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THE RELATIONSHIP BETWEEN HEART RATE VARIABILITY AND SWIMMING SPEED

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Abstract. *Heart rate variability can predict sports performance but is underused because its measurement is difficult. In the last five years, many companies have tried to make this measurement both easy to perform and very practical for coaches. In this study, 10 elite swimmers aged between 12 and 14 years were observed for 21 days. All swimmers were ranked in the first two places at the Romanian National Championships in at least one swimming event. In this period, they performed three speed tests at a 10-day interval. The speed test consisted of four repetitions of 50-meter freestyle, with a rest period of 5 minutes. Heart rate variability was measured every morning on the swimming deck just before practice. For this measurement, a very easy-to-use device was used, namely ithlete Finger Sensor, a photoplethysmography that was attached to a mobile phone and, after 55 seconds of measurement, the device provided an easy-to-interpret value. The relationship between heart rate variability measurements and swimming speed was interpreted. It was demonstrated that the results obtained for heart rate variability influenced the swimming speed results with a p-value < 0.001. This is one of the first studies to focus on how speed will depend on the measurement of heart rate variability just before the training session. For this reason, we cannot compare our results with those obtained in other studies. The current study also has some limitations, and one of the most important is the small number of participants*.

Keywords: *swimming, speed, heart rate variability.*

Introduction

The heart is the pump inside the human body, which is responsible for blood distribution throughout the body and is under the influence of the autonomic nervous system, namely the sympathetic and parasympathetic nervous systems. This influence has an important role in modifying heart rate and, more importantly, heart rate variability. Heart rate variability is the physiological phenomenon of the variation in the time interval between two heartbeats.

Heart rate, like any other signal that has cyclicity over time, can be represented in a power spectrum describing how much of that signal occurs at other frequencies. In this way, heart rate variability can be measured in a very low frequency spectrum, a low frequency spectrum and a high frequency spectrum. It is now known that body temperature, daily circadian rhythm and respiration influence heart rate variability at a given frequency. Sympathetic mediators such as epinephrine and norepinephrine have an influence on heart rate variability in a low frequency spectrum, and parasympathetic mediators have an influence on heart rate variability in a high frequency spectrum.

In the last 30 years, scientific researchers have studied the importance of heart rate variability in cardiac disease. Over the past five years, many scientific articles have shown the importance of heart rate variability for human health. For example, according to Sessa et al. (2018), heart rate variability as a predictive factor for sudden cardiac death can be very useful in assessing the death risk of a person with heart problems. Heart rate variability can also be used in the medical field (Duong, 2020) to determine the activity of the autonomic system in patients with certain infectious diseases such as tetanus. But what is the relationship between heart rate variability and sports performance?

Because this measurement has been increasingly feasible in the last 10 years, sports physiologists have begun to be more and more interested in this issue, and the applicability of heart rate variability has become greater in sport than in medicine. In the early years of studying heart rate variability and sport, recreational athletes were used more, and the results were very interesting. According to Vesterinen et al. (2011), heart rate variability has a good prediction of endurance training in recreational runners. In practice, heart rate variability is an important tool for observing the individual response to exercise in sports medicine and is more and more applied to professional athletes (Plews et al., 2013). Aubert et al. (2003) demonstrate that heart rate variability can be very important in assessing the training status of an athlete. Kajaia et al. (2017) highlight "progression of autonomic imbalance and depression of regulatory function of the autonomic nervous system in athletes with OTS [overtraining syndrome]" (p. 97). The study conducted by Malagù et al. (2021) also shows that using a small portable device helps predict the performance of a particular player in a football match when heart rate variability is measured. In the above study, the measurement was performed two days before the match. This is a very important issue because coaches can use objective reasons to pick a player with very good heart rate variability in the line-up. Applications of heart rate variability include assessing individual response to exercise in terms of adaptation or maladaptation, assessing post-exercise recovery, assessing training effectiveness and rest periods, as well as programming training intensity and volume (Dong, 2016).

In recent years, more and more research has been done on heart rate variability and performance in many sports, but mostly in laboratory conditions that are hard to reproduce in daily training. This is due to the use of EKG monitors, which are difficult to use by a coach who is not medically qualified. On the other hand, the cost of the equipment is high and not affordable to all clubs. In the last eight years, a new method for heart rate variability has been validated, namely the use of photoplethysmography finger sensors. A comprehensive review of over 30 studies by Schäfer and Vagedes (2012) has concluded that there is sufficient accuracy when participants are at rest. A more recent study (Heathers, 2013) that was looking for a way to test more people at affordable costs without losing measurement accuracy showed that a specific finger sensor (called ithlete) had a margin of error of less than 5% for all heart rate variability measures and also great potential to significantly increase the ability of collecting data on heart rate variability. Compared to the study by Schäfer and Vagendes (2012), ithlete Finger Sensor was tested at rest and during experimental stress. This was very important for athletes, who could thus use a single practical device to determine if their recovery was good enough.

