THE IMPACT OF RESPIRATORY MUSCLE FATIGUE ON THE QUALITY AND EFFICIENCY OF RESCUE ACTION

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Key words: respiratory muscle fatigue, CPR efficiency, lifeguards, rescue action

Abstract

Introduction. A lifeguard is a person in charge of ensuring safety in water environments. After a rescue, it is possible that s/he has to execute CPR. The European Resuscitation Council (ERC) as well as the American Heart Association are currently encouraging quality CPR performance. The lifeguard may be obliged to carry out CPR for a long period of time as the response of the Emergency Medical Service takes 5–8 min on average, and it can even reach up to 20 min. The normal respiratory muscle effort at maximal swimming intensity requires a significant fraction of cardiac output and causes leg blood flow to decrease. The main objective of this paper was to determine respiratory muscle fatigue (RMF) level in swimming at different intensities on the quality and efficiency of rescue actions in water.

Material and methods. The study involved 44 male lifeguards. Two tests were conducted: the first test involved the execution of 5 min of CPR (rested), and the second one in performing water rescue and subsequent CPR (exhausted) for 5 minutes. The quality of CPR at rest and in fatigue conditions was compared. The recording instrument was the Ambu Defib Trainer W (Wireless). The time and precision of the simulated water rescue was also registered. Two spirometry tests were performed: the first test was set before swimming and the second after (exhausted). Maximal respiratory pressures (PImax, PEmax) were evaluated before and directly after swimming at different intensities. The quality of respiratory muscle fatigue at rest and in fatigue conditions was compared. The recording instrument was portable the MicroLoop spirometer.

Results. After a simulated water rescue, there was a significant increase in parameters such as: resting ventilation volume per minute (3.06±22.10), exhausted (4.23 ±22.10, p < .001); resting ventilation rate (3.60±34.80), exhausted (4.80 ±34.80, p < .001); and resting stomach inflation (2.0±20.47), exhausted (5.80 ±20.47, p < .001). The greatest variation in the results of respiratory muscle fatigue both before and after swimming at different intensities was observed only in two parameters: maximal ventilation index (MVV) and peak exhaust flow (PEF).

Conclusions. The strongest correlation between the respiratory muscle fatigue level during different intensities of swimming and efficiency of the conducted rescue action occurred only in the case of supra maximum intensity efforts between forced expiratory volume, forced vital capacity and maximal voluntary ventilation.
Introduction

A lifeguard is a person responsible for safety in an aquatic environment. After a rescue operation in water, it is possible that the lifeguard will have to perform cardiopulmonary resuscitation (CPR). The European Resuscitation Council (ERC) and the American Heart Association encourage ensuring high quality resuscitation procedures. The lifeguard may be obliged to perform CPR for a long time, because the response of the emergency medical services takes an average of 5-8 minutes and can even take up to 20 minutes. With maximum intensity swimming, the normal effort of the respiratory muscles requires substantial heart ejection quality and results in a decrease of blood flow. The fact of being under water and operating with lack of access to oxygen makes such a situation highly extreme for the lifeguard [1]. So far, no empirical studies have been conducted on rescue action efficiency among lifeguards in stressful situations. In scientific literature, we can find several sources indirectly [2-4] as well as directly [5] related to this issue.

The respiratory muscles serve as support for the thorax, and their main task is the maintenance of respiratory function. For people, the most important respiratory muscle is the diaphragm. More than half of the diaphragm is composed of slow twitch oxidative fiber (type I), while the other half, of fast twitch oxidative-glycolytic (type IIA) and fast twitch glycolytic (type IIB) ones. This muscle is very well-supplied with blood and acquires the energy to work from substrates provided by the blood, e.g., lactates, glucose, free fatty acids and oxygen. Incorrect operation of the diaphragm leads to an overload of the rest of the respiratory muscles, which can cause headaches or pain in shoulders and cervical spine [6-8].

Activity of the respiratory muscles does not require a very large amount of energy even during maximum effort, since they are characterized by oxygen metabolism [6-8].

Many authors [9-14] suggest that respiratory muscles, as well as skeletal muscles, get tired during their work, which means that human exercise capacity is limited. Symptoms of fatigue of these muscles are increased during long-term efforts, lasting more than 20 minutes, at high intensity from 90 to 100% of the maximum human exercise capacity. Fatigue of the respiratory muscles can even be observed on the third day, usually after extreme and exhaustive efforts. Recent studies have shown that fatigue of these muscles also occurs during short maximal efforts, such as six-minute starting distances of a paddler or 200-m freestyle swimming [4,7,10,15-18].

Aim of the study

Thus, the main aim of this study is an attempt to determine the level of respiratory muscle fatigue (RMF) during swimming at different intensities. In addition, the study assumes the attempt to define the dependency between fatigue of the respiratory muscles and the efficiency of the on-going rescue operation performed by lifeguards.

