axis accelerometer), and HMC5883L (triple-axis magnetometer), resulting in a total of nine degrees of freedom. A 13 bit A/D converter was used for digitalize the data with 157Hz sampling rate. An Xbee wireless transmitter (Zigbee based) and a battery pack was also used in our data acquisition setup, as shown in Fig 2.
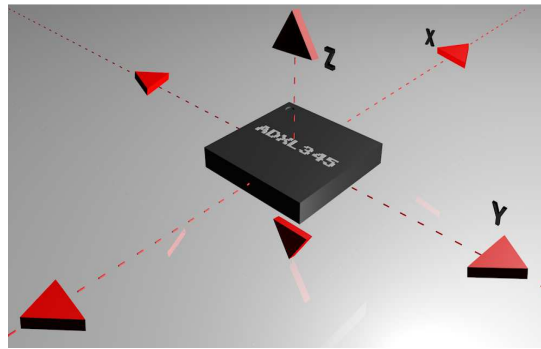

Figure 1: Axes of Acceleration Sensitivity.
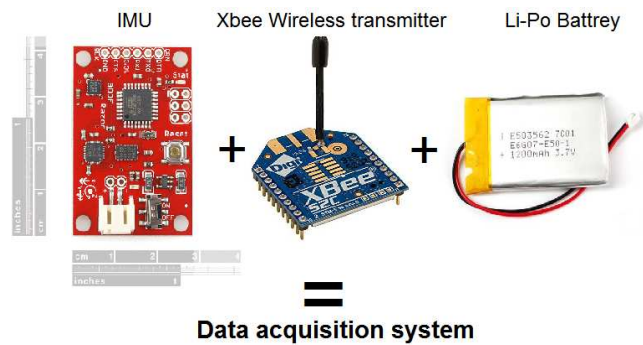
Figure 2: The data acquisition setup

1-. Gait patterns over a treadmill

The IMU setup was attached to the participants' right leg, on the lateral side of the fibula bone, above the ankle, as shown in Fig 3. The parameters extracted from the accelerometer measured data were maximum positive acceleration, maximum negative acceleration (deceleration), rise time, fall time, maximum frequency, and average frequency.
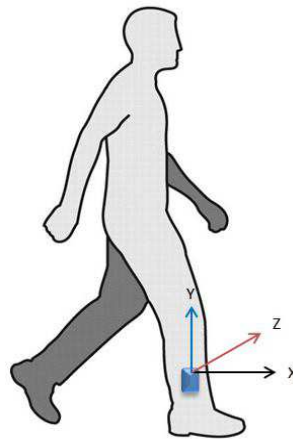
**Figure 3: The IMU setup was attached to the participants' right leg,
on the lateral side of the fibula bone, above the ankle.**

The treadmill speed was increased gradually in order to help the subjects reach the standard gait patterns in a period of 3 minutes, for two reasons: (1) to allow the subjects to warm up for the standard treadmill walking, and (2) to allow the subjects adapt to walking on the treadmill and create a standard walking pattern [14]. The test speed was 4km/h during data acquisition and the subjects were blinded to the staring time of data acquisition to maintain their standard adapted gait pattern and also to avoid distraction [15]. The IMU data (including three axes of accelerometer, three axes of gyroscope and three axes of magnetometer) were recorded for one minute.

2. Postural position

The subjects were seated and secured in an adjustable chair with their foot strapped to the footplate. In order to minimize the contribution of other muscles, subject's thigh was supported by limb support pad which was placed under distal femur. A 90° angle of the ankle joint was considered to be the neutral position (NP) and was defined as zero. All adjustments were completed precisely to facilitate alignment of the subject's axis of rotation (ankle joint) with the dynamometer shaft (Figure. 4).

In this test the IMU setup was attached and aligned to the footplate for measurement of the acceleration in its predefined three axes. An Isokinetic dynamometer (System 4, Biodex Medical Systems, Shirley, NY) was used to measure the subjects' velocity while performing foot rotation (in plantar-dorsi direction) in the postural position.

In order to let the subjects rotate their feet freely with minimum resistance from dynamometer, the system setup was adjusted so that no passive force was applied to the subjects' ankle.
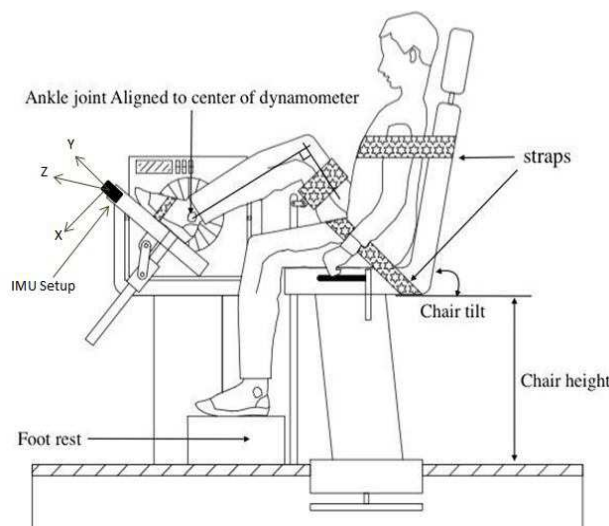
**Figure 4: isotonic test experimental setup. The subject sat on a chair and his/her ankle was aligned with
the dynamometer shaft.**