Another piece of information that was missing in most studies referred to the relationship between heart rate variability and swimming performance in pubertal swimmers. This is a period with high sport dropout rates, and more scientific training might lead to better progress, which could retain athletes in sport long time after these critical years. Several studies of senior elite swimmers report that there are some connections between heart rate variability and performance. For example, the study by Atlaoui et al. (2007) shows that there is a direct relationship between heart rate variability, swimming performance and fatigue score. The above author also reveals that heart rate variability has a well-documented connection with adrenalin and noradrenalin status in swimmers. Many swimming studies have been done on senior swimmers or swimmers who train less than 12 hours a week, but this is not usually the case in this sport. Junior swimmers commonly train more than 16 hours a week, hence the great need for a more specific type of monitoring their performance and recovery. But the most important thing is to discover a new way to make training more scientific and individualised for each athlete. Swimming professionals are very interested in implementing methods to assess and improve training and thus increase athletic performance and the competitive result.

The relationship between heart rate variability and swimming performance during training and competition has not been investigated so far.

The *purpose* of this study was to determine the relationship between heart rate variability changes and speed performance in junior elite swimmers.

Results

For this study, 10 swimmers were selected from the "Aqua Sport Citius" Swimming Club in Bucharest. The selection criteria for swimmers were: to be aged between 12 and 14 years; to be ranked in the top 3 swimmers in the country at least in one swimming event at the National Championships; to have attended more than 90% of the swimming training sessions in the last year. Thus, in our study, 4 swimmers were aged 14, 4 swimmers were aged 13 and 2 swimmers were 12 years old (Figure 1).

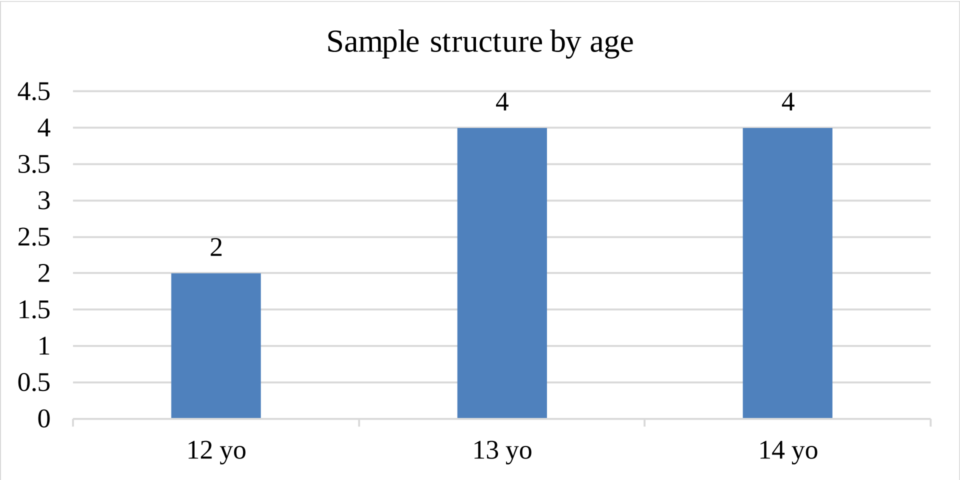

Figure 1. Age of participants

In terms of gender, 8 swimmers were boys and 2 were girls. Their distribution in percentage is shown in Figure 2.

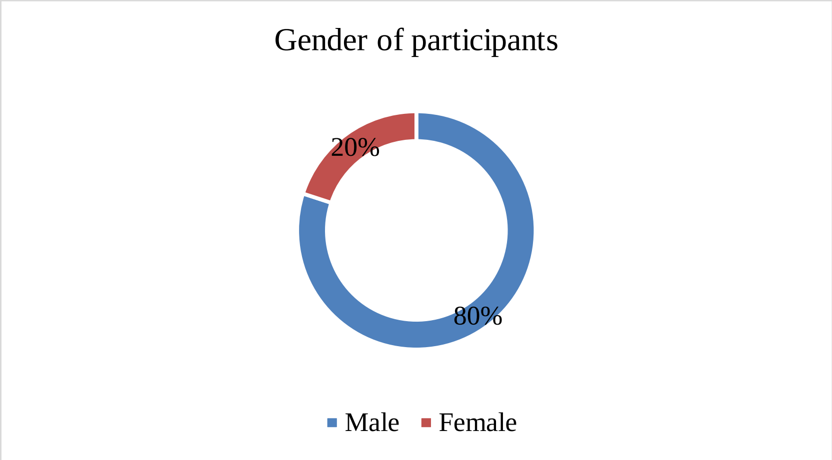

Figure 2. Gender of participants (in percentage)

