The Velocity Effect on GEDEM Measurements

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Abstract. Gait Evaluation Differential Entropy Measure (GEDEM) [1] is a new quantitative approach to evaluating the condition of a subject by monitoring the acceleration [2][3]. The approach is capable to identify medical conditions [2, 3] and is also not dependent on age, weight, height or BMI. The initial studies [4][5][6] required the walking on the ground along a straight line for 20-30 seconds. Due to the promising results of the method, work is currently carried out on a treadmill. The treadmill alleviates the constraint of long corridors, and additionally offers better control on the gait velocity, minimum deviation in the coronal plane, and less variability in the GEDEM values [7, 8]. This work investigates the relationship between the gait velocity and the GEDEM. The gait velocity is a measurement parameter that influences the gait acceleration spectrum and therefore it is expected to influence GEDEM values.

1 Introduction

Human walking patterns are different. Each person's ideal gait is a combination of periodic movements determined by the body characteristics and the personal ability to control the gait. In the case of neuromuscular and musculoskeletal pathologies or injuries, these movements are not periodic and provide random variability. The walking pattern variability reflects the quality of the individual neuromuscular control and increases in cases of neuromuscular and musculoskeletal pathologies or injuries [9]

Accelerometer methods have proved appropriate and reliable for gathering gait data. Human body motion acceleration measurements have been analyzed with the use of entropy, as a measure of randomness, during the last two decades. Accelerometer sensors are low cost, small, light and easy to be adopted into portable measuring systems.

Shannon introduced the term entropy in order to quantify the information on a signal [10]. The concept of entropy was proposed as a general measure for both the randomness and harmony by Christakis [11]. The entropy is correlated, by definition, to the variability and the randomness while harmony is defined as the property of

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systems to match each other. Systems in harmony provide periodic, repeatable and identical behaviour and thus they are easy to be recognized and serve for definite, prescribed purposes, able to be matched to related systems. Christakis [12, 13] distinguished between harmony and the randomness proposing appropriate models for each concept. The current physics and mathematics do not provide a coherent general background for the study of harmony while the entropy stands as a basic concept to measure the randomness of systems. Entropy reduction is considered as an indication but not a measure of harmony. Randomness is a different concept than harmony. Because of the relationship between entropy and harmony and the existence of relevant mathematical formulations, entropy was introduced as a measure to evaluate the quality of the human gait and, therefore, to detect injuries and pathologies.

In 1991, Pincus introduced the approximate entropy technique [14]. ApEn is a technique that can be used to quantify the irregularity or variability of short finite time series based on the statistics. ApEn is a measure of likelihood of predicting future behaviour of a time series based on past values of the signal.

Arif et al. [15, 16, 9] and other authors proposed accelerometers and Approximate Entropy for studying the effect of fatigue on walking stability and the walking stability of young and elderly subjects. Kavanagh et al. [17] used Approximate Entropy for studying the effect of ageing on the pattern and structure of head and trunk accelerations during walking.

Gait Evaluation Differential Entropy Measure (GEDEM) [1] is a new quantitative approach to evaluating the condition of a subject by monitoring the acceleration[2][3]. The approach is capable to identify medical conditions [2, 3] and is also not dependent on age, weight, height or BMI. A device records the gait acceleration. Through spectral analysis is possible to estimate and quantify the level of uncertainty in the movement and summarize it in the GEDEM index. The principle is that pathological or mental conditions will increase the movement uncertainty and non periodicity of the movement. The initial studies required the walking on the ground along a straight line for 20-30 seconds. This work investigates the relationship between the walking velocity and the GEDEM. The gait velocity is a measurement parameter that influences the gait acceleration spectrum and therefore it is expected to influence GEDEM values.

2 Measurement Protocol

2.1 General Overview of GEDEM Method

The GEDEM Method consists of the following steps. The measurement of the gait acceleration signal is the first step. The measurement device consists of a tri-axial accelerometer device connected appropriately to a data logger. The device is attached on the subject's body near the O5 (Figure 1). The human body Centre of Gravity (COG) is considered to be near the O5 [18, 19]. The COG is reflects body movements and has an important role in maintaining the dynamic stability during walking [15, 16, 9, 20]. The measurement devise is designed to achieve the minimum disturbance

on the subjects' walking. The subject executes a usual walking pattern; e.g. walk for 15 meters or walk for more than 15 seconds on treadmill.
In the second step, the gait acceleration signal is analysed by the differential Entropy method developed by Papadakis and Christakis [1]. Differential entropy values are obtained for each axis. In this study only the Z-axis results will be presented.

