Investigation of Relation between Sport’s Motion and Heart Rate Variability (HRV) Based on Biometric Parameters

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Abstract. Heart rate is the most important biometric data for human. Most of the human life status, such as stress, emotion, fatigue and others can be detected by monitoring and analyzing the heart rate. Heart rate has always been converted into Heart Rate Variability (HRV) due to the reason of HRV is a good indicator in identifying the condition of an individual during the sporting and training. HRV can be calculated easily by obtaining the values of RR intervals, where RR interval is the interval between the successive heartbeats. Thus, this study aims to investigate the relationship between the biometric parameters (heart rate and HRV) and the motions. Two categories of sport motion, which are slow and fast motions (each with backhand lift, forehand lift and forehand smash), had been considered in this study. It is found that most of the motions are positively correlated with heart rate but negatively correlated with HRV. Also, each fast motion is found to have a higher correlation with the HRV if compared with those of slow motion. Obviously, the pattern of motion is significant in affecting the biometric parameters especially the HRV.

1. Introduction
Biometric parameter is a value that measured and analyzed from biological data, such as heart rate, fingerprint, digital signature and etc. [1]. It can be used to identify the status of an individual, such as health status, adaptability, fatigue status and identification. The biometrics parameter, heart rate, has been widely used in various areas, such as medical science, sports science as well as technologies. It can be captured by using a heart rate monitor devices and is manipulated by the Autonomic Nervous System (ANS), which contains Parasympathetic Nervous System (PNS) and Sympathetic Nervous System (SNS); commonly, the SNS releases the hormone norepinephrine to accelerate the heart rate under stressful or excitement conditions while the PNS relaxes the body system by releasing the hormone acetylcholine to slow the heart rate and is most active under restful conditions. In other words, the increment of PNS together with the decrement of SNS will lead to the decrement of heart rate, which is in contrast to the increment of HRV. HRV is basically known as the variation between the heart rate intervals during exercise. It may differ for each individual according to genders, ages, athletic or non-athletic and other aspects, regardless of either before, during or after exercise. By obtaining the values of HRV, activities of the PNS can be known; the indicator of the SNS activities, however, is still remain unknown. Hence, it is important to study the relationship between the heart rate and the HRV with different types of motion in order to identify the status of an individual. This study is aimed to investigate the relationships between the HRV and the motions during the sports training or exercising so that the trainee or the coaches may able to plan a suitable training in order to maximize the adaptability.
2. Literature Review

2.1. Heart Rate Variability (HRV)

HRV is a measurement of the intervals between the heart rate and these intervals are called inter-beat (RR) intervals as shown in Figure 1. Figure 1 show a RR interval from a result of an electrocardiogram. There are two major types of measurement, time and frequency domains. Most of the time domain values are indicating the PNS activities. For short-term exercise, RMSSD (square root of the mean of the successive differences between adjacent RR intervals), SDANN (standard deviation of the average NN interval) and high frequency (HF) represent the PNS activities while the LF/HF (ratio of low frequency and high frequency) indicates the balance of ANS [2]. The HF can be an alternative option to the RMSSD [3].

Figure 1. RR interval between a heartbeat. [4]

Some researchers found that the low frequency (LF) can be an indicator of the sense of pressure from the baroreceptor [5-6]. The values of the HRV can be further normalized in case of the dataset is not normal distributed. The normalized method can be natural logarithms and simple logarithms in order to smooth the graphs and can be observed easily [7]. The HRV had been used to find its relationship with the gender, ages, athletic, training loads, endurance, and adaptability. Most of the researchers found that the HF or HRV is higher in female [1-2, 8-12]. As human ages up, their HRV began to decline [13-17]. However, some of the researchers found that the HRV is not related to age [18-19] especially in children [14]. HRV was found to be higher in athletic and there was no different between the athletes’ genders [18]. This result was supported by other researchers [3, 20-23]. Besides that, it was found that there is difference in HRV between before a motion, during a motion, and after a motion. The HRV before the motion (baseline) is normally higher due to the stationary status. The HRV is lower during the motions due to the usage of muscles cells as well as the activation of SNS activities and will be increased after each motion [24-25]. The recovery, dropping of the values of HRV to the baseline is considered as good recovery and leads to a good health [26]. When the appropriate continuous intensive training is implemented, the HRV can be improved and achieved positive adaptation of the training. Else, overtraining could occur, which may cause damage to the trainee in terms of injury and time spend on healing. Furthermore, the frequency domain of HRV in short-term can be used as an assessment to the performance of the sports’ motions and exercises from the results of the badminton matches performance [27].

