Heart Rate and Activity Measured during Volleyball Competition using Wearable Technology

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Abstract: Volleyball is characterised by intervals of high-intensity gameplay mixed with periods of relative rest. Monitoring the athletes' physiology during competition allows us to study the changes in exercise intensity throughout a game. In this study, eight elite male volleyball athletes measured their heart rate and activity during multiple games of the regular season in the Belgian Liga A and B using wearable technology. The data show a significant decrease in the heart rate for set 1 to 4, from 79.1 $\%HR_{max}$ to 73.9 $\%HR_{max}$. For activity, a decreasing trend is visually observed, but the difference is only significant for set 1 compared to the other sets. Finally, the performance did not vary significantly over the course of the different sets.

1 INTRODUCTION

Volleyball is a team sport with a highly variable and dynamic nature (Künstlinger *et al.*, 1987). The teams switch back and forth between offence and defence within a matter of seconds. Moreover, scoring can be the result of a single attack or a long-lasting, high-intensity rally. In addition to the dynamics of the game, players take up different roles and accordingly require a different skillset (Sheppard *et al.*, 2013). To illustrate, the libero is a defensive specialist and cannot take part in offence, the setter leads the offence and decides which hitter will attack, and the outside, middle and opposite hitters each have their own position for attacking. Studying volleyball athletes' physiology is interesting to identify the efforts that are required during a game and analyse how this changes over the course of the different sets.

From a physiology point of view, volleyball has traditionally been described as a high-power, predominantly anaerobic sport (Van Heest, 2003). Due to the rules and structure of the game, athletes experience intervals of intense exercise, but also have the opportunity to recover in between these intervals. During these intense exercise intervals, the athletes' body generates energy primarily from creatine phosphate stored in the muscle cells and from anaerobic glycolysis. During recovery periods, intracellular stores of creatine phosphate are replenished through aerobic pathways (Van Heest, 2003). It has been estimated that the overall energy demands of the sport are met by a combination of all three energy-producing pathways in the following proportions: the creatine phosphate system (40%), anaerobic glycolytic system (10%) and aerobic metabolism (50%) (Gionet, 1980).

Heart rate monitoring is a popular tool for quantifying the internal load in athletes (Buchheit, 2014). This approach is based on the linear relationship between steady-state work rate and heart rate (Hopkins, 1991; Arts & Kuipers 1994). Despite the abundance of tools for heart rate monitoring, data during volleyball competition is limited. Furthermore, the data that are available indicate a high variability. In the research of González *et al.* (2005), a mean value for the heart rate of 148 bpm was observed for the principal central players during their time on the court. This decreased to 124 bpm for the periods off the court. For the liberos, mean values of 137 and 131 bpm were noted for the time on and off the court respectively. In beach volleyball, a mean heart rate of 146 bpm was noted for a 3-set match (Jimenez-Olmedo *et al.*, 2017).

In this study, we aimed at analysing the evolution of the heart rate over the different sets. A similar analysis is performed with accelerometer data to identify changes in activity throughout the match.

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This way, we aim to gain insights into the exercise intensity during volleyball competition. Finally, the performance of the athletes was analysed.

2 MATERIAL AND METHODS

2.1 Experiment Design and Participants

Eight male elite volleyball athletes participated in this study. Four athletes collected data during games in the regular season of 2017-2018. They played together on a team in the Belgian Liga A (1st division). The other four athletes were monitored during the season of 2018-2019 and played on a team in the Belgian Liga B (2nd division). Table 1 shows the athlete's age, height, playing position, division and number of games during which data collected. In total, 63 unique measurements are included in this study.

Table 1: Info about the participating athletes.