2.2 Equipment

The Gait acceleration measurement device consists of an accelerometer sensor, a microcontroller, a voltage regulator, a memory, a transceiver and a battery. Accelerometer sensor is a tri-axial 12-bit accelerometer, capable to measure accelerations up to 2 g. The measurement device is based on an 8-bit microcontroller, ATTINY2313. The device dimensions are 125x65x25 mm weight 150 g (including the battery). Low weight is important to minimise the effect on the measurement. The data is transferred to PC via an RS232 port. The data is stored in a PC in ASCCI Format. An example of a typical raw accelerometer signal is presented in Figure 2. In this study only z-axis acceleration is was used.

Fig. 1. Accelerometry Device on the body.

3 Measurement Procedure

Acceleration data was collected whilst the participant walks across a distance of several metres on the treadmill. All measurements were performed in the afternoon. All subjects were asked to walk on the treadmill for at least 2 minutes before the measurements were obtained. The subject was not alerted with regard to the commencement of the measurement. The measurement duration was 30 sec. Subjects wore light clothes and thin shoes. The subjects were calm and not nervous.

3.1 Exercise Protocol

During the measurement, the treadmill inclination was zero. Five 5 repetitions for each velocity level were performed. The order of the velocity is random to avoid any systematic error.
The subjects are wearing light clothes and casual walking shoes. During the measurement, the subjects were asked to focus on a point on the wall positioned 140 cm above the floor lying directly in front of their walking path. This was to avoid distractions. In general, every possible measure was taken to avoid outside stimuli on the subject during the measurement.

The following treadmill speeds were selected:2.5 [km/h], 4.0 [km/h], 5.5 [km/h], 7.0 [km/h].

3.2 Subjects

The subjects' were interviewed. The surname, name, father name, gender, occupation, address, telephone, height, weight, age and medical history was recorded. All subjects signed an informed consent according to the University Institutional Review Board. The measurements were performed in the premises of the TEI of Crete in an airconditioned room. Care was taken to minimise distraction on the subjects during the measurements. All subjects are healthy individual. The names of the subjects are not presented.

Table 1.

No	ID	Gender	Age	Height	Weight	BMI
1	ZA	Male	26	172	70	23.6
2	MS	Male	23	165	65	23.8
3	MI	Male	23	177	60	19.1
	PP	Male	26	170	75	25.9
	AS	Male	24	180	89	27.4

4 Analysis/Discussion

4.1 X-axis Distribution GEDEM

This index represents the dispersion of the acceleration values in the axis of the movement. It is expected that increased velocity will lead to an increased dispersion. Fig. 2 presents the X-axis Distribution GEDEM values vs the gait velocity. It is obvious that as velocity increased the X-axis Distribution GEDEM values increase. It appears that the gradient of the increase is similar. In all the subjects, a gradient between 0.2 and 0.21 was exhibited. Only one subject has a higher value.

Table 2. X-Axis Distribution GEDEM Value vs Velocity Linear Model Coefficients.

	X-Axis Dist GEDEM		Y-Axis Dist GEDEM		Z-Axis Dist GEDEM	
Name	Intercept	Gradient	Intercept	Gradient	Intercept	Gradient
AS	-1.511	0.277	-1.076	0.2401	-1.434	0.317
MI	-1.48	0.2105	-1.42	0.1861	-1.677	0.3127
MS	-1.295	0.2027	-1.521	0.2444	-1.865	0.3246
PP	-1.309	0.2145	-1.352	0.1769	-1.578	0.3167
ZA	-1.279	0.2106	-1.411	0.2172	-1.861	0.3632

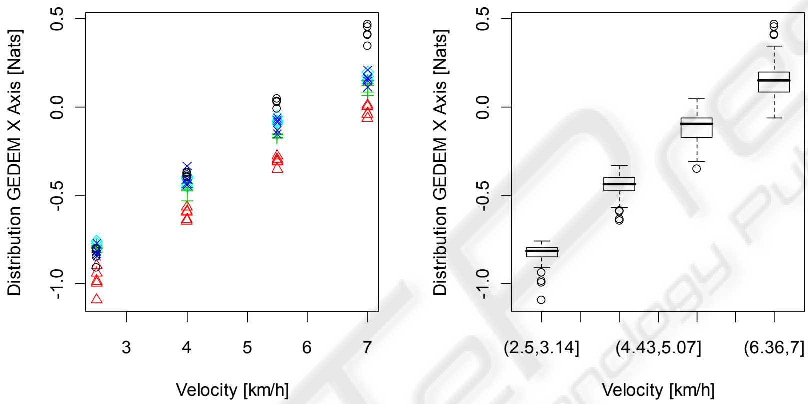

Fig. 2. X-Axis Distribution GEDEM vs Gait Velocity scatter plot (left) and whisker plot (right).