2.2. Sport’s Motion

Motion recognition is necessary for this study. The easiest method to capture a motion is to record a video of an individual during the exercises or training. However, it is troublesome that the observation to determine the quality of motion had to be done by coaches from the video. This observation technique may miss some action or several replays will be needed to analyze a motion. To measure the quality of a motion quantitatively, motions capturing method using physicals markers were developed. Yet, this method has a limitation as the placing of physical body markers need to be accurate in order to obtain precise data whenever the tracking of the movement is needed and this could be inconvenient.
for the participants during the data gathering. Therefore, a markerless motion capture method is developed to overcome this limitation. The Microsoft Kinect sensor device can be used to capture the motion in this method by using the depth-based recognition or skeleton-based technique [19]. The depth-based recognition is a process of classifying the sequences of depth in a specific activity [28] while the skeleton-based recognition is the method of on the human skeleton during activities [29]. The skeleton-based motion recognition had been used with Microsoft Kinect sensor to detect the athletes’ motion and the Range of Movement Index (RoMI) technique to determine the similarity index of the raw badminton stroke data [30]. It was found that there is a vital negative relationship between the two variables which 78% of the variables are correlated.

3. Experiment

3.1. Data Collecting

There were two categories of motion considered in this study, where the slow motion was required to be completed within 1 to 3 seconds and that of fast motion was within 1 to 2 seconds. In order to obtain the data of motions and heart rate, respectively, Microsoft Kinect Sensor and Hexoskin Wearable Biometric kit had been used. By wearing the Hexoskin smart shirt and performing the specific exercise motions in front of the Microsoft Kinect Sensor, the data of heart rate, RR intervals and motion during the moment of exercising and at rest could be obtained. The participant was first requested to stand still for 1 to 3 minutes at the beginning and followed by performing the specific badminton strokes for 30 times (in which the intervals between the strokes was 1 to 2 seconds) and then rested by standing still again for obtaining the recovery heart rate. These steps were repeated for three different badminton motions in slow and fast modes, where the three badminton motions considered were forehand smash, back hand and forehand lift. A simplified setup of the devices during training is illustrated in Figure 2.

![Figure 2. Data collection setup](image)

3.2. Data Processing

The collected data of motions were in three dimensional coordinate system, x, y, and z coordinates. The coordinates were then calculated into the radius, r, by using the formula of Euclidean norm as shown in Equation (1) and each coordinate is respected to the respective coordinates of the SpineBase as shown in Figure 3.

\[
r = \sqrt{(x-x_s)^2 + (y-y_s)^2 + (z-z_s)^2} \text{ (mm)},
\]

where \(x, y, \text{ and } z\) are the coordinates of the selected joint in three dimension; and, \(x_s, y_s, \text{ and } z_s\) are the coordinates of the SpineBase and \(\text{mm}\) is the unit of each radius of the joint. The obtained radius was then used to calculate the speed, \(s\), of the motions. As the Microsoft Kinect Sensor was used, there
were 30 frames captured in one second; thus, the duration taken for one frame is equal to \( \frac{1}{30} \) over 30 frames and hence the formula of speed, \( s \), is:

\[
s = \frac{r}{\frac{1}{30}} \text{ (mm/s)}. \tag{2}
\]

After the speed was calculated, the raw data of the heart rate and the motions were then combined to correlate each other so that the final datasets can be formed; here, the data of the joints of the hand and arm, such as ElbowRight, WristRight and HandRight, were used for calculating the mean of the radius and speed for each frame since the focus was on the motions of arm and hand only. Also, those of the fingers and thumb were excluded so that the accuracy of the data of motions can be assured. These steps were repeated for the cases of RR intervals for forming the corresponding final datasets with the data of motion.

![Figure 3](image-url)  
*Figure 3. The radius, \( r \) of the other joint respect to Spinebase. [31]*

### 3.3. Calculation of Correlation and Heart Rate Variability Value

With the intention of investigating the strength of the relationship between the biometric parameters and motions, hence, the calculation of the correlation is desired. Here, the correlation between the final datasets of heart rate or RR intervals and the motions were calculated by applying the Bivariate Pearson Correlation Analysis using Statistical Package for the Social Sciences (SPSS) software, in which a correlation coefficient \( R \) could be obtained. The value of the correlation coefficient, \( R \), is always in the range of -1 to +1; value of -1 indicates a strong inverse relationship whereas +1 indicates a strong direct relationship and there is no relation between the variables if the value is 0. Besides that, for the cases of before, during and after the motions, the RR intervals were also be used to calculate the values of HRV by using a HRV analysis software, Kubios HRV Standard.

### 4. Result And Discussion

The values of the correlation coefficient, \( R \), for different motions are shown in Tables I and II. As seen in Tables I and II, for each motion, it was noticed that the obtained \( R \) values were same for the cases of heart rate versus speed and heart rate versus radius; same situation was also observed for the cases of RR interval versus speed and RR interval versus radius. These situations were happened as the speeds were directly converted from the radius which was divided by 1/30 frame per second. It was obvious that the correlation coefficient, \( R \), of all the fast motions were higher if compared with those of slow motions; in other words, the effects of the fast motions on the heart rate and HRV are greater if compared with slow motions.

