Original article

Influence of intermittent aerobic performance on the variables of static and dynamic apnea performances

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Summary

Over the last years, sport diving has become one of the most studied physical activities. Several physiological responses have been described and analyzed during immersions of static, dynamic, and deep apnea sessions. These analyses, and several others, have been focused mainly on the cardiovascular and hemodynamic changes that this activity produces.
Objective: To determine the influence of aerobic performance of static and dynamic apnea before and after an out-water training based on the average velocity of a 12-minute test.
Material and Method: Eight apnea scuba divers of the Chilean Navy were part of this study. The variables measured were: aerobic performance measured through a 12-minute test, static and dynamic apnea. The protocol used for the aerobic performance development was a study based on the average velocity of a 12-minute test. The statistical analysis was performed with Student's t-test and the size of the effect with Cohen's d test.
Results: The aerobic performance showed a significant increase between the pre and post-test ($p < 0.001$; size of the effect = 1.263). The static apnea did not show significant modifications ($p > 0.05$; size of the effect = 0.025). Lastly, the dynamic apnea showed a significant increase in both measurements ($p < 0.05$; size of the effect = 0.404).
Conclusions: The result of the study showed that increasing the aerobic performance generates a rise in the distance of dynamic apnea. For that reason, it is suggested that apnea scuba divers perform out-water trainings based on the average velocity of 12-minute test as a complement to their immersion training.

Key words:
Aerobic performance. Static apnea. Dynamic apnea. 12-minute test. Average velocity of 12-minute test.

Influencia del rendimiento aeróbico intermitente sobre las variables de rendimiento de la apnea estática y dinámica

Resumen

En los últimos años, el buceo deportivo se ha convertido en una de las actividades físicas más estudiadas. Dentro de estas investigaciones, se han descrito y analizado las respuestas fisiológicas corporales durante las inmersiones de apnea estática y dinámica. De forma específica, los análisis se han centrado principalmente en los cambios cardiovasculares y hemodinámicos que esta actividad deportiva produce.
Objetivo: Determinar la influencia del rendimiento aeróbico en la apnea estática y dinámica antes y después de un entrenamiento fuera del agua basado en la velocidad promedio obtenida a través del test de 12 minutos.
Material y Método: Ocho buceadores de apnea perteneciente a la Escuela Naval de la Armada de Chile fueron parte del estudio. Las variables medidas fueron: rendimiento aeróbico a través del test de 12 minutos, apnea estática y dinámica. El protocolo usado para el desarrollo del rendimiento aeróbico fue basado en la velocidad promedio del test de 12 minutos. El análisis estadístico fue realizado a través de una t de Student y el tamaño del efecto con una d de Cohen.
Resultados: El rendimiento aeróbico mostró incrementos significativos entre el pre test y el post test ($p < 0{,}001$; tamaño del efecto = 1,263). La apnea estática no mostró cambios significativos ($p > 0{,}05$; tamaño del efecto = 0,025). Finalmente, la apnea dinámica mostró incrementos significativos entre ambas mediciones ($p < 0{,}05$; tamaño del efecto = 0,404).
Conclusiones: El resultado del estudio mostró que un incremento en el rendimiento aeróbico genera un aumento en la distancia alcanzada en apnea dinámica. Por tal razón, se sugiere que los buceadores de apnea realicen entrenamientos fuera del agua. Por último, los entrenamientos pedestres basados en la velocidad promedio de la prueba de 12 minutos, son un buen complemento del entrenamiento de inmersión.

Palabras clave:
Rendimiento aeróbico. Apnea estática. Apnea dinámica. Test de 12 minutos. Velocidad promedio del test de 12 minutos.

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Introduction

Over the last years, sport diving has turned into one of the most studied physical activities[1]. Several physiological responses have been described and analyzed during immersions of static, dynamic, and deep apnea sessions[2-4]. These analyses, and several others, have been focused mainly on the cardiovascular and hemodynamic changes that this activity produces[5-7]. In connection to these hemodynamic and cardiovascular changes demonstrated in the apnea practice, it has been described that during 215 ± 35 s of immersion the heart rate (HR) decreases by 20 beats per minute, while *systolic and diastolic blood pressure (SBP, DBP)* show an increase of 23 and 17 mmHg respectively during the first 20 ± 3 s (phase I). Then, in the following 92 ± 15 s both the HR and the blood pressure (BP) showed stability (phase II). Later, during the last 103 ± 29 s, SBP and DBP increased in a linear fashion reaching values close to 60% when comparing them with control, while HR remains unchanged (phase III). Lastly, the cardiac output (Q) was reduced by a 35% in phase I, while in phases II and III it did not show significant changes[1]. Several studies have reported that the SaO2 decreased along with immersion[6,8,9].