Due to the intended aim of the study, the research questions are formulated as follows:

1. Are there any dependencies, and if so, to what extent, between the level of fatigue of the respiratory muscles and different intensities of swimming?
2. Are there any dependencies, and if so, to what extent, between the level of fatigue of the respiratory muscles and efficiency of rescue action?
3. Are there any dependencies, and if so, to what extent, between the cardiopulmonary resuscitation procedure (CPR) before and after implementation of a simulated rescue operation?

Material and method

All diagnostic studies were conducted in 2017 at indoor pools of the University of Physical Education in Krakow. Studies were organized by the Department of Water Sports of the University of Physical Education in Krakow.

Study group:

The study involved 44 male lifeguards. Representativeness of the sample was obtained using a non-random (non-sample) sampling technique, and was a targeted choice [19]. The technique of purpose-based selection consisted in indicating persons who have:

- valid permits for the profession of water and life support officer of WOPR and Ministry of Interior and Administration in accordance with the Regulation of the Minister of Internal Affairs and Administration from 22 June 2012 regarding persons maintaining in water areas (Journal of Laws, No. 208, item 1240).
- More than half of rescuers, as much as 57.14%, have obtained the rank of lifeguard in the last 7 years. The remaining rescuers gained their rights between 2000 and 2010 (23.21%), and before 2000 (19.65%).
- current certificate of completed course and training of qualified first-aid before medical (KPP).
- Most of the rescuers passed their last CPP training in 2017 (35.71%), respectively, the rescuers carried out the training in 2016 (26.78%). The rest of the surveyed water rescuers (62.49) were trained in 2015-2014.
- one additional permit useful in water rescue [20].

All of the surveyed rescuers had additional qualifications or completed training useful in the work of rescuers. Most often, the respondents had the following qualifications: motorboat driver, sport/recreation instructor in water sports, yacht sailor. The training in which the re-
spendents participated were: rescue in fast flowing and flood waters, ice-rescue, rescue using a water scooter.

To assess the performance of the cardiovascular system and the physical condition of water rescuers, the Ruffier effort was used (30 squats in 30 seconds). The tests included pulse measurements before exercise, immediately after exercise, after during the first minute after the exercise test with the following calculation of the indicator of functional changes in the body (adaptive potential). The Ruffier index, which is used to assess the efficiency of the circulatory system in the body, was calculated using the formula \[ IR = \frac{(P + P1 + P2) - 200}{10}, \]
where: \( IR \) - Ruffier index; \( P \) - resting heart rate; \( P1 \) - heart rate immediately after the trial; \( P2 \) - heart rate after 1 minute of rest.

The average values of the results obtained for the Ruffier index are presented below.

### Methods and techniques of study:

The study used the method of direct observation. The study complied with the conditions applicable when using this method, such as: reliability, understanding, integrity and objectivity. In the field of observation, the main method was usage of the tests [22].

To solve the research problem, variables selected in accordance with the subject matter have been identified. Tools and research techniques have been selected; calculation of appropriate research indicators has been made.

The dependent variables in the presented work are:

1. The respiratory muscle fatigue level during swimming at different intensities.
2. The rescue action efficiency, evaluated both on a quantitative and qualitative basis.

Tests were implemented in two days.

The respiratory muscle fatigue level (RMF)

Organisation of research is presented in Figure 1. Below, there are descriptions of individual tests, taking the investigated parameters and the used research tools into account.

Assessment of respiratory muscle fatigue level (RMF) was executed twice:

- before the effort – rescue test – in an aquatic environment
- and just after the effort – rescue test – in an aquatic environment

using diagnostic spirometry, according to the recommendation of the Polish Psychiatric and Pneumology Association [23] regarding the execution of spirometric tests. Recommendations were prepared by a commission established by the Board of the Polish Physiological Society.

### Figure 1. The study organization and particular rescue tests

<table>
<thead>
<tr>
<th>No.</th>
<th>Age</th>
<th>Body mass [kg]</th>
<th>Body height [cm]</th>
<th>Ruffier Index [points]</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>&lt;25</td>
<td>&lt;70</td>
<td>&lt;170</td>
<td>44.87±5.84</td>
<td>very good</td>
</tr>
<tr>
<td>2.</td>
<td>25-29</td>
<td>70-75</td>
<td>170-175</td>
<td>45.13±4.28</td>
<td>good</td>
</tr>
<tr>
<td>3.</td>
<td>30-35</td>
<td>75-80</td>
<td>175-180</td>
<td>46.28±6.14</td>
<td>average</td>
</tr>
<tr>
<td>4.</td>
<td>35-40</td>
<td>80-85</td>
<td>185-190</td>
<td>47.98±5.95</td>
<td>weak</td>
</tr>
<tr>
<td>5.</td>
<td>&gt;40</td>
<td>&gt;80</td>
<td>&gt;190</td>
<td>53.12±5.35</td>
<td>very weak</td>
</tr>
</tbody>
</table>

Table 1. The lifeguards average values of the Ruffier index regarding age, weight and height
The position of the respiratory muscles was checked before each of the efforts to control the residual volume (RV) = PImax RV. Measurements were made in a seated position.