4.2 Y-Axis Distribution GEDEM

This index represents the dispersion of the acceleration values in the lateral axis (y-axis) (on the transverse plane perpendicular to the axis of movement). Since the total displacement on the Y-axis is zero, the uncertainty is calculated from oscillations around the zero acceleration value. As the velocity increases, the movement in the y-axis needs to be more pronounced. Therefore, it is expected that increased velocity will lead to an increased dispersion.

Fig. 3 presents the Y-axis Distribution GEDEM values vs the gait velocity. It is obvious that as velocity increased the Y-axis Distribution GEDEM values increase. Table 2 present the gradients of a linear model. It appears that the gradient of the increase range from 1.7 to 2.5.

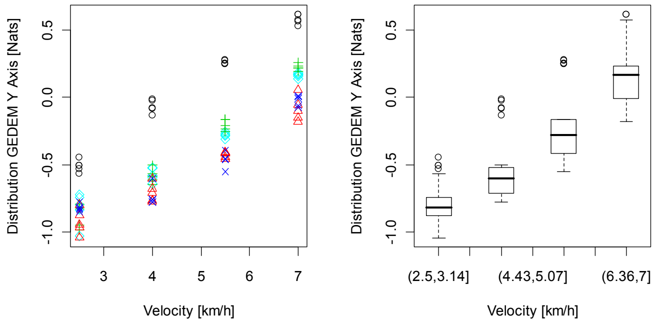

Fig. 3. Y-Axis Distribution GEDEM vs Gait Velocity scatter plot (left) and whisker plot (right).

4.3 Z-Axis Distribution GEDEM

This index represents the dispersion of the acceleration values in the vertical axis (z-axis). Similarly to the Y-axis It is expected that increased velocity will lead to an increased dispersion and therefore increased GEDEM index.

Fig. 4 presents the Z-axis Distribution GEDEM values vs the gait velocity. It is obvious that as velocity increased the Z-axis Distribution GEDEM values increase. Table 2 presents the gradients of a linear model. It appears that the gradient of the increase range from 3.1 to 3.6.

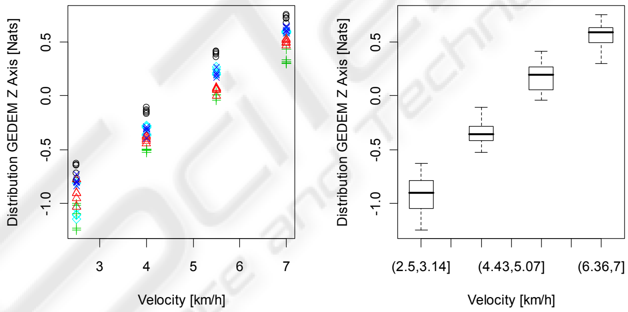

Fig. 4. Z-Axis Distribution GEDEM vs Gait Velocity scatter plot (left) and whisker plot (right).

4.4 X axis Spectral GEDEM

This index represents the dispersion of the power spectrum in the axis along the movement nt (x-axis). This index is lower if the number of frequency components which are important is less (i.e. when the movement is constant and at a certain rhythm). If there are significant changes in the rhythm then the index will increase.

Fig. 5 presents the X-axis Spectral GEDEM values vs the gait velocity. The figure initially appear not to be consistent. Because there is high dispersion during the initial values, a decrease around 5.5[km/h], and a further increase at 7.0[km/h]. This is attributed to the fact that at low velocities during the measurement on the treadmill, it was observed that the subjects were finding the velocity to low. As a result the limited length of the treadmill resulted in accelerations and decelerations trying to compensate for the movement; thus having a significant effect on the movement. The effect was different among the subjects (i.e. some performed better at 4.0[km/h], some better at 5.5[km/h]). Beyond 5.5.[km/h] the dispersion of the values increased.

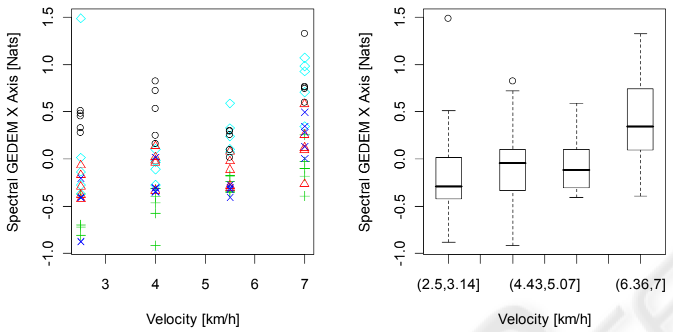

Fig. 5. X -Axis Spectral GEDEM vs Gait Velocity scatter plot (left) and whisker plot (right).

Table 3. X,Y,Z -Axis Spectral GEDEM Value vs Velocity Linear Model Coefficients.