Player	Age	Height	Position	Division	# games
1	19	193 cm	Outside	Liga A	8
2	21	197 cm	Outside	Liga A	8
3	19	174 cm	Libero	Liga A	8
4	32	195 cm	Opposite	Liga A	4
5	18	191 cm	Setter	Liga B	10
6	16	188 cm	Outside	Liga B	9
7	17	194 cm	Outside	Liga B	9
8	16	200 cm	Center	Liga B	7

Athletes were equipped with a wearable device to monitor physiological data throughout the entire game. The measurements were started before the warm-up and were stopped when the game was ended. The experimental set-up and data collection were approved by the social and societal ethics committee (SMEC) of the KU Leuven (cases 'G-2017 11 999' and 'G-2018 11 1432').

2.2 Data Collection

The BioHarness 3.0 chest strap (Zephyr Technology, USA) was used to monitor heart rate and activity continuously without affecting the athletes' performance. The device recorded the electrical skin potential differences at 250 Hz to construct the ECG signal. A value for the heart rate was automatically calculated and sampled to 1 Hz. Additionally, this heart rate signal was checked to match the original ECG rhythm.

Next to the heart rate, the device captured acceleration in a three-dimensional way at a frequency of 100 Hz. The axial accelerometer output was automatically band-pass filtered to remove non-human artefacts and gravity. This data was further processed by taking the mean acceleration for each axis per second and calculating the root-mean-square of the three axes. As a result, one signal for the activity of the athlete is obtained with a sampling frequency of 1 Hz.

Data regarding the actions and events that occurred during the competition were captured through the DataVolley scouting software (Data Project, Italy). The team's scouter labelled each contact with the ball as a serve (S), reception (R), attack (A), block (B), dig (D), set (E) or free ball (F). Additionally, raw video files were also available. This way, the timing of the different sets, the rotations and the substitutions were noted. In our analysis, we will take a closer look at the total number of actions that were performed during the game and the duration during which a player was on the playing field.

2.3 Data Analysis

2.3.1 Data Processing

First, the data was processed so that only the periods during which the athlete was part of the game were retained. This means filtering out substitutions. Since the libero has a special role and can be replaced continuously, only long term substitutions were considered. As González *et al.* (2005) also indicate, the time spent off-court for the libero is very short (29 s). Therefore, the libero has to be ready to enter the field at any moment.

Second, volleyball games are regularly interrupted by time-outs. During set 1 to 4, technical time-outs of 60 seconds are automatically imposed when the leading team reaches a score of 8 or 16. Furthermore, one or two additional time-outs can be taken by each team depending on the specific rules of the competition. Data during the time-outs were also omitted.

Third, the heart rate data was converted to a percentage of the maximal heart ($\%HR_{max}$) for each athlete. This was done to account for inter-individual differences in the range of the heart frequency.

Fourth, the data were processed per set. For each set, the mean values for the heart rate percentage, activity, numbers of volleyball actions and minutes played were calculated.

2.3.2 Statistical Analysis

For the analyses, the data of all athletes and matches are considered together. The analyses are performed on the level of the entire test population.

The aim of the statistical analysis was to determine whether the variables vary significantly throughout the game. First, a Kruskal-Wallis test was performed on the data for the different sets. This non-parametric test, checks the hypothesis that the distribution for at least one set differs significantly from another set. Secondly, significant Kruskal-Wallis tests were followed up with a pairwise comparison for each combination of two sets using a pairwise Student's t-test. For p-values smaller than a significance level (α) of 0.05, the tests are considered to be significant. Prior to the Student's t-test, the normality of the data was checked.

3 RESULTS

3.1 Heart Rate Throughout the Game

The evolution of the mean value for the $\%HR_{max}$ per set is visualised in Figure 1. The bars indicate the mean value for the distribution of each set and the whiskers indicate the standard deviation. Visually, it is clear that the heart rate tends to decrease from set 1 to 4. For set 5, this decreasing trend is not continued.

It has to be noted that both sets 4 and 5 are not played each game since the match ends when one team wins three sets. The number of measurements for set 1 to 5 is respectively 61, 61, 55, 30 and 5.

