



Medium term effects of physical conditioning on breath-hold diving performance



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ABSTRACT

The current study aimed to analyze the effects of physical conditioning inclusion on apnea performance after a 22-week structured apnea training program. Twenty-nine male breath-hold divers participated and were allocated into: (1) cross-training in apnea and physical activity (CT; n = 10); (2) apnea training only (AT; n = 10); and control group (CG; n = 9). Measures were static apnea (STA), dynamic with fins (DYN) and dynamic no fins (DNF) performance, body composition, hemoglobin, vital capacity (VC), maximal aerobic capacity (VO₂max), resting metabolic rate, oxygen saturation, and pulse during a static apnea in dry conditions at baseline and after the intervention. Total performance, referred as POINTS (constructed from the variables STA, DNF and DYN) was used as a global performance variable on apnea indoor diving. +30, +26 vs. +4 average POINTS of difference after-before training for CT, AT and CG respectively were found. After a discriminant analysis, CT appears to be the most appropriate for DNF performance. The post-hoc analysis determined that the CT was the only group in which the difference of means was significant before and after training for the VC ($p < 0.01$) and VO₂max ($p < 0.05$) variables. Inclusion of physical activity in apnea training increased VC and VO₂max in breath hold divers; divers who followed a mixed training, physical training and hypoxic training, achieved increased DNF performance.

1. Introduction

In apnea indoor diving competition, breath-hold divers compete to remain immersed as long as possible in static apnea (STA), and to dive the longest distance in the categories dynamic with fins (DYN) and dynamic no fins (DNF). Adverse effects, such as decompression sickness (Batle, 1999), narcosis or arterial embolism (Batle, 2002), observed during deep events, are not going to occur in the pool practice where the diver submerges barely 2 m; thus, hypoxic syncope is the main risk during apnea indoor practice (Fitz-Clarke, 2006).

Recent improvements in equipment, nutrition, and training have led to increases in apnea performance (Schagatay, 2009, 2010; Fernández, 2015). Practice and training is mainly responsible for performance in breath-hold divers; however, it is difficult to establish a rigid training model that suits all divers with different levels of ability, age, previous physical condition or anthropometry.

The effects of physical activity on apnea performance have not been clarified, probably because the effects of physical training and apnea

training were studied independently. The effects of physical training on apnea performance are controversial. While Bagavad showed in his study (Bagavad, 2014) a correlation between physical conditioning with apnea performance, Schagatay (Schagatay, 2000) did not find effects on apnea performance; however, this latter research concluded that physical training increased stamina, allowing prolongation of the struggle phase of apnea. In addition, a few longitudinal research studies of apnea training have been conducted (Schagatay, 2000; Bagavad, 2014; Fernández, 2015). The current study aimed to analyze the effects of physical conditioning inclusion on apnea performance after a 22-week structured apnea training program.

2. Materials and methods

2.1. Participants

Twenty-nine male breath-hold divers (36 ± 5 years of age) with two years of experience in breath-hold diving were divided in different

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training programs: (I) cross-training in apnea and physical conditioning (CT; $n = 10$); (II) apnea training (AT; $n = 10$); and (III) control group (CG; $n = 9$). No training intervention was carried out on the CG; however, regarding pre-post measurements, both the CG and the experimental groups performed them without any distinction between them. The participants were informed of the benefits and risks prior to signing the informed consent document to participate in the research. Participants diagnosed with cardiac, metabolic or respiratory diseases were excluded. The study was conducted in accordance with the Declaration of Helsinki (Harris and Atkinson, 2011) and approved by the institutional Human Research Ethics Committee (CSEULS-PI-114/2016).

2.2. Training procedures

All participants conducted 66 sessions of 60-minute of duration each. During the first session, CT was performed for 15 min with a dry strength circuit of 10 calisthenic exercises - squat, pull-up, push-up, squat, pull-up, push-up, squat, pull-up, push-up and squat- with 50 repetitions and 10 s of recovery. This was followed by swimming training in crawl, alternating each week between 45 min of swimming continuous training (14 RPE) and high intensive interval training (HIIT) (20 RPE). Regarding HIIT, volume and density were 3 series x 10 repetitions of 25 m with 20 s of recovery. During the second session, participants performed a specific hypoxic training in dynamic, that consisted of 40 repetitions of 25 m dynamic apneas to maximum individual underwater swimming speed with 20 s of recovery each 25 m. In the third session, divers conducted a specific hypoxic training in static. In this training divers performed 3 maximal static apneas with 10 min of full recovery between each apnea.