	X-Axis Spectral GEDEM		Y-Axis Spectral GEDEM		Z-Axis Spectral GEDEM	
Name	Intercept	Gradient	Intercept	Gradient	Intercept	Gradient
AS	0.1709	0.06568	1.733	-0.243	1.681	-0.371
MI	-0.4487	0.07911	1.059	0.008	1.609	-0.444
MS	-1.0123	0.1318	1.09	-0.092	1.244	-0.411
PP	-0.9658	0.15675	1.36	-0.096	1.356	-0.387
ZA	-0.4489	0.15491	1.171	0.092	1.336	-0.293

Table 3 presents the gradients of a linear model for each subject. This index could be used to determine a velocity that the subject is comfortable with.

4.5 Y axis Spectral GEDEM

This index represents the dispersion of the power spectrum in the lateral movement axis (y-axis) – on the transverse plane perpendicular to the movement. This index is lower if the number of frequency components which are important is less (i.e. when the movement is constant and at a certain rhythm). If there are significant changes in the rhythm then the index will increase.

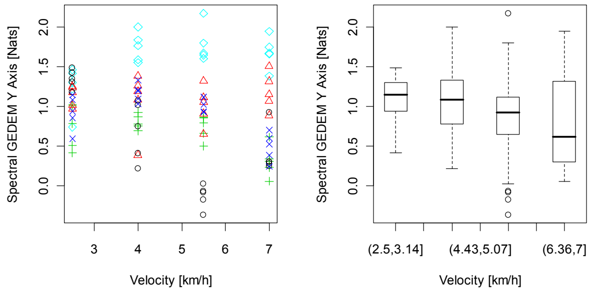

Fig. 6. Y-Axis Spectral GEDEM vs Gait Velocity scatter plot (left) and whisker plot (right).

Fig. 6 presents the Y-axis Spectral GEDEM values vs the gait velocity. There appear to be totally different trends in this graph between subjects. Others appear to increase and other to decrease. Due to the limited number of samples it was not possible to investigate a relationship, with other characteristics. This will be the subject of a further study.

Table 3 presents the gradients of a linear model for each subject. One is almost constant, two appear to increase and two to decrease.

4.6 Z axis Spectral GEDEM

This index represents the dispersion of the power spectrum in the vertical movement axis (z-axis) – intersection of Coronar and Sagittal planes. This index is lower if the number of frequency components which are important is less (i.e. when the movement is constant and at a certain rhythm). If there are significant changes in the rhythm then the index will increase.

Fig. 7 presents the Z-axis Spectral GEDEM values vs the gait velocity. Up to 5.5. [km/h], all subjects exhibit lower Z-axis Spectral GEDEM values with increasing velocity. Beyond 5.5. [km/h] the metric appears to level or increase in some subjects. It appeared that the movement on the treadmill beyond 4.0[km/h] was more regular than the vertical movement below 4.0[km/h]. This metric could be used to identify a velocity that the subject is comfortable with.

Table 3 presents the linear model gradients of Z-axis Spectral GEEM for each subject. The gradient values appear to be decreasing with values between -.29 and -.45.

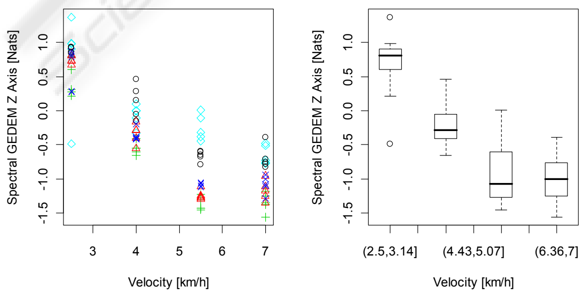

Fig. 7. Z -Axis Spectral GEDEM vs Gait Velocity scatter plot (left) and whisker plot (right).

4.7 Implications

Until now there was no understanding of the velocity effect on the GEDEM measurements. Through this work, the effect has been clarified. Also it was identified that a linear model between the measurements can be a good approximation in certain cases. Therefore a method for translating measurements to other velocities and comparing is possible.

Also some of the indexes with respect to the velocity exhibited inflection points. This is attributed to velocities that corresponded to measurements that the subject appeared to be more comfortable. As a result these indexes could be used to develop a methodology for identifying the normal gait velocity. However this is beyond the scope of this work.

5 Conclusions

This work presents the effect of gait velocity on GEDEM values. One of the problems until now was that it was not possible to compare measurements at different velocities.

Five subjects were measured. The subjects walked on a treadmill at 4 different velocity levels (2.5, 4 and 5.5 and 7km/h) and the accelerations were obtained. There was statistically significant evidence that the gait velocity influences the GEDEM values. In all cases a point of inflection appeared. The gradient of GEDEM index vs velocity appeared to be consistent and is possible to use the results for comparing GEDEM measurements at different velocity rates. Also this work maybe used to standardise a measurement protocol.

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