The PImax parameter determines the ability to generate strength by the inspiratory muscles during short, almost static contractions, with the flow of air through the respiratory tract almost completely closed.

The study took the following parameters of the respiratory system into account:

- the 1st second of forced expiratory volume (FEV1) – the volume of air exhaled during the 1st second of forced expiration,
- the 3rd second of forced expiratory volume (FEV3) – the volume of air exhaled in the 3rd second of forced expiration,
- FEV0 – percent of the vital capacity VC (FEV.75/VC)75/VC),
- maximum expiratory flow for 25% of residual FVC (FEF25),
- maximum expiratory flow for 50% of residual FVC (FEF50),
- maximum expiratory flow for 75% of residual FVC (FEF75),
- forced vital capacity (FVC) – the greatest volume of air exhaled during maximum respiratory effort,
- percentage of the forced expiratory volume in the 6th second (FEV0.75/FEV6),
- time of forced expiration between 25–75% of capacity (MET),
- duration of forced expiration (FET),
- peak expiratory flow (PEF) – registered in the course of testing maximum forced expiration – the largest flow rate obtained during forced expiration, beginning immediately after the deepest inspiration,
- maximum voluntary ventilation (MVV) – the total maximum ventilation measured within 12 s and converted to the minute ventilation.

**Rescue tests conducted with various exercise intensity**

The intensity of the effort in an aquatic environment was determined by using various rescue tests. The intensity of the exercise was estimated on the basis of Maglischo’s [27] recommendations, just as is the effort determined in swimming.

**Rescue tests**

The study included the following rescue tests corresponding to the established parameters in determining the intensity of efforts in water:

1. 50 m rescue style <50” – the supramaximal intensity of effort – V5
2. 75 m rescue action in water <3:30” – the maximum intensity of effort – V4
3. 100 m freestyle <1:40” – the submaximal intensity of effort – V3
4. 400 m freestyle <8’ – the average intensity of effort – V2
5. 600 m rescue jog <14’ – the low intensity of effort – V1

**50 m rescue style** – maximum swimming speed (100%), supramaximal intensity of the effort – V5. The assumption of the tests was to swim a 50 m distance in rescue style, with the head above water. The pass criterion was to obtain a time below 50 seconds. The measurement was taken manually using a Casio stopwatch with an accuracy of 0.01 sec.

**75 m rescue operation** – very high swim speed (90%), maximum intensity of effort – V4. The rescue operation was based on a simulated rescue action in water, which consisted of the following items:

1. Throwing a rescue tube in the 2.5 m wide path at a distance of no less than 10 m – no pass after 3 attempts results in the need to swim an extra distance of 20m.
2. Safe entry into the water (for example by performing a rescue jump) from the shore with a lifeguard belt or buoy.
3. Swimming a distance of 40 m (of which 25 m was freestyle, 15 m rescue style).
4. Swimming a distance of 10 m under water and getting the dummy from the bottom.
5. Towing the dummy for a distance of 20 m.

After meeting the criterion of time, the CPR algorithm was performed, consisting in using the algorithm of dealing with a person saved from water on the dummy. **100 m freestyle** – medium-high speed of swimming (80%), submaximal intensity of effort – V3. The test consisted in swimming 100 m freestyle. The test was passed if the participant maintained within the time limit of less than 1 minute 40 seconds. The measurement was taken manually using a Casio stopwatch with an accuracy of 0.01 sec.

**400 m freestyle** – low-medium speed of swimming (70%), medium intensity of effort – V2. The main purpose of the test was to swim 400 m freestyle. The test was passed if the participant maintained within the time limit of below 8.00 min. The measurement was taken manually using a Casio stopwatch with an accuracy of 0.01 sec. The selection of this test was facilitated by the fact that in different organisations and rescue services around the world, this is the most popular test used in the verification of certified lifeguard degrees.

The test was carried out in accordance with the standards of the ILS (International Life Saving Federation).
600 m rescue jog – low speed of swimming (60%), low intensity of effort – V1. The test task was to swim a distance of 600 m according to the scheme:
1. Rescue jump (legs apart) with fins held in the hands.
2. Putting fins on without touching elements of the shore.
3. Swimming a a distance of 300 m with fins in any style.
4. Taking off fins, putting them ashore (without touching the elements of the shore).
5. Swimming a distance of 100 m, breaststroke, face-down.
6. Swimming a distance of 25 m under water.
7. Swimming a distance of 75 m with methods used in water rescue: i.e. on the left side, right side, on the back.
8. Swimming a distance of 100 m, front crawl.

The evaluation of participants during the test was based on the following parameters:
1. Time and speed of swimming (T) and (V). The speed and time of swimming was measured by the Omega Timing electronic set for measuring time and was expressed as:

$$\bar{V} = \frac{d}{t} \quad \text{Equation 1.}$$

Where:
- $\bar{V}$ is the speed of swimming,
- $d$ is the distance covered by the swimmer,
- $t$ is the time required to cover the distance.

