THE EFFECT OF THE CONFIGURATION OF THE DIVE'S TOWED EQUIOMENT ON THE LIFEGUGUARD PHYSIOLOGICAL OVERLOAD

Rafał Mikołajczyk[1)], Marcin Sikora[2)], Olga Łakomy[1)], Aleksandra Żebrowska[2)], Piotr Siermontowski[3)]

[1)] Department of Physiological and Medical Sciences, Academy of Physical Education Katowice, Poland
[2)] Institute of Healthy Living, Academy of Physical Education Katowice, Poland
[3)] Department of Underwater Works Technology, Naval Academy Gdynia, Poland

ABSTRACT

The aim of the study was to determine the effects of rescue swimming on lifeguard cardiorespiratory system assessed based on heart rate (HR), lung ventilation ($\dot{V}E$), oxygen uptake ($\dot{V}O_2$) and blood lactate concentration (LA). Furthermore, we also investigated the possible impact of the rescue equipment of the towed diver on the lifeguard physiological overload and towing speed. Exercise variables were measured in lifeguards aged 25.5 ± 6. years before and immediately after the swimming a distance of 50 m with a person in tow with or without diving equipment. There were no significant effect of different protocols of towing on $\dot{V}O_2$. The type of towing protocols have a significant effect on HR, $\dot{V}E/\dot{V}O_2$ ratio, and blood LA levels. The towing time and the average towing speed during simulated rescue operation were significantly different depending on the type of the towing person's equipment. Towing a diver wearing only a dry suit significantly reduces the towing time, increases towing speed and may be result in better exercise tolerance and less fatigue for rescuer compared to towing a diver in a full classic or wing diving set.
Keywords: water rescue, diving, rescue and buoyancy equipment, fatigue

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INTRODUCTION

In rescue operations, the lifeguard's experience in rescue techniques used in the aquatic environment contributes to the protection of human live [1,2,3]. These professionals acquire extensive technical training enabling them to conduct safer and effective operations. It is emphasized that an important element in a water rescue operations is towing a drowning person, which not only takes the longest, but also puts the greatest burden on the rescuer [4,5]. The determinants of the effectiveness of rescue action are lifeguard's performance skills and fatigue resistance [6,7]. The physical demands in a rescue action are associated with running, rescue swimming and the effectiveness of the cardiopulmonary resuscitation techniques used. Although the technical and physical skills of lifeguards have been extensively studied in previous research data, there are few studies identifying physiological factors associated with improving the lifeguard cardiopulmonary performance [2,8,9]. From a physiological point of view, exercise training has the potential to strengthen muscle contraction, improve oxygen capacity, and therefore, the effectiveness of cardiopulmonary resuscitation intervention [10].

In order to assess the physiological factors determining the lifeguards efficacy, previous research data have been conducted after performing a simulated rescue operation in which a standard dummy was used [4,8]. It has been shown that the oxygen uptake, blood lactate concentration and the heart rate increase during the rescue, which means that aerobic capacity are fundamental to the lifeguard's performance during the rescue [10]. The results of the previous research data showed that the exhaustion of the lifeguard did not have a substantial impact on the quality and effectiveness of the rescue procedures [6]. However, the study was conducted in conditions isolated from fatigue, which could be caused by the body mass of a towed person and, in the case of a towed diver, by a type of buoyancy equipment [11,12].

There are two main types of buoyancy control device (BCD) for scuba divers. The first one is a classical dive vest (CDV) and the second one is a wing dive vest (WDV). Buoyancy control device allows the diver to control the depth of the dive (i.e., buoyancy) and ascend to the surface. Moreover, a BCD is capable of keeping the diver, even an unconscious one, afloat with the head inclined backward to prevent water from entering the airway, thus increasing the odds of survival [12,13,14].

Therefore, the success of rescue operations of divers is partly dependent on the ability of a BCD to keep a diver afloat before they are towed to safety, as well as a lifeguard performance and rescue techniques used in the aquatic environment. Moving an injured diver through the water is one of the most important, but also the most overlooked aspects of a dive rescue [14]. After the towing an injured diver to the shore or a boat, the next step of the rescue is to find a way to get the diver out of the water [13]. The manoeuvre may be very difficult due to the impact of towing on the rescuer's body overload and fatigue. This may be the most difficult and physically demanding part of the rescue operation. Safety of the aquatic lifeguards should take into account factors related to additional load depending on a diver's rescue action.