In this context, a significant decrease has been observed in the arterial oxy-hemoglobin saturation level (SaO2) during maximum immersion and dry apnea. However, decrease in SaO2 is significantly higher during immersion when compared to dry apnea ($p = 0.04$)[8].

Concerning the physiological factors that are more challenging in static and dynamic apnea practice, several studies have described that HR, stroke volume (SV) and Q, SBP, DBP, mean blood pressure (MBP), systemic vascular resistance (SVR), SaO2, spleen and lungs size condition the performance in static and dynamic apnea[10,11]. Similarly, the same hemodynamic, cardiac, and lung variables show a direct relation with aerobic performance and VO_2max[12,13]. Therefore, it is likely that aerobic training enhances apnea performance.

Despite the fact that apnea diving has been widely studied, many of those studies have only been based on the organic responses[6,7]. Studies have also tried to measure some of the pathologies resulted from this practice[14,15], but in only a few opportunities the adaptations to training processes have been visualized[16]. More precisely, only some hemodynamic differences among divers and non-divers have been proved[17]. In this investigation, Tocco *et al.*[17] showed that divers trigger a bradycardia and an adjustment in the systemic vascular resistance faster than the control subjects, in particular in heart rate and systemic vascular resistance[17]. Similarly, Nishiyasu *et al.*[18], showed the relationship present between the degree of bradycardia induced by apnea and the vascular response in arms and legs during knee extension exercises. This research showed that the subject with a greater bradycardia, by breath holding during knee extension during the exercise, also showed a greater vasoconstriction in both active and inactive muscles[18]. It is safe to infer that intermittent endurance training for this population is limited or otherwise the results and adaptations in out-water training have not been published.

In connection to the changes in aerobic and VO_2max performance generated from high-intensity interval training, this training method has shown a significant increase in VO_2max when compared with other training methods of low intensity[19,20]. Unfortunately, there is no enough evidence on intermittent endurance training and/or out-water trainings *being performed* by divers in order to increase aerobic performance and hence increase their performance in static, dynamic or deep apnea tests. The main objective of this research was to determine the influence of the aerobic performance over static and dynamic apnea before and after the performance of an intermittent endurance training based on average velocity of 12-minute test.

Material and method

Experimental approach to the study. Chile is comprised of more than 4.000 meters of coastline making diving practice very attractive for the population. However, the low temperature of the ocean (14 to 17 °C)[21] only allows the sport to be practiced in the warmer months of the year (October – April). That is why divers have to perform two types of training during the colder months of the year (May – September). On one hand, they perform indoor training in swimming pools – *a high-cost alternative of difficult access,* and, on the other hand, *they develop their physical* condition mainly through peak oxygen uptake (VO_2max) performing intermittent endurance training.

Subjects. Eight male apnea divers from the Chilean Navy (age: 20.2 ± 1.22 years, weight: 73.6 ± 5.3 Kg, height: 176.6 ± 5.3 cm, Body Mass Index: 23.6 ± 1.5 Kg/m^2, fat percentage: 15.3 ± 2.9%) were part of the study (Table 1). In *order to define the sample, years of experience performing apnea diving was an inclusion criteria*. Subjects had a minimum of two years of diving practice. During these two years, all subjects were part of 3 weekly session trainings (two session in a heated pool at 26°C and one session in the ocean with temperatures ranging from 14°C to 17°C)[21]. As an inclusion criterion, the selection of participants only included those subjects who did not smoke and were not taking any medication that could risk their health by performing high-intensity tests (12-minute test) and dynamic and static apnea.

All sportsmen and coaches were informed about the aim of the study and the possible risks of the experiment. Subsequently, they all signed a written consent before starting the protocol. The signed consent and the study were approved by the Human Investigation Committee of the University of Granada, Spain (register number 231/CEIH/2016).

Before starting the study, weight, height, and skin folds were measured in all subjects. All subjects of the investigation were asked to not ingest caffeine, any drugs or substances that would increase their metabolism

Table 1. Characteristics of the sample (median ± SD).