Although these swimmers are at puberty, they have extensive experience in swimming. They train over 18 hours a week and, because they have been doing this sport for more than 6 years, all participants have accumulated at least 3,000 hours of swimming training in their lifetime. Four swimmers have even completed more than 5,000 training hours so far. This is an important thing to remember, because the more a swimmer has trained in their life, the lower their performance variability in training and competition. Figure 3 shows the number of training hours performed by the swimmers included in this study.

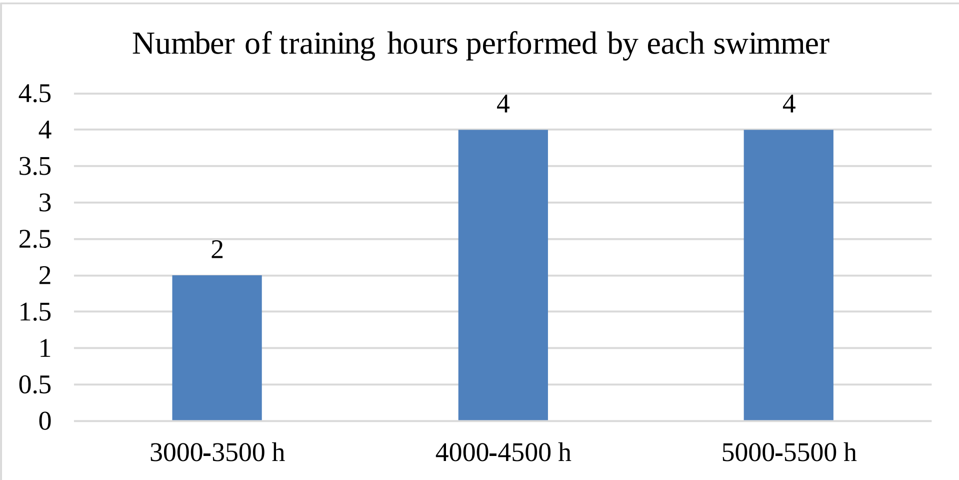

Figure 3. Number of training hours performed by each swimmer

The study was performed only on elite swimmers in Romania. Although the number of swimmers in this study is only 10, their results at the National Championships are good: so far, they have won 120 medals at the Romanian National Championships for their age group. On average, each swimmer has ranked 12 times in the top 3 in Romania until now. Of these 120 medals, 27 were gold, 47 were silver and 46 were bronze. Figure 4 shows the number of medals won by the studied swimmers at the Romanian National Championships.

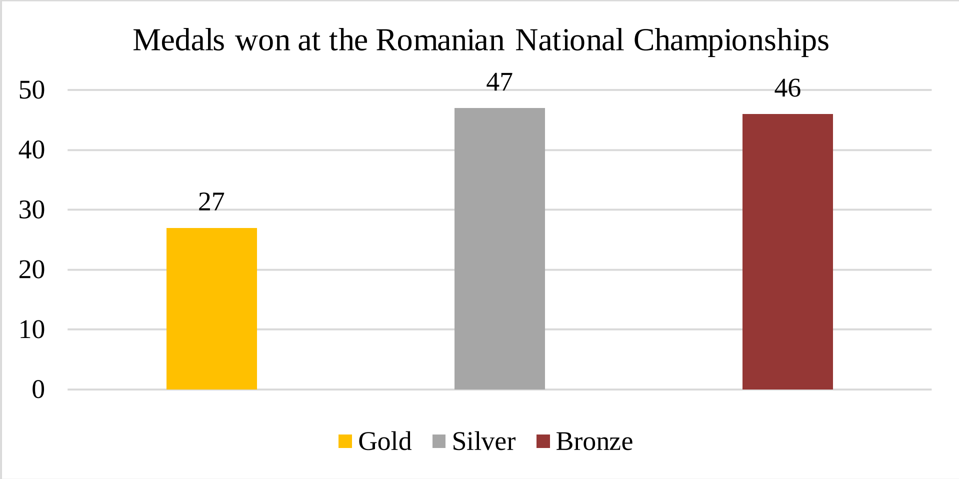

Figure 4. Medals won by the studied swimmers at the Romanian National Championships

For this study to be more accurate, all swimmers performed the same number of training sessions, namely nine per week. All workouts lasted two hours, which resulted in 18 training hours per week. Of these 18 hours, 12 involved water training and 6 were based on dry-land training. The workouts took place every day, from Monday to Saturday. Sundays were always free. On Mondays, Thursdays and Saturdays, there were two training sessions per day. All sessions were identical in terms of intensity and duration, beginning and ending at the same hour. They took place in a 25-meter swimming pool with eight lanes. The water temperature was between 28^0 and 29^0 C.