In this study, we aimed to explore the effects of rescue swimming on lifeguard cardiorespiratory system assessed based on heart rate, lung ventilation, oxygen uptake and blood lactate concentration. Furthermore, we also investigated the possible impact of the rescue equipment of the towed diver on the lifeguard physiological overload and towing speed.

MATERIALS AND METHODS

The study enrolled seven male and four female lifeguards aged 25.5 ± 6.8 years, a body mass of 78.3 ± 19.5 kg, a body height of 177.8 ± 10.2 cm, and a BMI of 24.5 ± 3.7 kg/m^2. The body mass of the participants was determined using bioelectrical impedance analysis (an InBody570 analyser, Biospace Inc., Seoul, South Korea). All participants had valid medical examinations and showed no contraindications to participating in the study. Written informed consent was obtained from all participants prior to the study commencement. The study objectives, experimental procedures and the related risks were explained to all participants verbally. They were also informed that they could withdraw from the study at any time. The study was approved by the local Ethics Committee, no. 02/2022.

Tests were conducted in an indoor swimming pool of a 25 m long, in water at 26C° under the same environmental conditions. Before the tests, participants' heart rate (HR), resting and maximal oxygen uptake ($\dot{V}O_2$), lung minute ventilation ($\dot{V}E$), and blood lactate concentration (LA) were determined. The physiological parameters were measured before and in response to rescue protocols. The rescue protocols consisted of repeatedly swimming a distance of 50 m. Each life guard completed four distances (50 m) of towing a person (body weight 84 kg, body high 182 cm and body surface area = 2,05 m^2). During each protocols (50 m's distance) a towing person wearing different suit: a dry suit with a classical dive vest (TCDV), ,a dry suit with a 'wing' dive vest (TWDV), a dry suit (TDS) and a swimming suit (TSS) (Scheme 1, the towing test protocol). The order of the towing protocols was determined randomly and the interval between each test was at least 3 days. Participants' oxygen uptake ($\dot{V}O_2$), the percentage of carbon dioxide in exhaled air ($\dot{V}CO_2$), minute ventilation ($\dot{V}E$), breathing frequency (BF), and tidal volume (TV) were recorded. Calculations were made to determine their relative oxygen uptake ($\dot{V}O_2$/kg), and the percent of maximal oxygen uptake ($\dot{V}O_2$max pred). Blood capillary samples were taken for blood lactate concentrations analyses (LA). The time of towing (TTime) was measure and the mean towing linear speed (TSpeed) was calculated.

The effect of physical exercise on participants' respiratory indicators was assessed using an ergospirometer (Ergo2000M, MES software, Poland). HR values were recorded continuously throughout each test (POLAR H10 HearRate with 3.1.1 version software, Kempele, Finland). The measurements of blood lactate (LA) in the fingertip capillary blood were performed pre- and post-tests using the GEM Premier 3000 with IQM (Instrumentation Laboratory).

The data recorded during the tests were subjected to a statistical analysis, which included basic descriptive statistics. Each variable's distribution was assessed for normality using the Shapiro-Wilk test. The ANOVA with repeated measures was preceded by the Levene's test for homogeneity of variance. The effect of the rescue towing protocols (TDS, TCDV, TWDV and TSS) and the exercise test effect (resting values vs. immediately post swimming values) on the analysed variables was assessed. The level of statistical significance was set at $p < 0.05$. The data were processed using the Microsoft Excel spreadsheet (2019) and the statistical analysis was performed in Statistica v. 13.3 by StatSoft (Poland).

Fig. 1 The towing test protocol.