The AT group, performed a specific hypoxic training in dynamic, on the first and second session, and a specific hypoxic training in static, on the third session. Glossopharyngeal insufflation (Seccombe, 2006) was not allowed during training for any group.

2.3. Test procedures

Measurements were performed under similar environmental conditions in a sports laboratory, a health center and a 25-meter pool with 2-meter depth. The test battery sequence was performed chronologically in five visits in different days, as follows: Visit 1– STA; Visit 2 – DNF; Visit 3– DYN; Visit 4 – body composition, blood count, spirometry and an incremental test on treadmill; Visit 5 – resting metabolic rate, and pulse-oximetry during a static apnea in dry conditions.

2.3.1. STA, DYN and DNF performance

Same protocol was performed, previous to apnea, to avoid possible warming effects. Thus, before STA, a 15-minute warm-up consisted of 10 min of relaxation, two minutes of static apnea and a three-minute countdown on the surface until maximal attempt. Regarding the DYN and DNF, a 15-minute warm-up was performed comprising 10 min of relaxation, 50 m in the specific (fins or no fins) dynamic discipline and a three-minute countdown on the surface. After warm-up, the divers attempted to achieve the maximal individual time or distance. In all the disciplines, during the last 30 s of the countdown, the participant placed the nose clip and performed a maximal inspiration.

2.3.2. Physiological variables

Body fat and fat-free mass were measured by whole-body dual-energy X-ray absorptiometry (GE Lunar Prodigy; GE Healthcare, Madison, Wisconsin). Regarding hematological values, hemoglobin (Hb) and hematocrit were analyzed by a blood count analysis at the health center and under fasting conditions; a portable spirometry test (Spirostik, Geratherm) was performed as well to calculate vital capacity (VC). Before starting the test, we explained the technique to the subject: sitting, with knees bent and feet resting on the floor. In this way, the nasal

clip was placed and the participant would make a relaxed, but maximum inspiration, at the end of which the mouthpiece would be placed; then, he was to perform slow expiration, maintaining a constant flow until residual volume. This procedure was repeated three times, with at least 30 s of rest between each measurement and the highest value of the three measurements was registered (Wanger, 2005).

The incremental test to measure maximal oxygen consumption (VO_{2max}) and maximal heart rate was performed on a treadmill (H/P/COSMOS 3P[®] 4.0, H / P / Cosmos Sports & Medical, Nussdorf-Traunstein, Germany). The volume and composition of expired gases were measured using a gas analyzer (Ultima CPX, Medical Graphics) and the heart rate measured by electrocardiogram (WelchAllyn, CardioPerfect). After a five-minute warm-up at 10 km h^{-1} , the speed was increased 1 km h^{-1} every minute until volitional exhaustion of the participant. Throughout the test the treadmill elevation was maintained at 1%. VO_{2max} was noted as the average of the two highest values of 15 s of VO_2 consecutive reached toward the end of the test, as long as the values of VO_2 and HR have stabilized despite the increase in the intensity of the effort.

Resting metabolic rate was measured, breath-to-breath (Ultima CPX, Medical Graphics), over 15 min by indirect calorimetry. According to a previous study (Melanson et al., 2002), a minimum of 15 min of steady state, determined as $< 10\%$ fluctuation in oxygen consumption and $< 5\%$ fluctuation in respiratory exchange ratio between CO_2 and O_2 , was considered criteria for valid resting metabolic rate (RMR). Participants performed the test in fasting conditions after 12 h without physical effort. The environmental conditions established were as follows: a quiet laboratory with the lights off, 550 m of altitude, $22.5 \pm 1 \text{ }^\circ\text{C}$, with $55 \pm 3\%$ relative humidity.