The length of the study was 4 weeks. Every training day, therefore 6 times per week, heart rate variability was measured at 05:20 in the morning. For this purpose, we used the ithlete Finger Sensor photoplethysmograph and the ithlete application for Android and iPhone users. All swimmers sat down for five minutes before measurements were performed. The ithlete Finger Sensor recorded heart rate variability for 55 seconds, and then a specific value was displayed on the phone screen.

A specific swimming test was used to measure speed, which consisted of four repetitions of 50-meter freestyle. The same swimming style had to be used by each athlete to allow making correct comparisons between them. They had a rest period of 5 minutes. The time was recorded after each repetition using a Tyr Z-100 stopwatch. Each repetition was initiated from the starting block. Table 1 shows the average time obtained by each swimmer. In this test, a shorter time means that the speed was higher, and more seconds indicate that the speed was lower. The test was performed three times, with a 10-day interval between tests.

Table 1. *Average time obtained by each swimmer in the speed test*

Swimmer	Test 1	Test 2	Test 3
Swimmer 1	30.25	30.42	30.40
Swimmer 2	30.10	29.80	29.60
Swimmer 3	26.50	26.75	27.90
Swimmer 4	28.70	29.30	29.80
Swimmer 5	31.07	31.10	30.30
Swimmer 6	27.50	26.75	26.07
Swimmer 7	28.85	28.75	29.05
Swimmer 8	28.50	28.80	29.80
Swimmer 9	33.50	34.80	32.40
Swimmer 10	30.00	30.60	29.70

The null hypothesis was that speed was not dependent on heart rate variability in any of the three tests. Table 2 shows the values obtained after performing the statistical analysis. The ANOVA test was used for these correlations.

Table 2. *ANOVA test for the relationship between heart rate variability and speed*

ANOVA						
Source of variation	SS	df	MS	F	P-value	F crit
Sample	1254.899	9	139.4333	6.021430781	2.65274E-05	2.124029
Columns	35232.36	1	35232.36	1521.510627	1.87871E-33	4.084746
Interaction	2022.01	9	224.6678	9.702286403	1.12762E-07	2.124029
Within	926.2468	40	23.15617			
Total	39435.52	59				

Alternative hypothesis H1: Since the p-value < 0.001, speed depends on heart rate variability in the three successive tests. The p-value was statistically significant for all values (sample, columns and interaction). This observation is confirmed by Fisher’s test, where the calculated value (F) is greater than the tabular value (F crit).

Pearson’s correlation coefficient confirms the alternative hypothesis H1. Table 3 shows a strong negative correlation between heart rate variability and tests. The coefficient of correlation between the first test and the first heart rate variability has the value -.0627 with a good level of significance (p-value = 0.052), which means that, if the first measurement of heart rate variability is higher, the results of the first test are better (more than 60%).

The coefficient of correlation between the second measurement of heart rate variability and the second speed test has the value -0.688 with a good significance level (p-value = 0.028, which is less than 0.005). This means that, if the second measurement of heart rate variability is higher, the speed of the second speed test is higher (more than 68%).

The coefficient of correlation between the third measurement of heart rate variability and the third speed test has the value -0.541 (p-value = 0.1) with a low significance level (p > 0.05). This means that, if the third measurement of heart rate variability is higher, the swimmer is faster, but due to the low level of statistical significance, these findings cannot be extrapolated to the general population. This result is only valid for the 10 tested swimmers.