RESULTS

There was a significant effect of exercise (rescue swimming) on $\dot{V}O_2$ ($F=55.8$, $p<0.001$, $\eta^2=0.85$). The $\dot{V}O_2$ was significantly higher at the completion of rescue swimming protocols compared to baseline levels ($p < 0.001$) (Fig.2.). There were no significant effect of different protocols of towing on physiological variables of aerobic capacity. No significant differences were found in the $\dot{V}O_2$ between the rescues protocols, neither at $\dot{V}O_2$ (ml/kg/min) nor percent of $\dot{V}O_2max$ predicted values (Table 1). The intensity of each protocol expressed by the percentage of $\dot{V}O_2max$ was > 80% and has a tendency to lower values after towing person with dry suit (TDS). The type of towing protocols have a significant effect on HR, the ventilation-perfusion ratio ($\dot{V}E/\dot{V}O_2$), and blood LA levels ($p = 0.033$, $p = 0.038$ and $p < 0.001$, respectively) (Table 1).

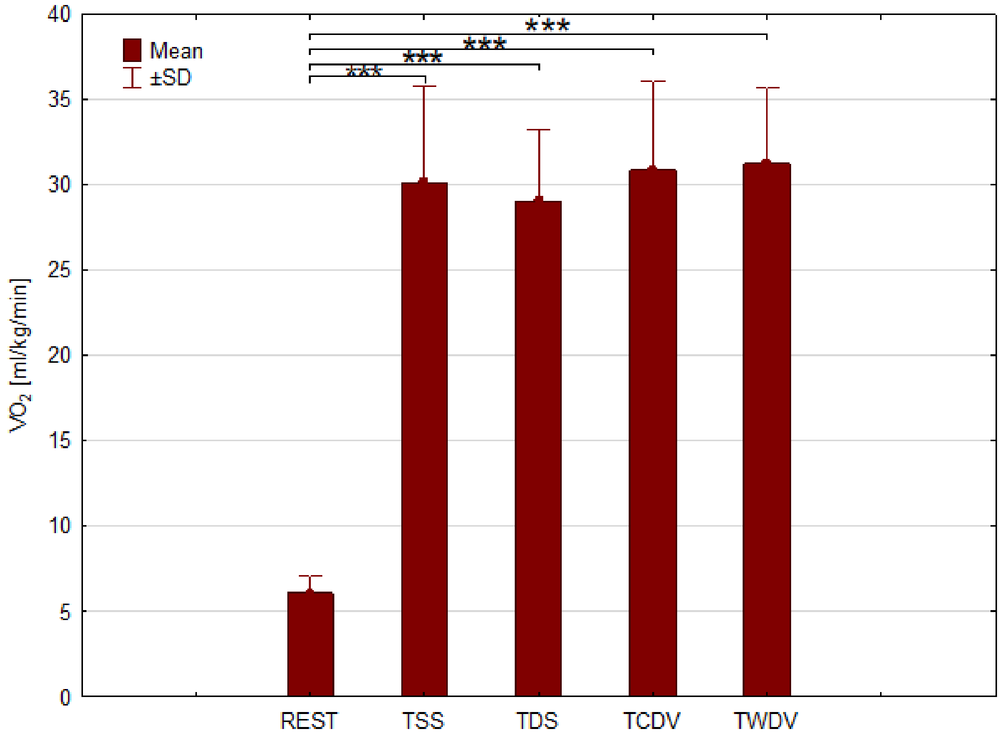
The participants' heart rate increased in all towing protocols but a significant difference was found only between TSS (167.0 ± 12.0 b/min) and TDS (161.0 ± 11.0 b/min) (post-hoc $p<0.05$). Also % of HR max pred. was significantly higher in TSS (87.6 ± 10.2 %) compared to TDS (84.6 ± 10.1 %) ($p < 0.05$). No significant differences in the lung ventilation ($\dot{V}E$) between the protocols were observed, but there was a significant difference in the $\dot{V}E/\dot{V}O_2$ between TDS (29.6 ± 5.2 L) and TCDV (32.1 ± 7.1 L) protocol ($p < 0.05$). The LA concentrations increased significantly in response to the TWDV protocol compared to TSS ($p < 0.001$) (Fig.3). The statistical analysis revealed type of rescue towing protocols effects on the TTime and TSpeed ($F = 71.9$; $p < 0.000$ and $F = 55.3$; $p < 0.000$, respectively). The TTime was significantly lower after TDS compared to other types of towing (TSS, TCDV and TWDV) as well as TCDW was lower than TWDV ($p < 0.05$) (Fig.4a.). There were no statistically significant differences in TSpeed between the TCDV and TWDV. Towing speed was significantly lower in TSS protocols compared to TDS) ($p < 0.05$). (Fig. 4b.).