To allow the full-range of motion, the predefined range of motion was set to the maximum passive range of motion for each subject. Once the setup was ready, the subjects were asked to perform dorsi and plantar flexion with their maximum speed and maximum range of motion for five trials where each trial lasted 120s. Figure 5 shows the amplitude of acceleration in X-axis versus time for a representative subject during the gait test and isotonic tests.

(a)   **(b)**
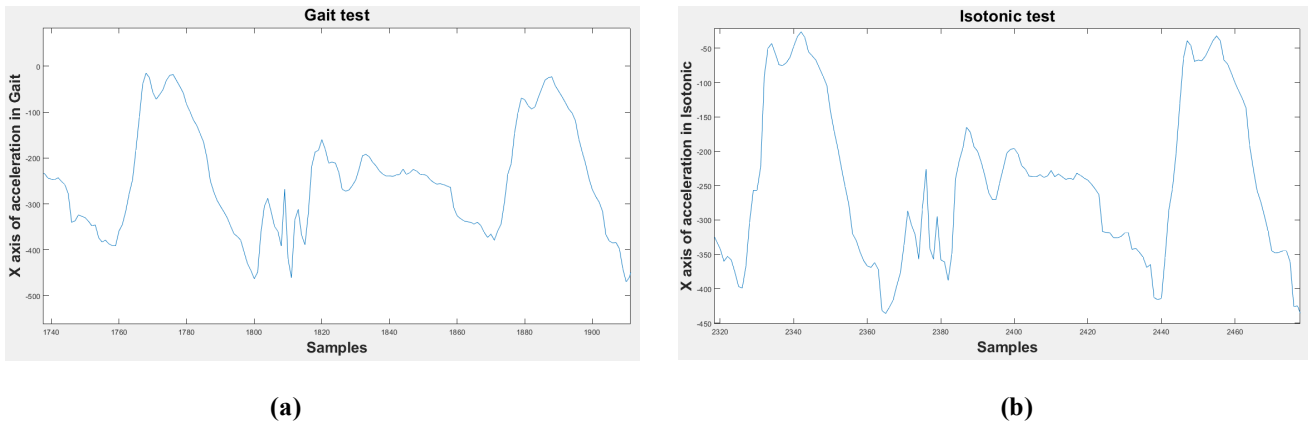
**Figure 5: The amplitude of acceleration in X-axis during (a) gait and
(b) isotonic tests is plotted for a representative subject.**

B. Data Processing

Data processing was performed using Matlab 2016b. The raw data were bandpass filtered between 0.25-20 Hz using a 6th order Butterwroth filter, to remove the baseline and high-frequency noises.

The total acceleration was calculated using acceleration of the moving directions (sensors X and Y) using the following equation (the acceleration in z direction was negligible and thus removed from the equation).

$$\text{Total Acceleration} = \sqrt{ACCX^2 + ACCY^2} \qquad\qquad (1)$$

where ACCX and ACCY were the measured accelerations in X and Y directions.

Different features were examined to identify those that can better discriminate the task performance.. Consequently, six features were selected including: acceleration rise time and fall time ,maximum positive and negative acceleration, and maximum and mean frequency. These features were calculated and averaged during the test period [16]. For this purpose, first, peaks and zerocorssings of the smoothed signal were identified to determine the maximum and negative acceleration, and rise time and fall time. Figure 6 shows the result of this algorithm for the entire acceleration data of a representative subject.
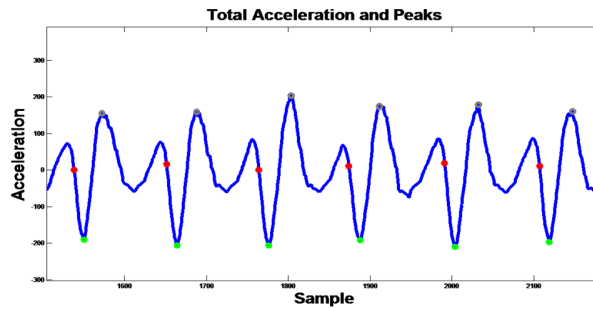
Figure 6: The peak detection results in the Acceleration data of a representative subject; green dots show maximum deceleration, red dots show zero crossing and gray dots show maximum acceleration.