Table 3. *Pearson's correlation between heart rate variability and the speed test*

		HRV1	HRV2	HRV3
Test 1	Pearson's Correlation	**-.627**		
	p-value	**.052**		
Test 2	Pearson's Correlation		**-.688**	
	p-value		**.028**	
Test 3	Pearson's Correlation			**-.541**
	p-value			**.106**
	N	10	10	10

Discussion

Training and recovery are very difficult to balance in sports training. Usually, a coach without a great medical team does not have many technological methods to determine exactly how well an athlete has recovered for a specific workout and what should be done to maximise training adaptations. Another problem is that each person is unique, and a swimmer may respond in one way to the workout, while another swimmer may respond differently to the same workout. This is important because coaches typically train more than one swimmer, which is why achieving good individualisation with a large group is quite difficult. Heart rate variability measurement is a very easy-to-use tool to assess the recovery of athletes between two swimming sessions, but individualisation with a large group is a hard thing to do. The value of heart rate variability can be measured in the morning of the practice day, and this value can be used to adjust the training for each swimmer. The good part is that the new finger sensors are easy to use and do not require medical staff to measure and interpret it. Coaches can see all the values recorded by their swimmers at home on their phones and can make changes as they want. Our test shows that heart rate variability can be easily used to determine the swimmers' speed on a specific day. It can be used to establish the type of training to be done on a given day according to the measurements of heart rate variability. For example, if we have planned a speed workout but we find that most of our swimmers have lower heart rate variability, we can change it to endurance training in order to help them recover more easily and be able to better train the next day. Another example: if we have planned an easy workout one day to help our athletes recover after a hard workout performed the previous day but we see that heart rate variability has good values in most swimmers, we can plan a speed workout to increase the swimming intensity and effectiveness.

Another important use of these findings is in the tapering period, just before a competition when, without easy-to-use specific measurements, it is hard to find out whether recovery is going well or not. It is known that athletes need to be in their best possible shape at each competition. But if tapering is too long, they will lose the training adaptations gained during the hard training hours; on the contrary, if tapering is too short, they will not recover well and will be in their best shape only after the competition, which would be a bad thing. Long-distance swimmers need shorter tapers than sprint swimmers and, because most of the time the groups are mixed, it is very hard to determine what each swimmer should do in each workout so as to perform well in competition. By using heart rate variability with finger sensors, we can optimise tapering to increase heart rate variability and enhance speed in swimming competitions.

These findings can also be used in the relay events of swimming competitions. In major competitions where many swimmers are at about the same level, heart rate variability can be an important tool to determine who will qualify for the relay race and who will not. Until recently, coaches used only the latest swimming result in competitions or their intuition to determine who will make the relay, but from now on, more scientific methods can be used.

This study was conducted only on swimmers who trained for many hours. It is known that, for highly trained athletes, the variability of speed performance from one day to another is smaller than in the case of less trained athletes. If we correlate this with the fact that heart rate variability has a high statistically significant correlation with swimming speed in these athletes, we can extrapolate the results to less trained swimmers.

The study was performed on swimmers who trained from 05:30 to 07:30 every morning, and heart rate variability was measured just before the training session in the swimming pool. Further studies need to establish whether we can extrapolate the results to swimmers who have different training hours or whether heart rate variability can be measured in the morning or should be done just before the workout.

A weak point of this study was the small number of female participants. According to Lutfi and Sukkar (2011), women have different heart rate variability compared to men because the overall autonomic activity is higher in males. It is difficult to say that these findings will be the same if the female/male ratio is closer to 1.

We need to determine in other studies whether our findings can be extrapolated to different age groups and different types of training, whether there is a relationship between heart rate variability and endurance, but we also need to identify the factors that have the greatest influence on heart rate variability (in addition to workouts) to establish different strategies in order to make more changes and thus produce more quality-based instead of quantity-based training. Negative emotions are known to have a strong impact on heart rate variability, and Morales et al. (2012) show it in a study of judo athletes before competitions, but what about positive emotions? There is a high hope that, with more and more studies, we will find a way to achieve individualisation for each athlete, and this individualisation will be possible for larger groups of swimmers that work with a single coach.

There are many questions that need to be answered in the future, after this study. The field of technology in sport and the field of heart rate variability have many things to reveal in the years to come. But we will certainly find out more important things about this topic with each study produced. The future of sports training looks great with technology helping us more and more to be better coaches. We predict that, in the next 10 years, the daily use of technology will make the difference between great champions and simple athletes.

Conclusion

Although we cannot yet extrapolate these findings to larger groups, we have found that speed is directly related to heart rate variability: if the heart rate is higher, the swimmer is faster. Studies in the field of sports physiology have focused on changes in heart rate variability depending on training parameters (volume or intensity). This is one of the first studies to focus on how speed will depend on the measurement of heart rate variability just before the training session. For this reason, we cannot compare our results with those obtained in other studies. The current study also has some limitations, and one of the most important is the small number of participants. Therefore, further studies should involve more participants to make the results more significant. It will also be very interesting to determine the relationship between endurance and heart rate variability.

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