Tab. 1

Physiological variables and towing time and speed in response to different towing protocols (mean± SD).

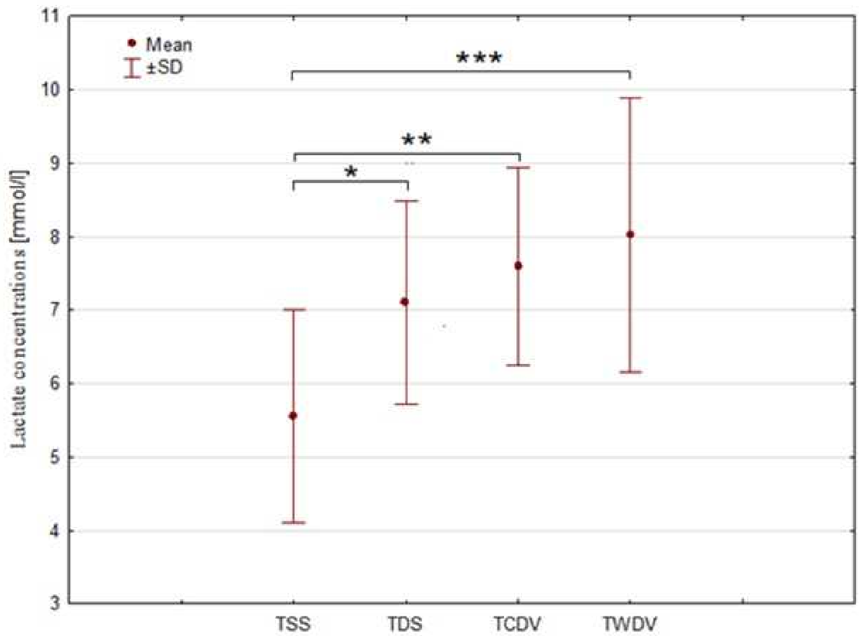
Variable	**TSS**	**TDS**	**TCDV**	**TWDV**	***F***	***p-value***	**η^2**
$\dot{V}O_2$ [ml/kg/min]	30.1 ± 5.4	29.1 ± 4.0	30.8 ± 5.0	31.2 ± 4.8	0.9	0.441	0.085
$\dot{V}O_2$ max [%]	83.0 ± 13.4	81.0 ± 14.7	84.7 ± 10.3	86.1 ± 11.4	0.9	0.459	0.08
HR [bpm]	167.0 ±12.2	161.3 ±11.5	162.3 ±15.0	163.1 ±13.3	**3.4**	**0.032**	**0.25**
HR max [%]	87.6 ±10.2	84.6 ±10.1	85.1 ±10.6	85.5 ±10.7	**3.3**	**0.033**	**0.25**
VE [l/min]	69.1 ± 18.0	66.8 ± 19.1	74.7 ± 17.2	74.5 ± 18.3	2.6	0.067	0.21
VE/ $\dot{V}O_2$ [l]	30.0 ± 4.4	29.6 ± 5.2	32.1 ± 7.1	31.2 ± 5.8	**3.2**	**0.038**	**0.24**
LA [mmol/l]	5.56 ± 1.3	7.1 ± 1.3	7.6 ± 1.2	8.0 ± 1.7	**10.4**	**<0.001**	**0.63**
TTime [sec]	86.1 ± 9.0	79.8 ± 8.5	100.5 ± 8.4	106.8 ± 8.6*	**71.9**	**<0.000**	**0.88**
TSpeed [m/sec]	0.6 ± 0.1	0.6 ± 0.1	0.50 ± 0.1	0.47 ± 0.0	**55.3**	**<0.000**	**0.85**

T– towing, SS – swimming suit; DS – dry suit; CDV– classic dive vest; WDV– wing dive vest; $\dot{V}O_2$ – oxygen uptake; $\dot{V}E$ – minute lung ventilation; HR – heart rate; LA – lactate concentration; TTime – towing time; TSpeed – towing speed
** – statistically significantly different between TCDV and TWDV.*



