**Comparison of acceleration and jerk in detecting unstable walking**

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**Abstract.** Accelerometers have been widely used for human activity recognition as an early prediction of fall risk. However, acceleration data do not consider the force of gravity. Recent studies found that jerk, the derivative of acceleration, can describe the changes of body accelerations without considering the sensor orientation. This might overcome the issues caused by the displacement of the sensor, especially if a smartphone-based accelerometer is used as the sensor. This study aimed to compare the performance of acceleration and jerk in detecting postural stability using the postural stability index (PSI). Slightly different daily activity living such as walking on a flat surface, walking upstairs, and walking downstairs were chosen to compare the sensitiveness of acceleration and jerk in detecting the slight postural sway in healthy subjects. The collected data were pre-processed using the 8-modes of ensemble empirical mode decomposition (EEMD). Then, the multiscale entropy (MSE) of each intrinsic mode function (IMF) was calculated, and in the end, the PSI values were obtained. The paired t-test calculation using acceleration data showed that walking on a flat surface and walking downstairs are significantly differen (p = 0.039). Whereas, the jerk dataset could not distinguish walking on a flat surface and walking downstairs (p = 0.228). From this result, it is evident that acceleration is better in recognizing human activities than jerk.

1. **Introduction**

Unstable walking may occur as a result of injury, illnesses, and old age. It can barely noticeable and may develop to falls if the treatment is too late. The prevalence of falls is common in older adults’ populations with one out of three older adults experience falls each year [1]. Young adults also are at risk of falls if they have a history of injury or illnesses [2, 3]. Young adults with a motor disability have a greater risk of falling [3]. Falls can cause further health problems physically and psychologically [4]. Therefore, early detection of unstable walking may help in preventing falls.

As mentioned above, unstable walking can be barely noticeable and the postural sway in non-fallers may not as significant as the fallers. Thus, determining healthy subjects are at risk of fall may be difficult. The postural stability index (PSI) was introduced to discriminate the postural sway in healthy subjects [5]. The PSI can be used as early detection for the potential risk of falls. The index was constructed using the concept of multiscale entropy (MSE). Signal data obtained from accelerometers are decomposed using ensemble empirical mode decomposition (EEMD) and then the complexity index of each decomposed mode is calculated using MSE. Ultimately, the index is obtained by dividing the complexity index of the dominant mode with the total complexity indexes [5, 6].

Accelerometers are common device in human activity recognition due to their ability to provide an objective and non-intrusive measure of activity. Smartphone-based accelerometer gained popularity for its cost-effectiveness and ease of use [7]. It can be put inside the pocket of the subject to capture the activity. However, this might cause the displacement of the smartphone in the pocket. Thus, the acceleration data might not be valid. Past studies used jerk instead of acceleration data to overcome the issues caused by the loosely attached sensor [8]. Jerk can present the sensor orientation although the sensor is frequently shifted.

Motivated by the promising results by using jerk-based features, the current study aimed to evaluate the performance of acceleration compared to jerk in detecting unstable walking using the PSI. The activities chosen in this study were walking on a flat surface, walking upstairs, and walking downstairs with the consideration those activities are all normal walking without any obstacles. By doing the evaluation, it can be seen whether jerk is indeed better than acceleration in detecting subtle changes in slightly different activities of healthy subjects. The organization of this paper is prepared as follows. The methodology section describes the dataset and theoretical background behind the study. Results and discussions are then presented in section 3. Finally, the conclusion is presented in section 4.

1. **Methodology**

The dataset in this study was taken from the study by Malekzadeh et al. [7]. The data was collected using the iPhone 6s smartphone-based accelerometer with a sampling frequency rate of 50 Hz. The smartphone was kept in the subjects’ front pocket. Twenty-four subjects (14 females and 10 males) with the age of 28.79±5.44 years performed daily activity living tasks in the laboratory with the same environment and condition. In this study, walking on a flat surface, walking upstairs, and walking downstairs were selected because of the slight differences. The dataset was pre-processed with 8-modes of EEMD and the MSE value was calculated for each intrinsic mode function (IMF). Ultimately, the postural stability index of each walking task was calculated [5, 6].

* 1. *Acceleration and jerk*

Acceleration is the rate of change of velocity in terms of speed and/or direction. In human activity recognition, acceleration is the most common to be used. However, it excludes the force of gravity and thus it is just a consequence of static load [9]. Jerk is the derivative of acceleration and can be felt like the change of accelerations. The magnitude of the jerk represents the changes in accelerations independently from the sensor orientation [8]. Thus, jerk might be able to overcome the problem of sensor orientation displacement that might happen when the smartphone on the subjects’ pocket moves its position.