Heart rate and oxygen saturation were monitored during a maximal static apnea in dry conditions. Before beginning the test, the diver rested for 10 min in the prone position, with head and upper limbs leaning on a table placed in front of the stretcher. During the last 30 s of the countdown, a nose clip was placed to avoid possible air leakage. At that point, the participant performed a maximal exhalation followed by a maximal inspiration; glossopharyngeal insufflation was not allowed. Throughout the static apnea test, the average heart rate (HR_{avg}) and the minimum heart rate (HR_{min}) were recorded. To calculate the HR_{avg} , only the heart rate data after first 30 s were analyzed; i.e., once the heart rate was stabilized (Breskovic, 2012). The oxygen saturation was monitored by a pulse oximeter (CMS 50 F) placed on the second finger of the left hand. A minimal value of oxygen saturation was collected during the test (SpO_{2min}). Time during static apnea in dry conditions (STA_{dry}) was recorded, also.

2.4. Statistical analyses

The effects of training on performance and physiological variables were analyzed using repeated measures analysis of variance (ANOVA). In order to improve the power of the test and to reduce Type I error, a repeated measures multiple analysis of variance (MANOVA) was used in the case of a set of variables defined in a cohesive theme (Tabachnick and Fidell, 2007). Moderate correlations ($r = 0.3$ to 0.7) led to determine the group of variables: STA, DYN and DNF in the case of performance variables, whereas the groups VO_{2max} , Hb and VC (related to the lung storage), percent of body fat (PBF) and lean body mass (LBM) (measuring body composition) and RMR and HR_{avg} (corresponding to the individual metabolic rate) were established with the physiological variables.

A post-hoc analysis was performed when significant differences were detected between the groups. Regarding ANOVA, the specific contrast tests were used, when the homogeneity of the variances was achieved, with Bonferroni correction. When interaction occurs, the effect of one factor on a response depends on the level of (an) other factor (s). Thus, we cannot consider the main effects of the factors separately as the main effects and interaction need to be considered as a whole to

Table 1

Means and standard deviations (SD) of the scores obtained before and after the training interventions as well as the differences between cross training (CT), apnea training (AT) and control group (CG). POINTS variable, used as a performance indicator, is constructed from the variables STA, DNF and DYN. Significant differences between pre- post were marked by * (p < 0.05), ** (p < 0.01) and ^{NS} (no significant differences).

	STA (s)	DNF (m)	DYN (m)	POINTS
CT(n = 10) PRE	185 ± 46	65 ± 14	71 ± 18	100 ± 24
POST	249 ± 43	79 ± 17	90 ± 25	130 ± 29
Dif	63 ± 36**	14.50 ± 14**	19 ± 15**	30 ± 15**
AT (n = 9) PRE	182 ± 46	55 ± 12	65 ± 13	96 ± 19
POST	250 ± 33	64 ± 13	79 ± 13	122 ± 14
Dif	68 ± 35**	9 ± 15*	14 ± 9**	26 ± 17**
CG(n = 10) PRE	152 ± 46	45 ± 10	59 ± 9	82 ± 15
POST	160 ± 56	47 ± 14	57 ± 15	86 ± 23
Dif	8 ± 31 ^{NS}	3 ± 11 ^{NS}	-2 ± 13 ^{NS}	4 ± 15 ^{NS}

describe the relationship between input and output. However, discriminant analysis was used as a post-hoc procedure of the MANOVA, with the objective of determining which dependent variables discriminate between the training programs and analyzing their contributions. The significance level considered in all the developed tests was 0.05.

3. Results

Tables 1 and 2 summarize the mean and standard deviations (SD) of the scores obtained before and after the training interventions as well as the differences between them. (Tables 1 and 2)

3.1. Performance variables

Total performance, referred as POINTS in this work, was used as a global performance variable on a Apnea Indoor diving. It is constructed from the variables STA, DNF and DYN. In particular, each second the athlete remains immersed in STA was multiplied by 0.2, whereas each meter reached at DNF and DYN was multiplied by 0.5. AIDA International – one of the official freediving competition organizing bodies – uses these scores during championships: The diver with the highest score wins the competition. The analysis of variance of repeated measured data for the POINTS variable indicated the effect of the training group (F = 6.270, p < 0.01), time (F = 45.019, p < 0.001) and the interaction between both (F = 7.409, p < 0.01) to be statistically significant. Profile graphs (Fig. 1) show weak discrepancies between CT and AT estimated marginal means. Nevertheless, there are notable differences between control group and both CT and AT estimated marginal means. In Table 1, significant differences between pairs of measures of both time and training group factors were collected

Table 2

Means and standard deviations (SD) of the scores obtained before and after the training interventions as well as the differences between cross training (CT), apnea training (AT) and control group (CG). VO_{2max}, maximum oxygen consumption; VC, vital capacity; Hb, hemoglobin; BFP, body fat percentage; LBM, lean body mass; RMR, resting metabolic rate; STA_{dry}, static apnea time; HR_{avg}, average heart rate during static apnea; HR_{min}, minimum heart rate during static apnea. Significant differences between pre- post were marked by * (p < 0.05), ** (p < 0.01) and ^{NS} (no significant differences).