Also the maximum and mean frequency were computed from the Fourier transform of the acceleration signal (Fig. 7).
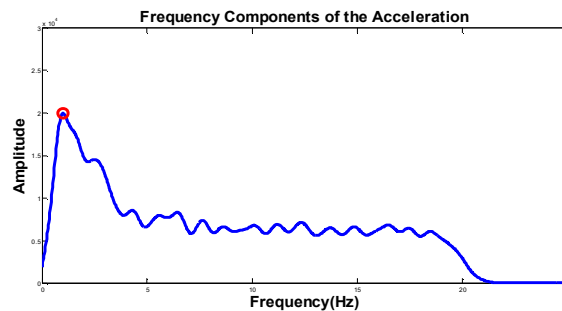

**Figure 7: Frequency response of the acceleration signal.
The red dot shows the maximum frequency.**

IV. RESULTS

Table 2 summarizes the measured features in both tests, averaged across the subjects.

**Table 2 : The features extracted during gait and isotonic tests, averaged across the subjects.
The standard devition is also shown.**

Feature	Isotonic	Gate(Fast walk)
Maximum Acc positive	1081.4 ± 7.9	427.5829 ± 4.3
Maximum Acc negative	-493.9466 ± 12.1	-242.5521 ± 9.6
Rise time	0.2510 ± 0.9	0.248 ± 0.8
Fall time	0.2329 ± 0.3	0.2344 ± 0.4
Maximum frequency	1.0339 ± 1.7	0.9154 ± 1.5
Mean frequency	4061.6 ± 23.2	4852.6 ± 37.8
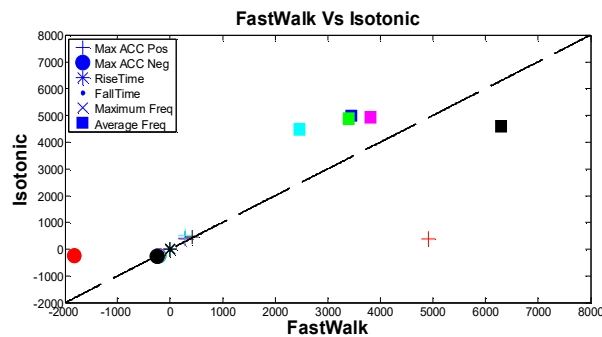
Figure 8: Group average results of main features extracted from isotonic data versus gait data

Figure 8 shows the features extracted in the isotonic test versus those extracted in the gait test.

The results show that there is a nearly linear relationship between the parameters of these two tests and Figure 9 shows the features correlation between the Isotonic and Gait test.
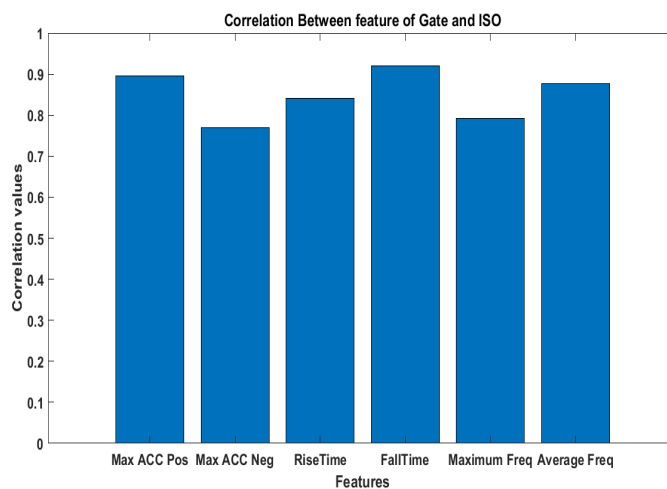
Figure 9: Correlation of features between the gate and isotonic tests.

V. DISCUSSION AND CONCLUSIONS

In this study an IMU was developed and utilized to determine the relationship between kinematic measures of isotonic posture and gait tests.

The results show a strong correlation between the acceleration data of the gait and isotonic tests. This resulted in a high correlation of the acceleration features between these two tests. This suggests the possibility of estimating gait kinematic features from the postural isotonic test. These findings have clinical significance as they show that it is possible to predict

gait impairments for patients who cannot possibly participate in gait assessment because of their impairment severity. Furthermore, the analysis of gait requires gait lab facilities, which is expensive. Thus, by using a portable IMU, the cost and efforts can be substantially reduced. The results of this work, should be confirmed by further studies on a larger sample size as well as on patients with walking impairment.

The major limitation of this study was that numerical integration of the measured signal to compute velocity and position, was not possible, because the initial velocity and position were not available.

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