* 1. *Ensemble empirical mode decomposition*

Ensemble empirical mode decomposition (EEMD) is a self-adaptive method to analyze the non-stationary and nonlinear signals such as the human physiological data [10]. This method was proposed to solve the mode mixing issues in empirical mode decomposition (EMD). The original signal is added by white noise, then it is decomposed to obtain the *n* layers of IMFs (IMF11, IMF12, …, IMF1n). Thus, there are *m* x *n* IMF components where *m* denotes the number of ensemble members and *n* is the *n-*th layer of IMF. The decomposed results are averaged, and each layer of IMF is calculated as follows.

(1)

* 1. *Multiscale entropy*

Since its introduction by Costa et al., multiscale entropy (MSE) has shown promising results in the biomedical research field [5, 6, 11, 12, 13]. The MSE quantifies the complexity of time series data by constructing the consecutive coarse-grained.

(2)

where *τ* denotes the scale factor and *N/τ* is the length of each coarse-grained time series. Subsequently, sample entropy (SampEn) is calculated for each of the coarse-grained time series plotted as a function of the scale factor.

(3)

where *A* denotes the total number of forward matches of length *m*+1 and *B* denotes the total number of templates match of length *m* [11]. The complexity index (CI) is obtained by summing up the value of the SampEn.

(4)

* 1. *Postural stability index*

The postural stability index (PSI) was introduced as a measure to discriminate the postural sway in healthy subjects. The postural difference in healthy subjects is barely noticeable, unlike the difference between fallers and non-fallers. This index could be used as early detection of unbalanced movement. The PSI uses the 8-modes EEMD to decompose the signal data. The CI of each IMF is then calculated to determine the stability index. The IMF3 is chosen as the dominant IMF due to its instantaneous frequency is close to the frequency of walking [5, 6].

(5)

1. **Results and discussion**

The current study evaluated slightly different activities, namely walking on a flat surface, walking upstairs, and walking downstairs performed by young and healthy subjects. The purpose of selecting slightly different activities was to see the sensitivity of acceleration and jerk in distinguishing slightly different activities. The PSI of all tasks done by each subject was calculated for comparison, as can be seen in Table 1.

For acceleration data, the PSI of walking on a flat surface (average of 0.299±0.100) is lower than walking upstairs (average of 0.305±0.116) and walking downstairs (average of 0.340±0.064). However, the trend of the PSI values in each subject varies. For example, subjects 1 and 24 showed a decreasing trend with walking on a flat surface has the highest PSI, and walking downstairs has the lowest PSI value. Whereas, subjects 2, 15, 17, and 23 showed an increasing trend with walking on a flat surface has the lowest PSI, and walking downstairs has the highest PSI value. The rest of the subjects have a U-shaped trend with walking upstairs as either the highest or the lowest PSI value. Subject 3, 5, 7, 8, 9, 12, 19, and 20 showed a U-shaped trend with walking upstairs as the highest PSI value. Meanwhile, subject 4, 6, 10, 11, 13, 14, 16, 18, 21, and 24 showed a U-shaped trend with walking upstairs as the lowest PSI value.