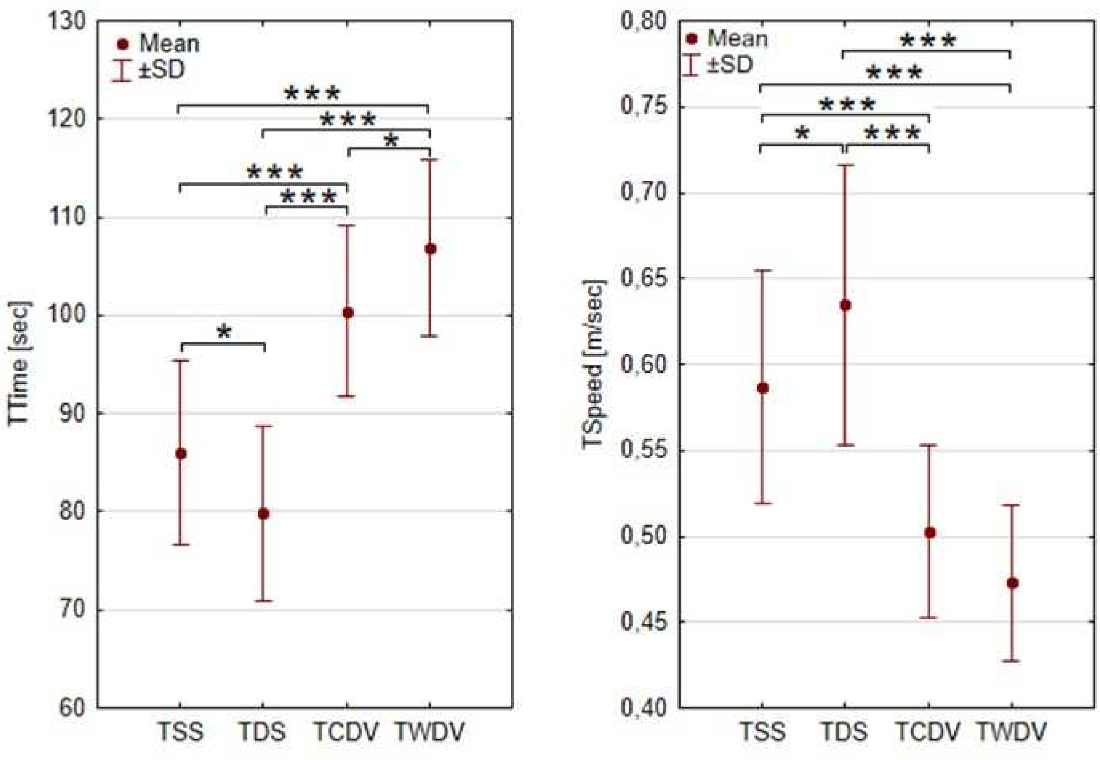
$\dot{V}O_2$ – oxygen uptake; TSS-towing in swim suit, TDS- towing dry suit, TCDV-towing classic diving vest, and TWDV- towing wing diving vest
**** p<0.001– statistically significant differences between pre exercise values (REST) and post towing protocols*

Fig. 2 Oxygen uptake at rest and in response to different towing protocols.



TSS-towing in swim suit, TDS- towing dry suit, TCDV-towing classic diving vest, and TWDV- towing wing diving vest
** p<0.05; ** p<0.01;*** p<0.001– statistically significant differences between protocols.*

Fig. 3. Blood lactate concentrations in response to different towing protocols.



TTime – towing time, TSpeed – towing speed, TSS – towing in swim suit, TDS – towing dry suit, TCDV – towing classic diving vest, and TWDV – towing wing diving vest
** p<0.05; p<0.001– statistically significant differences between protocols*

Fig.4 a and Fig. 4 b. Towing time and towing speed (TSpeed) in response to different towing protocols.

DISCUSSION

In the present study, the effects of towing a person equipped with the rescue and buoyance equipment of various configuration and a person without such equipment over a distance of 50 meters on lifeguard cardiorespiratory system heart rate, oxygen uptake and effectiveness of towing were evaluated. This research study is innovative due to the fact that not only the strain towing has on a lifeguard but also the configuration of the towing person's rescue equipment (type of buoyancy vest) on their performance were assessed. The study results show that the lifeguards who towing person with different type of buoyancy vest (different rescue equipment configuration) have higher overload of cardiorespiratory system compared to the lifeguards towing person with dry suit.