Experimental group (n = 8)	
Age (years)	20.7 ± 1.2
Height (cm)	175.0 ± 5.6
Weight (Kg)	72.4 ± 5.4
BMI	23.7 ± 1.7
Body fat (%)	15.5 ± 2.7
Initial distance of 12-minute test (m)	3118.4 ± 148.5
Aerobic performance (mL•Kg^{-1}•min^{-1})	55.0 ± 3.4

BMI (body mass index); SD (standard deviation); mL•Kg-1•min^{-1} (milliliters of oxygen per kilogram of body weight per minute).

48 hours before pre and post test. Also, subjects were asked not to perform any vigorous activities twelve hours before the pre and post test. The time lapse of intake of the last meal before the tests was also controlled. The time registered was two hours for pre and post test.

Protocols and variables. Weight and height were measured with a Health Stadiometer Scale or Meter Professional® to characterize the sample. Skin folds were measured with a F.A.G.A.® caliper. Biceps, Triceps, Subscapular and Supra Supraspinal were measured to determine fat percentage using the Durnin & Womersley method[22].

The application of protocol used a pre-experimental intra-subject design with a pre and post test. *This study used the application of a training session based on average velocity of 12-minute test (AV.12-min test) obtained through a 12-minute test.*

Aerobic performance. The aerobic performance was evaluated with a 12-minute test (Cooper test). This test is able to measure the peak indirect oxygen uptake and the average velocity. This test was selected due to its convenience to assess all subjects simultaneously, *also because* minimum equipment was needed and it proved to be a good cardiovascular indicator. This test shows a strong correlation with the peak oxygen uptake. Therefore, the 12-minute test is an objective test that reflects the cardiovascular condition of an individual[23,24]. The evaluation was carried out in a 400-meter athletic track before and after *the application* of an experimental protocol based on AV.12-min test. Before the evaluation, subjects were encouraged to cover as much distance as possible and, during the test application, all participants received oral cheers from their diving coaches as well as from the researchers. With regard to the time *in which* the 12-minute test was performed, both the pre and post test were performed at 12:00 pm. This allowed the researcher to control specific variables such as temperature, humidity, and wind. The environmental conditions in which the test was performed were: 18°C and 34% relative humidity. The post test environmental conditions were: 20°C and 37% relative humidity.

The distance covered was measured in meters and then converted into kilometers (Km). The VO_2max was obtained with the following equation[23]:

$$VO_2max\ (mL \cdot Kg^{-1} \cdot min^{-1}) = (22.351 \times \text{distance in kilometers}) - 11.288$$

Also, the average velocity of 12-minute test (AV.12-min test) applied in the experimental protocol was determined through a 12-minute test:

AV.12-min test (m/s) = (distance in meters performed in 12 minutes/ 720 seconds)

Apnea evaluation. In connection to the static and dynamic apnea, these were performed in a pool measuring 50 meters in length and two meters deep with a water temperature of 26°C. Both tests were carried out during the same day (static apnea was evaluated first, and dynamic apnea second). With regard to the time the dynamic and static apnea test was performed, both the pre and post test were performed at 12:00 pm. This allowed the researcher to control specific variables such as temperature and humidity. The environmental conditions were the following: 26°C and 63% relative humidity.

Static apnea. In order to determine the performance of static apnea, the authors measured the longest period of time in seconds (s) that each subject held their breath with their entire body under water. In connection to time recording, the timer started when the subject submerged their airways into the pool and it was stopped when any or all airways would surface. Each subject was evaluated individually, and the protocol considered a resting time of three minutes before starting the test. Also, during the application of the test, all subjects were allowed to be near the edge of the pool.

Dynamic Apnea. In order to determine the performance in dynamic apnea, the authors considered the greatest distance in meters (m) that each subject could swim in a horizontal position after one single immersion at two meters deep in the pool. Subjects were located at one of the ends of the first pool lane with the sole of their feet touching the wall, placing one hand on the starting platform, and looking at

Table 2. Structure of the Aerobic Training Program based on the average velocity of a 12-minute Test.