There were two tests:
- the first test involved the execution of two, 5-minute CPR procedures (rested lifeguard),
- and the second one – after completion of rescue operations in water, CPR (tired lifeguard).

The quality of the CPR at rest and in conditions of fatigue was compared. The study was performed on the Ambu Defib Trainer (wireless). The time and quality of simulated rescue operations in water were also recorded.

In terms of respiratory muscle fatigue, two spirometry tests were performed:
- the first test was set before the rescue operation in the water,
- and the second one immediately after the completion of the rescue operation.

Maximum respiratory pressure (PImax, PEmax) was evaluated before and directly after the operation. The quality of the respiratory muscle fatigue at rest and in a state of fatigue was compared. Results were registered by the MicroLoop portable spirometer.

**Results**

The first stage of the research was to conduct primary computations of descriptive statistics regarding the diagnosed parameters for different swimming intensities, as well as for indicators that determine the efficiency of an on-going rescue operation.

The statistical characteristics of the results concerning the intensity of swimming as well as rescue action efficiency are shown in Table 2.

The data in Table 2 show the statistical characteristics of swimming intensity during different rescue tasks and the efficiency of the rescue operation. The greatest diversity between the groups in the results regarding the intensity of swimming (Tab. 2) was observed in parameters: 600 m rescue jog – V1 – $\bar{V} = 788.78 \pm 64.73$, 400 m

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$\bar{x}$</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>R</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 m rescue style – V5</td>
<td>47.09</td>
<td>3.69</td>
<td>42.18</td>
<td>54.63</td>
<td>12.45</td>
<td>13.62</td>
</tr>
<tr>
<td>75 m rescue operation – V4</td>
<td>132.90</td>
<td>26.95</td>
<td>101.20</td>
<td>193.80</td>
<td>92.60</td>
<td>726.14</td>
</tr>
<tr>
<td>100 m freestyle – V3</td>
<td>83.21</td>
<td>8.57</td>
<td>69.17</td>
<td>99.36</td>
<td>30.19</td>
<td>73.40</td>
</tr>
<tr>
<td>400 m freestyle – V2</td>
<td>450.50</td>
<td>34.14</td>
<td>380.81</td>
<td>488.00</td>
<td>107.19</td>
<td>1,165.56</td>
</tr>
<tr>
<td>600 m rescue jog – V1</td>
<td>788.78</td>
<td>64.73</td>
<td>693.31</td>
<td>885.38</td>
<td>192.07</td>
<td>4,190.43</td>
</tr>
<tr>
<td>Rescue action efficiency indicator (score)</td>
<td>4.42</td>
<td>1.06</td>
<td>2.58</td>
<td>5.93</td>
<td>3.35</td>
<td>1.12</td>
</tr>
</tbody>
</table>

**Key:**
- $\bar{x}$ – Mean
- Min – Minimum value
- Max – Maximum value
- R – Range
- V – Coefficient of variation
- SD – Standard deviation

| Effectiveness of the operation (%) | 77.79 | 14.18| 51.60| 98.81| 47.21| 201.02 |
freestyle – V2 – $\bar{x}$ 450.50 ± 34.14 and also efficiency of rescue action (%) – $\bar{x}$ 77.79 ± 14.18.

The next step was analysis of the obtained results concerning the level of respiratory muscle fatigue (RMF) during swimming at different intensities, both before and after the rescue task in an aquatic environment.

Data on the results of the second spirometric test after the rescue operation are shown in Table 3.

The greatest diversity between groups in the results regarding respiratory muscle fatigue level after the rescue operation (Tab. 3) were observed in the following parameters: MVV (ind)/2 - index of the maximum voluntary ventilation that was in the range of $\bar{x}$ 51.00 ± 27.27 and PEF/2 - Peak expiration flow, which was in the range of $\bar{x}$ 512.00 ± 71.21.

In order to determine the correlation between respiratory muscle fatigue level while swimming at varying intensities and the efficiency of the rescue operation, Spearman’s rank correlation was used.

As it can be seen from the data in Table 4, the following negative and quite significant correlations ($p < 0.05$) have been identified between:

- the result for the distance of 50 m rescue style defining the speed V5 and the FEV1 parameter (-0.77) before and the FEV1 (-0.57) after the exercise (the forced expiratory volume in the 1st second) and the FEV1 parameter (-0.44) in another test after the exercise (the forced expiratory volume in the 1st second) and the FVC parameter (-0.79) before the exercise and FVC (-0.70) after the rescue action (forced vital capacity),

- the result for the distance of 100 m freestyle, defining the speed V3, the result for the distance of 50 m rescue style, defining the speed V5 and the FEV0.75 (-0.65) parameter before the exercise (percentage of vital capacity VC-FEV0.75/VC) and the FEVO parameter 75 (-0.45) in another study after the exercise (percentage of vital capacity VC-FEV0.75/VC).