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| Table 1. Calculated postural stability index | | | | | | |
|  | Acceleration | | | Jerk | | |
| Subject | Flat | Upstairs | Downstairs | Flat | Upstairs | Downstairs |
| 1 | 0.543 | 0.429 | 0.330 | 0.273 | 0.298 | 0.175 |
| 2 | 0.241 | 0.245 | 0.387 | 0.245 | 0.257 | 0.220 |
| 3 | 0.320 | 0.547 | 0.318 | 0.317 | 0.479 | 0.381 |
| 4 | 0.298 | 0.196 | 0.275 | 0.259 | 0.194 | 0.234 |
| 5 | 0.223 | 0.471 | 0.307 | 0.328 | 0.285 | 0.286 |
| 6 | 0.191 | 0.117 | 0.351 | 0.257 | 0.212 | 0.217 |
| 7 | 0.348 | 0.378 | 0.333 | 0.267 | 0.304 | 0.278 |
| 8 | 0.203 | 0.363 | 0.344 | 0.449 | 0.112 | 0.267 |
| 9 | 0.289 | 0.367 | 0.351 | 0.324 | 0.287 | 0.324 |
| 10 | 0.308 | 0.289 | 0.375 | 0.295 | 0.235 | 0.328 |
| 11 | 0.358 | 0.275 | 0.309 | 0.217 | 0.247 | 0.165 |
| 12 | 0.224 | 0.302 | 0.278 | 0.302 | 0.236 | 0.180 |
| 13 | 0.283 | 0.173 | 0.366 | 0.302 | 0.222 | 0.341 |
| 14 | 0.239 | 0.090 | 0.264 | 0.245 | 0.188 | 0.206 |
| 15 | 0.230 | 0.270 | 0.292 | 0.255 | 0.332 | 0.322 |
| 16 | 0.256 | 0.212 | 0.339 | 0.339 | 0.188 | 0.274 |
| 17 | 0.252 | 0.315 | 0.431 | 0.190 | 0.267 | 0.215 |
| 18 | 0.578 | 0.493 | 0.553 | 0.786 | 0.214 | 0.362 |
| 19 | 0.353 | 0.446 | 0.415 | 0.094 | 0.260 | 0.458 |
| 20 | 0.204 | 0.315 | 0.304 | 0.390 | 0.285 | 0.237 |
| 21 | 0.226 | 0.200 | 0.299 | 0.263 | 0.216 | 0.210 |
| 22 | 0.382 | 0.281 | 0.335 | 0.318 | 0.275 | 0.221 |
| 23 | 0.235 | 0.272 | 0.359 | 0.283 | 0.134 | 0.302 |
| 24 | 0.390 | 0.268 | 0.253 | 0.237 | 0.279 | 0.227 |

Whereas for jerk data, the PSI of walking on a flat surface (average of 0.301±0.123) is higher than walking upstairs (average of 0.250±0.072) and walking downstairs (average of 0.268±0.073). Similar to the acceleration data, there is no trend in the PSI values. Logically, walking on a flat surface should be the most balanced movement considering there is no challenge in a normal walking on a flat surface. Based on the average of the PSI values from acceleration data, the lower the value, the more balance the movement. Meanwhile from jerk data, the higher the value, the more balance the movement. Thus, walking downstairs is the least balanced movement based on acceleration data, and walking upstairs is the least balanced movement based on jerk data. Both walking upstairs and downstairs are more challenging than walking on a flat surface since both require more balance skills. Difficulty in walking upstairs and downstairs is associated with poor balance, reduced grip strength, and neurological disorders [14]. Walking upstairs is more tiring than downstairs because it against the force of gravity. While walking downstairs is associated with a higher risk of falls. To compensate for the challenges, people walk slower when people walking downstairs and upstairs [14, 15, 16].

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| **Table 2.** Paired t-test calculation | | | | | |
| Paired t-test | Acceleration | | | Jerk | |
| Activities | | 2-tailed | 1-tailed | 2-tailed | 1-tailed |
| Flat - Upstairs | | 0.801 | 0.401 | 0.114 | 0.057 |
| Flat - Downstairs | | 0.039 | 0.020 | 0.228 | 0.114 |
| Upstairs - Downstairs | | 0.123 | 0.062 | 0.346 | 0.173 |

The paired t-test was used to see whether the PSI of each task is different from one another (Table 2). Using acceleration data, walking on a flat surface and walking downstairs are significantly different. Whereas, all activities are no different when using jerk data. Interestingly, the test showed that walking upstairs and walking downstairs are not different, although the PSI values for both tasks seem different. The paired t-test showed that the PSI cannot distinguish the walking on a flat surface and walking upstairs for both acceleration and jerk data. It is also unable to differentiate the walking upstairs from walking downstairs. This inability to discriminate the tasks might happen because the sampling frequency in this study is 50Hz, whereas the sampling frequency in the past study was 30Hz [Nurwulan journal & conf]. Past studies comparing the sampling frequency rate found that low sampling frequency is better for human activity recognition [17, 18]. Further studies to evaluate the effect of the sampling rate might be able to describe whether the frequency rate affects the results of the PSI values.

1. **Conclusion**

This study evaluated the performance of acceleration and jerk in discriminating walking on a flat surface, walking upstairs, and walking downstairs in healthy subjects using the postural stability index (PSI). The motivation of this study was to compare the sensitivity of acceleration and jerk in distinguishing slightly different daily activities. Based on the evaluation using a paired t-test, acceleration data could detect the difference between walking on a flat surface and walking downstairs. Whereas, jerk data could not discriminate the three walking activities. From the values of the PSI using acceleration data, walking downstairs seems to be the least stable movement. Although both walking upstairs and downstairs are more challenging than walking on a flat surface, the young adults could perform walking upstairs better than walking downstairs. In conclusion, the acceleration is still better than jerk in recognizing human activities.

1. **References**

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