Months	February											
Week	1			2			3			4		
Type of Microcycle	In			Lo			Lo			Re		
Sessions by Microcycle	3			3			3			3		
Load per session	CT	SA & DA	3x1200 90% re 3:30	5x800 90% re 1:00	6x1000 90% re 1:30	2x2000 85% re 2:30	3x1200 90% re 1:00	1x6000 80%	3x1600 85% re 2:00	3x800 100% re 2:00	2x2000 90% re 3:00	1x3000 85%
Weekly volume (m)	3600			14000			14400			10200		
Average velocity in 12 - minute test	90%			87%			85%			92%		
Periods	Accumulation											
Low intensity												
Middle intensity												
High intensity												

CT (Cooper Test [12-minute test]); SA (static apnea); DA (dynamic apnea); In (introduction); Lo (load); Re (regenerative); Co (competitive); m (meters); MAV (maximum aerobic velocity); % (percent); re (rest).

the direction of the apnea. All movements had to be performed at the bottom of the pool. In relation to the evaluator, he was standing at the edge of the pool. The distance considered for dynamic apnea was measured from the edge of the pool until the point where the head of the divers emerged. In case of reaching the opposite end of the pool, subjects had to touch the end wall with hands and feet and then return in the opposite direction. A metric tape was placed at the edge of the pool in order to determine the exact distance reached in dynamic apnea.

Treatment. The aim of the protocol application was to develop VO_2max in divers connected to the AV.12-min test. This training plan was performed under the application of the periodization model of Block, specifically the Accumulation, Transformation and Realization model (ATR). This periodization model was used since it is one of the most used models to increase VO_2max in endurance sports[25]. The ATR model is characterized by allowing a better concentration of the training load[26]. This load concentration is the most decisive and important component of the block planning[27,28]. In connection to the program, this consisted of three mesocycles. The first mesocycle of accumulation consisted of obtaining the largest possible training volume. Then, in the transformation phase, the volume was reduced and the intensity increased. Finally, in the performance stage, the intensity was increased and the volume was adjusted to the projected distance in the 12-minute test (Table 2 and Figure 1).

Statistical Analysis. The variables of VO_2max, static apnea time, and dynamic apnea time were analyzed with the Kolmogorov-Smirnov (K-S) test. The differences between pre and post test were analyzed with a Student's t-test and intra-class correlation coefficient (ICC), while the size of the effect (SE) was calculated using Cohen's d test. This analysis considered the following values: insignificant ($d < 0.2$), small ($d = 0.2$ hasta 0.6), moderate ($d = 0.6$ a 1.2), big ($d = 1.2$ a 2.0), or very big ($d > 2.0$). The level of significance for all statistical analysis was $p < 0.05$. The data analysis was performed with Graphpad Instat Versión 3.05® software.

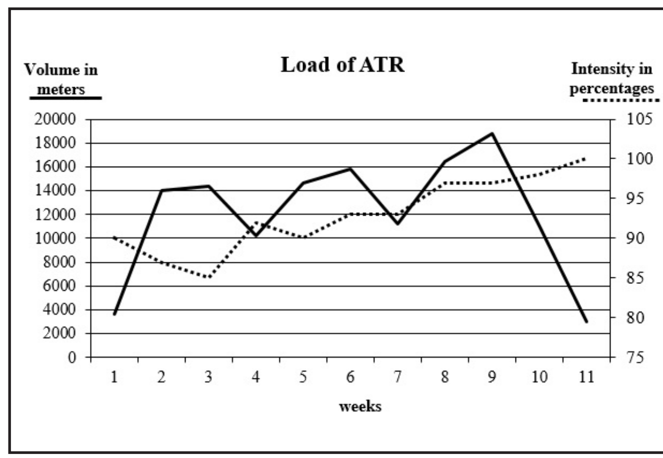
Results

Progressions and differences. The VO_2max obtained through the 12.minute test was significantly higher in post test than in pre test ($p < 0.0001$; SE = 1.263). Static apnea time was not significantly different between the pre and post test training period ($p > 0.05$; SE = 0.025). Finally, dynamic apnea distance was significantly higher in post test than in pre test ($p < 0.05$; SE = 0.404) (Table 3).

Discussion

The main observation in this study was that the dynamic apnea performance significantly increased after post exercise training intervention compared to pre-test, suggesting that the out-water endurance exercise training program in this study enabled the improvement of apnea diving performance.

Figure 1. Volume and intensity distribution of the Aerobic Training Program based on the average velocity of a 12-minute Test.