The other included parameters showed weak (negative and positive) correlations or their absence ($p < 0.05$), especially between the parameters specifying respiratory muscle fatigue level and efficiency of the rescue operation.

The data shown in Table 5 indicate the following, rather strong (negative and positive) correlation ($p < 0.05$) between:

### Table 3. Statistical characteristics of respiratory muscle fatigue level after rescue action

<table>
<thead>
<tr>
<th></th>
<th>$\bar{x}$</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>R</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV1/2</td>
<td>4.08</td>
<td>0.65</td>
<td>2.87</td>
<td>5.05</td>
<td>2.18</td>
<td>0.43</td>
</tr>
<tr>
<td>FEV0.75/2</td>
<td>3.90</td>
<td>0.62</td>
<td>2.87</td>
<td>4.82</td>
<td>1.95</td>
<td>0.39</td>
</tr>
<tr>
<td>FVC/2</td>
<td>4.12</td>
<td>0.80</td>
<td>2.82</td>
<td>5.12</td>
<td>2.30</td>
<td>0.64</td>
</tr>
<tr>
<td>FEV3/2</td>
<td>4.07</td>
<td>0.84</td>
<td>2.54</td>
<td>5.12</td>
<td>2.58</td>
<td>0.70</td>
</tr>
<tr>
<td>PEF/2</td>
<td>512.00</td>
<td>71.21</td>
<td>385.00</td>
<td>611.00</td>
<td>226.00</td>
<td>5,071.40</td>
</tr>
<tr>
<td>FEV0.75/FEV6 /2</td>
<td>95.36</td>
<td>8.25</td>
<td>75.00</td>
<td>100.00</td>
<td>25.00</td>
<td>68.05</td>
</tr>
<tr>
<td>FEV25/2</td>
<td>7.90</td>
<td>1.12</td>
<td>6.20</td>
<td>9.51</td>
<td>3.31</td>
<td>1.26</td>
</tr>
<tr>
<td>FEV50/2</td>
<td>6.42</td>
<td>1.18</td>
<td>4.74</td>
<td>8.23</td>
<td>3.49</td>
<td>1.39</td>
</tr>
<tr>
<td>FEV75/2</td>
<td>4.28</td>
<td>1.61</td>
<td>0.03</td>
<td>5.74</td>
<td>5.71</td>
<td>2.59</td>
</tr>
<tr>
<td>MVV (ind)/2</td>
<td>151.00</td>
<td>27.27</td>
<td>105.00</td>
<td>189.00</td>
<td>84.00</td>
<td>743.60</td>
</tr>
<tr>
<td>MET2</td>
<td>0.59</td>
<td>0.98</td>
<td>0.13</td>
<td>3.54</td>
<td>3.41</td>
<td>0.96</td>
</tr>
<tr>
<td>FET/2</td>
<td>0.83</td>
<td>0.26</td>
<td>0.61</td>
<td>1.55</td>
<td>0.94</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Key:

/2 Second test – fatigue
FEV1 Forced expiratory volume in the 1st second
FEV3 Forced expiratory volume in the 3rd second
FEV0 Percentage of vital capacity VC (FEV75/VC)
FVC Forced volume of lungs
FEV0.75/FEV6 Percentage of forced expiratory volume in the 6th second
FEF25 Maximum expiration flow for 25% of residual FVC
FEF50 Maximum expiration flow for 50% of residual FVC
REF75 Maximum expiration flow for 75% of residual FVC
MVV Index of maximum voluntary ventilation
MET Time of forced expiration between 25–75% of capacity
PEF Peak expiration flow
The impact of respiratory muscle...

### Table 4
Spearman's rank correlation between parameters defining respiratory muscle fatigue level and different intensities of efficiency rescue action

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FEV1/1</th>
<th>FEV1/2</th>
<th>FEV0.75/1</th>
<th>FEV0.75/2</th>
<th>FVC/1</th>
<th>FVC/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 m rescue style – V5</td>
<td>-0.77</td>
<td>-0.57</td>
<td>-0.65</td>
<td>-0.42</td>
<td>-0.79</td>
<td>-0.70</td>
</tr>
<tr>
<td>75 m rescue operation – V4</td>
<td>0.10</td>
<td>-0.11</td>
<td>0.14</td>
<td>-0.25</td>
<td>0.15</td>
<td>0.01</td>
</tr>
<tr>
<td>100 m freestyle – V3</td>
<td>-0.26</td>
<td>-0.44</td>
<td>-0.15</td>
<td>-0.45</td>
<td>-0.31</td>
<td>-0.37</td>
</tr>
<tr>
<td>400 m freestyle – V2</td>
<td>-0.04</td>
<td>-0.16</td>
<td>0.06</td>
<td>-0.19</td>
<td>-0.08</td>
<td>-0.15</td>
</tr>
<tr>
<td>600 m rescue jog – V1</td>
<td>-0.15</td>
<td>-0.16</td>
<td>-0.11</td>
<td>-0.10</td>
<td>-0.21</td>
<td>-0.28</td>
</tr>
<tr>
<td>Rescue action efficiency indicator (score)</td>
<td>-0.23</td>
<td>-0.07</td>
<td>-0.21</td>
<td>0.03</td>
<td>-0.25</td>
<td>-0.08</td>
</tr>
<tr>
<td>Rescue action efficiency (%)</td>
<td>-0.10</td>
<td>0.11</td>
<td>-0.14</td>
<td>0.25</td>
<td>-0.15</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