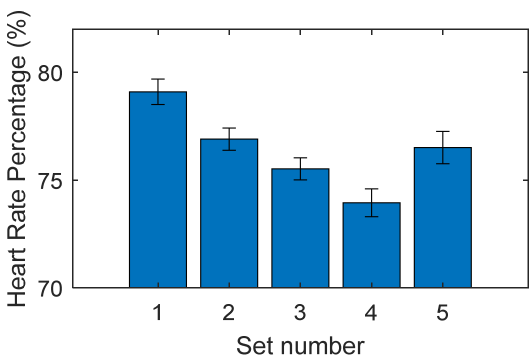

Figure 1: Evolution of the mean for $\%HR_{max}$ over the different sets. The whiskers indicate the standard deviation.

The Kruskal-Wallis test indicates a significant difference ($p = 2.94e-6$). Furthermore, Table 2 shows the p-values that correspond to the pairwise Student's t-test for each combination of two sets. The decreasing trend from set 1 to set 4 is significant. The mean heart rate for set 5 does not differ significantly from any other set.

Table 2: P-values for the pairwise Student's t-test for the mean heart rate. Values smaller than the significance level (α = 0.05) are presented in *italic*.

p-value	S1	S2	S3	S4	S5
S1	/				
S2	*< 0.001*	/			
S3	*< 0.001*	*0.007*	/		
S4	*< 0.001*	*0.006*	*0.045*	/	
S5	0.198	0.661	0.703	0.905	/

3.2 Activity Throughout the Game

The evolution of the mean value for the activity per set is visualised in Figure 2. The bars indicate the mean value for the distribution of each set and the whiskers indicate the standard deviation. Visually, the activity tends to decrease from set 1 to 5.

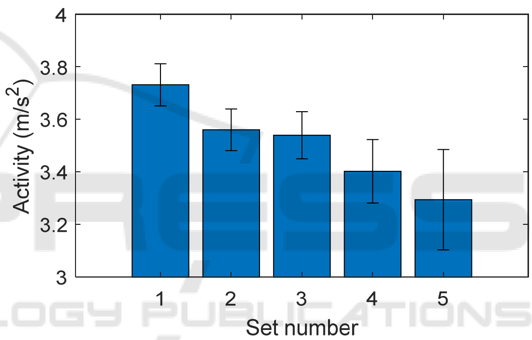

Figure 2: Evolution of the mean activity over the different sets. The whiskers indicate the standard deviation.

The result of the Kruskal-Wallis test is significant ($p = 0.003$). Additionally, Table 3 shows the p-values for the pairwise Student's t-test for each combination. The tests indicate that the difference in activity is only significant for set 1 compared to set 2, 3 and 4. For the other combinations, this is not the case.

Table 3: P-values for the pairwise Student's t-test for the mean activity. Values smaller than the significance level (α = 0.05) are presented in *italic*.

p-value	S1	S2	S3	S4	S5
S1	/				
S2	*< 0.001*	/			
S3	*< 0.001*	0.536	/		
S4	*0.010*	0.083	0.112	/	
S5	0.105	0.259	0.356	0.374	/

3.3 Performance Throughout the Game

Similar to the previous analyses, the performance of the athletes was studied with respect to the different sets. Figure 3 indicates the mean value and standard deviation for the total number of actions performed per athlete. Figure 4 shows the mean value and standard deviation for the number of minutes during which the individuals were actively participating in the game (i.e. not substituted).

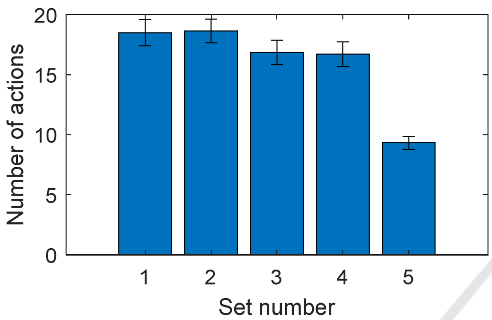

Figure 3: Mean and standard deviation for the number of actions performed during each set.