March												April							
5			6			7			8			9			10			11	
Lo			Lo			Re			Lo			Lo			Re			Co	
3			3			3			3			3			3			3	
4x1200 90% re 1:30	6x800 100% re 2:00	1x5000 80%	6x1000 95% re 1:30	6x800 100% re 1:00	1x5000 85%	6x800 100% re 1:30	2x2000 90% re 2:30	1x4000 90%	6x800 100% re 1:30	7x1200 90% re 1:30	2x1600 100% re 3:30	6x1000 100% re 2:30	4x2000 90% re 2:30	2x2400 100% re 4:30	5x800 100% re 1:30	2x2000 95% re 3:30	1x3000 95%	CT	SA & DA
14600			15800			11200			16400			18800			11000			3000	
90%			93%			93%			97%			97%			98%			100%	
Transformation												Realization							

Table 3. Distance of 12-minute test, estimated VO_2max, time in static apnea and distance in dynamic apnea before and after a training session based on the average velocity of a 12-minute test.

	pre test median ± SD	post test median ± SD	t de Student	d de Cohen	ICC
12-minute test distance (m)	2966 ± 154	3179 ± 182	***	1.263	0.83
Estimated VO_2max $mL•Kg^{-1}•min^{-1}$	55.0 ± 3.4	59.7 ± 4.0	***	1.263	0.83
Static apnea time (s)	91.4 ± 35.7	92.3 ± 11.2	ns	0.025	0.44
Dynamic apnea distance (m)	36.2 ± 11.2	40.9 ± 12.3	*	0.404	0.92

$mL•Kg^{-1}•min^{-1}$ (milliliters of oxygen per kilogram of body weight per minute); s (seconds); m (meters); SD (standard deviation); ns (not significant); ICC (intraclass correlation coefficient); * $p < 0.05$; *** $p < 0.001$.

As previously mentioned, most of the research collected has been focused on cardiovascular and hemodynamic changes in static and dynamic apnea[29]. Therefore, the focus of this research is based on the usage of out-water training methods as a companion to the specific training of apnea diving. It is difficult to compare and debate over supplementary intermittent endurance trainings applied to diving practice, since some researchers conducted endurance training that increased aerobic performance with the capacity of static and dynamic apnea. However, the authors could not find information connected to training methods that would increase aerobic performance or VO_2max. In this last case, the evidence is vast and varied[26,27]. Nonetheless, Kapus *et al.*[30] reported that after a one-year intervention there was significant evidence of changes in the diver's capacity to perform maximum static apnea but, due to the fact that the study was a case study, more research was needed to establish the influence of the individual components of apnea training for diving performance.

Only a few studies have reported the increase of static and dynamic apnea performance with a rise in the aerobic performance through intermittent endurance training. Most of the interventions consulted for this research showed hemodynamic and cardiovascular variables[5,6,9], but only a few concluded that static and dynamic apnea can be influenced by other variables. Such is the case of Kjeld *et al.*[31], these researchers evaluated if the ischemic pre-conditioning of the forearm affected static and dynamic apnea under water. The researchers showed evidence that the ischemic pre-conditioning reduced the oxygen saturation of 65 to a 19%. A different study made a correlation between the degree of bradycardia induced by apnea and the degree of vasoconstriction of legs and arms during the dynamic extension of both knees[18]. At the same time, Schiffer *et al*. observed the effects of inorganic nitrate supplementation on the diet over static and dynamic apnea[32]. They concluded that nitrate supplementation reduced oxygen saturation in comparison to the placebo.

Even though the literary review for this article did not include researches connected to out-water treatments for the development of VO_2max, this variable is fundamental to increase the performance in both static and dynamic apnea. That is why the authors have constantly monitored the variables that are directly connected to the VO_2max and their athletic performance[33,34]. There is also a connection to the diver's safety, mainly to the flux of oxygen to the brain in apnea conditions[35-37] or pulmonary edemas post immersion[15].

As evidenced in this research, the out-water treatment together with the diver's apnea training was useful to improve their performance. Likewise, it has been shown that the implementation of field test, such as the 12-minute test, and the determination of the VO_2max[23,24] allowed the design and implementation of personalized exercises based on AV.12-min test.

Finally it is worth mentioning that this research operated only on the VO_2max based on intermittent endurance training. It is suggested to implement extra training to the muscles involved in the respiratory cycles such as the diaphragm[30] and glossopharyngeal insufflations[33]. It is also important to consider a control group for future research. In this study, it was difficult to include a control group since apnea divers population was limited. Furthermore, placing inexperienced subjects under tests of maximum static and dynamic apnea carries risks to their integrity.

Conclusions

The result of the study showed that increasing the aerobic performance generates a rise in the distance of dynamic apnea. For that reason, it is suggested that apnea scuba divers perform out-water trainings based on AV.12-min test as a supplement to their immersion training.

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