**Key:**
- FEV1 – Forced expiratory volume in the 1st second
- FEV0.75/VC – Percentage of vital capacity VC
- FVC – Forced vital capacity

### Table 5
Spearman's rank correlation between the parameters defining respiratory muscle fatigue level and different intensities of rescue action efficiency rescue action

<table>
<thead>
<tr>
<th>Parameters</th>
<th>FEV3/1</th>
<th>FEV3/2</th>
<th>PEF/1</th>
<th>PEF/2</th>
<th>FEV0.75/FEV6/1</th>
<th>FEV0.75/FEV6/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 m rescue style – V5</td>
<td>-0.79</td>
<td>-0.70</td>
<td>0.32</td>
<td>0.25</td>
<td>0.45</td>
<td>0.39</td>
</tr>
<tr>
<td>75 m rescue operation – V4</td>
<td>0.15</td>
<td>0.01</td>
<td>0.29</td>
<td>-0.22</td>
<td>0.25</td>
<td>-0.05</td>
</tr>
<tr>
<td>100 m freestyle – V3</td>
<td>-0.31</td>
<td>-0.37</td>
<td>0.14</td>
<td>-0.29</td>
<td>0.40</td>
<td>0.08</td>
</tr>
<tr>
<td>400 m freestyle – V2</td>
<td>-0.08</td>
<td>-0.15</td>
<td>0.30</td>
<td>0.00</td>
<td>0.61</td>
<td>-0.02</td>
</tr>
<tr>
<td>600 m rescue jog – V1</td>
<td>-0.21</td>
<td>-0.28</td>
<td>0.22</td>
<td>0.15</td>
<td>0.53</td>
<td>0.15</td>
</tr>
<tr>
<td>Rescue action efficiency indicator (score)</td>
<td>-0.25</td>
<td>-0.08</td>
<td>0.33</td>
<td>0.04</td>
<td>-0.26</td>
<td>0.03</td>
</tr>
<tr>
<td>Rescue action efficiency (%)</td>
<td>-0.15</td>
<td>-0.01</td>
<td>0.29</td>
<td>0.22</td>
<td>-0.25</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Key:**
- FEV3 – Forced expiratory volume in the 3rd second
- FEV0.75/FEV6 – Percentage of forced expiratory volume in the 6th second
- PEF – Peak expiration flow

- the result for the distance of 50 m rescue style, defining the speed V5, and the FEV3 parameter (-0.79) before and FEV3 (-0.70) after the exercise (the forced expiratory volume in the 3rd second) and the FEV0.75/FEV6 (0.45) parameter before the exercise (percentage of forced expiratory volume in the 6th second),
- the result for the distance of 100 m freestyle, defining the speed V3, and the FEV0.75/FEV6 (0.40) parameter before the exercise (percentage of forced expiratory volume in the 6th second),
- the result for the distance of 400 m freestyle, defining the speed V2, and the FEV0.75/FEV6 (0.61) parameter before the exercise (percentage of forced expiratory volume in the 6th second),
- the result for the distance of 600 m – rescue jog, defined by the speed V1, and the FEV0.75/FEV6 (0.53) parameter before the exercise (percentage of forced expiratory volume in the 6th second),
- the result for the distance of 50 m rescue style, defining the speed V5, and the FEV3 parameter (-0.79) before and FEV3 (-0.70) after the exercise (the forced expiratory volume in the 3rd second) and the FEV0.75/FEV6 (0.45) parameter before the exercise (percentage of forced expiratory volume in the 6th second),
- the result for the distance of 100 m freestyle, defining the speed V3, and the FEV0.75/FEV6 (0.40) parameter before the exercise (percentage of forced expiratory volume in the 6th second),
- the result for the distance of 400 m freestyle, defining the speed V2, and the FEV0.75/FEV6 (0.61) parameter before the exercise (percentage of forced expiratory volume in the 6th second),
- the result for the distance of 600 m – rescue jog, defined by the speed V1, and the FEV0.75/FEV6 (0.53) parameter before the exercise (percentage of forced expiratory volume in the 6th second),

The other included parameters showed, however, poor relationships or lack thereof ($p<0.05$), especially between parameters specifying respiratory muscle fatigue level and efficiency of the rescue operation.