For all cases except slow forehand lift, it was noticed that the heart rate and the motion were positively correlated as shown in Figure 4 to Figure 7. This indicated that when the distance or the speed was increased, the heart rate was slightly increased. Also, it was noticed that the variation of the heart rate during the motion and after the motion was small, especially for the cases of slow motion;
this finding was found to be in consistent with the obtained values of HRV (RMSSD) during and after the motion, as shown in Table III. By obtaining the values of HRV (RMSSD), the adaptability of the athlete to particular motion could be known; when the variations between the before, during and after the motion are small, it is known that the athlete has been adapted to that particular motion and hence the level of difficulty of the motion could then be increased. On the other hand, if the variations are large, it is known that the athlete has not been adapted to that particular motion and same training of the motion should be continued or the level of training could slightly be reduced. The greater variation of the heart rate during and after the motion for the cases of fast motion was expected to be the consequence of the fast movement of the arm and more power of the muscles was used. To perform a rapid movement, more muscle cells are involved due to the frequent blood pumping of the heart to supply the oxygen to the muscle cells. Therefore, the heart rate will become higher during the motion and it will decrease gradually after the motion; by standing still after the motion, the heart rate will try to recover from the motion by reducing slowly until it recovers to the baseline. However, the increasing of the heart rate after the motion was noticed in the case of slow forehand smash, in which its HRV value was slightly decreased; it was expected that the difference was caused by the tiredness of continuous exercising.

Table 1. R-Values for Slow Motions.

|   | Backhand Lift | Forehand Smash | Forehand Lift |
|---|---------------|----------------|---------------|
| HR vs. $s$ | + 0.059 | + 0.081 | - 0.215 |
| HR vs. $r$ | + 0.059 | + 0.081 | - 0.215 |
| RR vs. $s$ | - 0.131 | - 0.105 | + 0.197 |
| RR vs. $r$ | - 0.131 | - 0.105 | + 0.197 |

Table 2. R-Values for Fast Motions.

|   | Backhand Lift | Forehand Smash | Forehand Lift |
|---|---------------|----------------|---------------|
| HR vs. $s$ | + 0.392 | + 0.391 | + 0.387 |
| HR vs. $r$ | + 0.392 | + 0.391 | + 0.387 |
| RR vs. $s$ | - 0.350 | - 0.361 | - 0.362 |
| RR vs. $r$ | - 0.350 | - 0.361 | - 0.362 |

Table 3. RMSSD in Millisecond for Each Motion.

| Motions                  | Before | During | After  |
|--------------------------|--------|--------|--------|
| Slow backhand lift       | 15.6171| 11.3654| 12.6619|
| Slow forehand smash      | 13.4615| 09.1166| 09.1064|
| Slow forehand lift       | 11.5103| 10.1890| 10.3180|
| Fast backhand lift       | 37.6120| 20.4005| 31.3174|
| Fast forehand smash      | 18.4618| 16.5073| 18.3533|
| Fast forehand lift       | 29.5996| 14.6951| 23.5590|
Figure 4. Scatter plot of heart rate versus speed for slow backhand lift

Figure 5. Scatter plot of heart rate versus radius for slow backhand lift

Figure 6. Scatter plot of heart rate versus speed for fast backhand lift
Figure 7. Scatter plot of heart rate versus radius for fast backhand lift

Figure 8. Scatter plot of heart rate versus speed for slow forehand lift

Figure 9. Scatter plot of heart rate versus radius for slow forehand lift
On the other hand, different situation was observed in the case of the slow forehand lift motion, where the heart rate and the motion were found to be negatively correlated as shown in Figure 8 and Figure 9; the heart rate was decreased as the speed or distance was increased. The difference was expected to be the result of the fairly low intensity of the motion, in which the motion of slow forehand lift was incapable to create a sufficient large distance and speed value and thus lesser power of muscles was required. Commonly, the relationship between the heart rate and the HRV is inversely correlated [32]; this was agreed well by the opposite sign of the obtained $R$ values for the cases of RR intervals versus motions as shown in Tables I and II. In addition, the RR intervals were decreased during the motion as the radius and speed were increased, especially for the case of fast forehand lift motion as depicted in Figure 10. Again, this could be shown by the values of HRV ($RMSSD$) in the Table III in which the HRV value during the motions (whereas the heart rate is increasing) is found to be lower than at rest. Also, the changes between heart rate and RR intervals during the fast motions are larger if compared with those of slow motions as shown in Figure 11. As mentioned previously, this could be due to the higher strength was used during fast movement of the arm.

![Figure 10. RR intervals and motions versus time taken for fast forehand lift](image1)

![Figure 11. RR intervals and motions versus time taken for Slow forehand lift](image2)
5. Conclusion
In this study, the time domain of the HRV (RMSSD) is used and the results found that the HRV is negatively correlated with the motions. Furthermore, the result of the heart rate, which is positively correlated with the motions was found. From the result of the correlation, the fast badminton motions have a stronger correlation than slow motions to the biometric parameters. The HRV after the slow badminton motions is almost the same with the HRV during the slow motions while the fast badminton motions show greater differences between the values of the HRV.

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