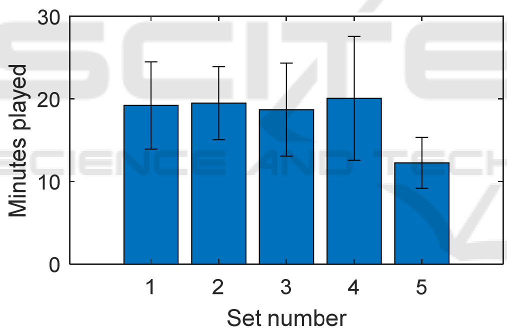

Figure 4: Mean and standard deviation for the time played during each set.

For both performance variables, no significant differences were observed across the five sets according to the Kruskal-Wallis test. A p-value of 0.052 and 0.121 was obtained for the data in Figure 3 and Figure 4 respectively.

4 DISCUSSION

First, we note that the mean value for the heart rate decreases significantly from set 1 to 4 in our test population. On average, a decrease of 5.2 $\%HR_{max}$ (or 10.5 bpm in absolute numbers) is observed. The decreasing trend in the heart rate can partially be explained by the decrease in the total activity obtained from the accelerometer data. However, the differences in the activity are only significant for set 1 compared to all other sets.

The decrease in $\%HR_{max}$ can be interpreted as a decrease in exercise intensity. In literature, González *et al.* (2005) also noted a decrease in the heart rate over the different sets. These observations might be linked to fatigue. Initially, athletes play the game at a high level of exercise intensity, but as the competition continues, the exercise intensity gradually decreases because athletes are getting tired. With a total game duration between about 70 to 120 minutes, this seems to be a valid hypothesis. However, no reference measure for the level of fatigue was used in this study. Additionally, we also note that fatigue is often linked to cardiovascular drift, which is a gradual intensity-independent increase in heart rate (Achten & Jeukendrup, 2003). While these data show an opposite trend, they also show a decrease in the external load (i.e. activity). Therefore, the analogy with cardiac drift is difficult to make.

Other factors such as stress and game tactics are also likely to affect the measured variables (Schneider *et al.*, 2018). Stress was not considered in this study. The performance of the athlete for the different sets could indicate a change in the tactics. However, both performance variables did not seem to vary. One would expect there to be a difference between set 5 and all other sets since the fifth set is ended at a score of 15 instead of 25. From the visual representation of the data, these expected differences seem to be present. However, the limited amount of observations for the fifth set limits the statistical power of this analysis.

We have to bear in mind that the analyses are based on data of the entire test population. If we consider the data for each individual, the decreasing trend in the heart rate is more pronounced in certain athletes, whereas the trend is barely or not significant in others. Also, the current population only consists of eight athletes. For the generalisation of these observations, data collection has to be performed on a larger scale.

5 CONCLUSIONS

Surprisingly, very few studies were found on the heart rate and exercise intensity of volleyball players during competition. Accordingly, a comparison of our data with other observations was not in order. This research illustrates how the heart rate ($\%HR_{max}$), activity and performance change over the course of a volleyball game. Although each match is unique, a significant decreasing trend in the heart rate is observed on the level of the population. Besides, only a significantly higher activity is observed in the first set. Finally, the performance of the athlete (expressed in the number of actions and minutes played) does not show a significant trend over the course of the set.

Monitoring volleyball athletes using wearable technology, during practice and competition, can help to understand the exercise intensity and requirements of the athletes. This research provides a first overview of how the heart rate, activity and performance change during competition. More detailed analyses, for example on the dynamics of the heart rate in relation to the recovery periods, will lead to new insights and provides us with tools to assess the status of the athlete during each phase of the competition. Real-time information on the athlete's physiological status could provide coaches and staff with additional information to make tactical decisions during the game.

For future research, we advise using reference measures for factors such as stress, fatigue, recovery, etc. and to adopt a more advanced time series analysis approach. Furthermore, a larger test population will lead to generalisation of the data and identifying potential differences between positions on the field.

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