As indicated by the data in Table 6, there are positive, quite strong correlations ($p<0.05$) between:
- the result for the distance of 50 m rescue style, defining the speed V5, and the FEF25 3 parameter (0.46) after the exercise (maximum expiratory flow for 25% residual FVC),
- the result for the distance of 400 m freestyle, defining the speed V2, and the FEF75 3 parameter (0.45) in the first test before the exercise (maximum expiratory flow for 75% residual FVC),
- the rescue action efficiency defined by speed V4 and the FEF25 parameter (0.53) in the 2nd test after rescue action (the maximum expiratory flow for 25% of the residual FVC).
The other included parameters showed a negative, weak relationship or lack of correlation ($p < 0.05$).

As can be seen from the data in Table 6, the following negative and quite significant correlations ($p < 0.05$) have been identified between:

- the result for the distance of 50 m rescue style, defining the speed $V_5$, and the MVV parameter (-0.75) before and the MVV (-0.59) after the exercise (the maximum voluntary ventilation) and the MET parameter (-0.60) before and MET (-0.51) after the exercise (the time of forced expiration between 25-75% capacity) and the FET parameter (-0.62) in the 2nd test after rescue action (duration of forced expiration),
- the result for the distance of 100 m freestyle, defining the speed $V_3$, and the MVV parameter (-0.48) after the exercise (maximum voluntary ventilation) and the MET parameter (-0.47) before the exercise (time of forced expiration between 25-75% of capacity) and the FET parameter (-0.46) after the exercise (duration of forced expiration),
- the result for the distance of 600 m – rescue jog determined by speed $V_1$, and the MET parameter (-0.53) before the exercise (time of forced expiration between 25-75% of capacity) and the FET parameter (-0.60) before the exercise and MET (-0.54) after the exercise (duration of forced expiration).

The remaining included parameters showed negative, weak correlations or their absence ($p < 0.05$), especially between parameters specifying respiratory muscle fatigue level and efficiency of the rescue action.
Table 8. The basic statistical characteristics of the CPR 2 efficiency procedure after performing a rescue action

<table>
<thead>
<tr>
<th>CPR 2 parameters</th>
<th>X</th>
<th>SD</th>
<th>Min.</th>
<th>Max.</th>
<th>R</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>VmV2</td>
<td>4.23</td>
<td>1.26</td>
<td>2.40</td>
<td>6.10</td>
<td>3.70</td>
<td>1.58</td>
</tr>
<tr>
<td>IV2</td>
<td>1.90</td>
<td>0.32</td>
<td>1.00</td>
<td>2.00</td>
<td>1.00</td>
<td>0.10</td>
</tr>
<tr>
<td>VR2</td>
<td>4.80</td>
<td>0.63</td>
<td>4.00</td>
<td>6.00</td>
<td>2.00</td>
<td>0.40</td>
</tr>
<tr>
<td>VV2</td>
<td>0.86</td>
<td>0.18</td>
<td>0.50</td>
<td>1.10</td>
<td>0.60</td>
<td>0.03</td>
</tr>
<tr>
<td>Si2</td>
<td>5.80</td>
<td>5.39</td>
<td>0.00</td>
<td>14.00</td>
<td>14.00</td>
<td>29.07</td>
</tr>
<tr>
<td>ECCR2</td>
<td>126.10</td>
<td>13.08</td>
<td>102.00</td>
<td>144.00</td>
<td>42.00</td>
<td>171.21</td>
</tr>
<tr>
<td>C/Relx2</td>
<td>40.90</td>
<td>4.84</td>
<td>32.00</td>
<td>45.00</td>
<td>13.00</td>
<td>23.43</td>
</tr>
<tr>
<td>Cd2</td>
<td>51.30</td>
<td>9.62</td>
<td>33.00</td>
<td>64.00</td>
<td>31.00</td>
<td>92.46</td>
</tr>
<tr>
<td>PbECC2</td>
<td>8.30</td>
<td>1.42</td>
<td>6.00</td>
<td>10.00</td>
<td>4.00</td>
<td>2.01</td>
</tr>
<tr>
<td>Whp2</td>
<td>46.50</td>
<td>75.87</td>
<td>0.00</td>
<td>230.00</td>
<td>230.00</td>
<td>5,756.72</td>
</tr>
<tr>
<td>L2</td>
<td>141.50</td>
<td>111.11</td>
<td>0.00</td>
<td>320.00</td>
<td>320.00</td>
<td>12,346.28</td>
</tr>
<tr>
<td>C/Vent2</td>
<td>31.20</td>
<td>2.57</td>
<td>28.00</td>
<td>37.00</td>
<td>9.00</td>
<td>6.62</td>
</tr>
</tbody>
</table>

Key:
- VmV2 – Ventilation per minute
- IV2 – Initial ventilation
- VR2 – Respiratory rate
- VV2 – Inspiration volume
- Si2 – Puffs into the stomach
- ECCR2  – Frequency of chest compressions
- C/Relx2 – Ratio of compressions to relaxation
- Cd2 – Depth of compressions
- PbECC2 – Breaks between compressions
- Whp2 – Wrong hand position
- L2 – Relaxation
- C/Vent2 – Ratio of compressions to inspirations