Importantly, the lower towing speed and higher blood lactate concentration after TWDV compared to a dry suit or a dry suit with a classic diving vest was also noted. The results seem to be

The results seem to be especially important in divers' rescue operation, in which the physical capacity of lifeguards is important not only for the success of the rescue operation, but also for reducing the risk of sudden cardiovascular incident associated with excessive fatigue and an decrease exercise tolerance [4]. Four sessions of pool test with the different rescue equipment of the towed person for lifeguards indicated that the $\dot{V}O_2$ values, in relative terms were comparable between the rescues protocols. Participants had relative oxygen uptake values indicating high exercise load (> 80 % of $\dot{V}O_2max$), but the $\dot{V}O_2$ was lower than the values obtained during the incremental pool test for lifeguards (36.5 ml/kg/min. to 45.6 ml/kg/min.) [5,8].

Previous studies have shown that endurance exercise training enhances rescuers' resistance to fatigue, but a rescuer towing a diver may need to exercise at a higher intensity to increase the exercise tolerance [3,9,10]. Maximal oxygen uptake ($\dot{V}O_2max$,) and the lactate concentration (LA) during exercise are important indicators of lifeguards endurance. Previous studies of elite lifeguards have shown that the rescue technique was partially attributed to a higher $\dot{V}O_2max$ and lower fatigue [15,16]. In addition, monitoring oxygen uptake and other cardiopulmonary components, such as heart rate, lung ventilation, and blood lactate concentrations may provide information about the performance status during rescue action.

Another significant result of the study is the increase of the ventilation-perfusion ratio after towing person with classic dive west and a tendency to higher $\dot{V}E/\dot{V}O_2$ between the TDS and TWDV (29.6 ± 31.2 ± 5.8 L, but due to the small effect size (η2) no conclusions can be drawn for the general population. The lifeguards towing person with a dry suit had the lowest cardiopulmonary parameters, such as HR, HR max and VE/ $\dot{V}O_2$ indicating that towing person in a dry suit has the least strain on the body function, hence can be the most efficient way of towing a casualty. Similarly, the authors [15] concluded that wearing a dry suit whilst towing a casualty with a one-hand jaw was the fastest method of towing.

The increased levels of cardiopulmonary specific variables, such as HR, VE, and $\dot{V}O_2$ have been commonly observed in athletes immediately after prolonged swimming and have been shown to be a result of excessive hemodynamic stress on the heart, an increase in oxygen demand due to an increase in the energy cost of muscle work [17]. It is hypothesized that exercise stress associated with swimming and rescue person with classical dive vest (CDV) or a wing dive vest makes the lifeguards makes the rescuer more susceptible to fatigue, but, the impact of technical skills on towing efficiency cannot be ruled out.

It seems that the significantly shorter time of towing person in a dry suit compared to other diving vests is the most important finding of the study suggesting that unfastening the wing or a classic diving vest during towing may increase the speed of a rescue action. On the other hand, according to the research [18], the classic vests keep the lifeguard on the water surface on the back in an oblique position, which prevents the lifeguard's face from immersing in the water when the towing had to be paused due to, e.g. fatigue. Determining the effects of different rescue equipment configuration of the towed diver on effectiveness of rescue procedures and related effects on the physiological determinants of exercise performance of lifeguards subjected to exercise training requires further investigation.

The main conclusion of the study is that the towing time and the average towing speed during simulated rescue operation were significantly different depending on the type of the towing person's rescue equipment (type of buoyancy vest) (Tab. 1). Towing a diver wearing only a dry suit significantly reduces the towing time, increases towing speed and may be result in better exercise tolerance and less fatigue for rescuer compared to towing a diver in a full classic or wing diving set.

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Aleksandra Żebrowska
kierownik Katedry Nauk Fizjologiczno-Medycznych
Akademia Wychowania Fizycznego w Katowicach
a.zebrowska@awf.katowice.pl