The data contained in Table 8 show statistical efficiency characteristics of the CPR procedures after the rescue action. The greatest diversity between the groups in the results concerning the CPR2 procedures after performing the rescue operation (Tab. 8) have been observed in the following parameters:
- relaxation L2 was in the range of $\bar{x} \pm 111.11$,
- wrong hand position Whp2, expressed as the number, was in the range of $\bar{x} \pm 75.87$
- ECCR2 frequency of compressions (expressed in number of compressions per minute) was within $\bar{x} \pm 13.08$.

Discussion

The main aim of this study was to determine respiratory muscle fatigue (RMF) level during swimming at different intensities. In addition, the work assumed the attempt to define the dependency between fatigue of the respiratory muscles, and the efficiency of an on-going rescue action performed by the lifeguards. Accurate statistical analysis allowed to start with defining the characteristics of the study group from the point of view of swimming at different intensities while performing rescue operations. There was a certain relationship noted: the lower the intensity of swimming within the rescue operations, the greater was the variety between groups. The largest divergence between the candidates for lifeguards was observed at the longest distances, namely 600 m V1 rescue jog and 400 m freestyle – V2.

That swimming velocity V2 and the parameters of oxygen uptake kinetics were not correlated to imply that pulmonary ventilation changes were harmonised with the rate of oxygen uptake. According to some authors [28-31], the level of pulmonary ventilation can be expressed through a so-called ventilatory equivalent of oxygen uptake $VO2(RCP)/V'CO2max$.

At the V3 level of the test, the physiological parameter peak expiratory flow (PEF) and voluntary ventilation (MVV) proved to be, as before, the strongest and statistically significant determinants of swimming velocity. The higher PEF at level V3 of the test suggests that the physiological response to excess CO$_2$ generated by lactic acid metabolism in active muscle tissue was hyperventilation. These results are too similar to the other authors' findings [32-34].

At level V4 of the test, parameters reached their maximum values. Another determinant of swimming velocity at this level of the test was the respiratory exchange...
rate RER4, because its value resulted from much higher breathing frequency and greater respiratory volume. In the literature, it is explained that such a significant increase in pulmonary ventilation against its resting level is enabled by breathing frequency rising to almost 50 cycles per minute and the respiratory volume growing by approx. 2.5 l. The presence of high V'CO2/kg (Relative Carbon Dioxide Output) may be an indication that hyperventilation that appeared at level V4 continued [32-35]. At this level of the test, the subjects probably exercised at maximum intensity. There is evidence that maximal aerobic exercise has a major effect on physiological parameters, such as V'CO2, VO2/kg, BF and VE. Maximum-intensity exercise considerably increases RER4, V'CO2 4 and VO2 4, as well as oxygen uptake per minute [28,30,31]. The changes are caused by a higher breathing frequency and increased respiratory volume being physiological responses to excess CO2 generated by lactate metabolism. This relationship confirms that the determinants of swimming velocity established for this level of the test were correct [36,37].

Subsequently, characteristics of the study group were conducted in the estimates expressing rescue action efficiency. As far as the characteristics of the rescue action efficiency carried out in water are concerned, the obtained test results may indicate good quality of the operation expressed as the indicator of effectiveness, as well as qualitative assessment, expressed as a percentage. In these two settings, the group was quite homogeneous, as indicated by the calculated SD in the valuation per share (±1.06), and the percentages of operation efficiency (±14.18).

Conclusions

Detailed analysis of the collected and developed research material allowed to formulate the following generalizations:

1. The strongest correlation between respiratory muscle fatigue level during different swimming intensities and efficiency of the conducted rescue action occurred only in the case of supra maximum intensity efforts between forced expiratory volume, forced vital capacity and maximal voluntary ventilation.

2. Respiratory muscle fatigue level (before and after the rescue action) showed greatest variation in two parameters: maximal voluntary ventilation and peak expiratory flow.

3. It can be assumed that there are dependencies between resuscitation and circulatory procedures (CPR) before and after a simulated rescue action, because:

   • after the rescue action, there is a significant increase in: relaxation, ventilation per minute, respiratory frequency - amount of puffs into the stomach, wrong hand position,

   • after the rescue action, there is a slight increase in: initial ventilation, inspiratory volume, the frequency and ratio of compressions to inhalation and relaxation,

   • after the rescue action, such parameters decrease as: the depth of compressions and intervals between them.

Applicative form

Research aimed at improving the effectiveness of saving human life and health are important and deliberate, as assistance to people in distress is the primary water rescue task. Monitoring and documentation of changes in respiratory muscle function and endurance under the influence of physical effort can be conducted in a manner consistent with evidence-based medicine.

References:


The impact of respiratory muscle...


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