	VO2 max (ml/kg/min)	VC (L)	Hb (g/dl)	BFP (%)	LBM (%)	RMR (cal*min)	STA _{dry} (s)	HR _{avg} (% HRmax)	HR _{min} (% HRmax)	SpO _{2min} (%)
CT(n = 10) PRE	47 ± 4	5.33 ± 0.72	15.9 ± 1.2	26.2 ± 6.3	70.8 ± 5.9	1.1 ± 0.2	184 ± 45	30 ± 3	24 ± 4	90 ± 5
POST	51 ± 6	5.88 ± 1.13	15.9 ± 1.1	25.4 ± 6.1	71.5 ± 5.7	1.1 ± 0.3	206 ± 34	29 ± 2	21 ± 3	86 ± 7
Dif	4 ± 3*	0.55 ± 0.50**	-0.1 ± 0.5 ^{NS}	-0.8 ± 1.8 ^{NS}	0.8 ± 1.7 ^{NS}	0.0 ± 0.2 ^{NS}	22 ± 21**	-1 ± 4 ^{NS}	-3 ± 3**	-4 ± 8 ^{NS}
AT (n = 9) PRE	47 ± 6	5.90 ± 1.26	15.4 ± 1.2	25.0 ± 7.2	72.0 ± 6.7	1.1 ± 0.2	175 ± 68	31 ± 3	22 ± 3	85 ± 11
POST	47 ± 5	6.01 ± 1.45	15.2 ± 1.0	24.6 ± 7.4	72.3 ± 6.8	1.2 ± 0.2	212 ± 36	32 ± 3	20 ± 1	84 ± 11
Dif	0 ± 4 ^{NS}	0.11 ± 0.45 ^{NS}	-0.3 ± 0.5 ^{NS}	-0.3 ± 0.8 ^{NS}	0.3 ± 0.7 ^{NS}	0.1 ± 0.2 ^{NS}	37 ± 26**	1 ± 2 ^{NS}	-2 ± 2*	-1 ± 9 ^{NS}
CG(n = 10) PRE	53 ± 10	5.20 ± 1.04	15.5 ± 0.8	22.4 ± 7.0	74.4 ± 6.6	1.2 ± 0.2	167 ± 55	31 ± 5	27 ± 3	90 ± 8
POST	50 ± 8	5.27 ± 1.10	15.4 ± 0.8	23.4 ± 7.8	66.4 ± 25.6	1.2 ± 0.3	152 ± 58	31 ± 4	27 ± 2	88 ± 7
Dif	-2 ± 5 ^{NS}	0.07 ± 0.23 ^{NS}	-0.1 ± 0.6 ^{NS}	1.0 ± 4.3 ^{NS}	-8.1 ± 24.2 ^{NS}	0.0 ± 3.6 ^{NS}	-15 ± 4 ^{NS}	0 ± 4 ^{NS}	0 ± 0 ^{NS}	-1 ± 6 ^{NS}

(Fig. 1).

Group linear discriminant analysis identifies a set of linear combinations of dependent variables (LDF) that discriminate groups. After a stepwise regression the variables included in the model were STA2 and DNF2, leaving out DYN2. The number of LDFs is the number of groups minus 1; thus two discriminant functions were necessary to achieve significant discrimination: Function 1 = 0.575·Z_{STA2} + 0.539·Z_{DNF2} and Function 2 = -1.126·Z_{STA2} + 1.144·Z_{DNF2}, where Z_x is the standardized score of the variable X. Both LDFs were statistically significant (p < 0.001 and p < 0.01 respectively). The coefficients of the LDFs are a measure of the importance of each variable for distinguishing groups. Thus, the first function these coefficients indicates that STA2 was more important in distinguishing, while DNF2 had a larger contribution for the second function. The graph in Fig. 2 shows the subjects' scores on the discriminant functions and centroids of each group. We can see from the graph that the centroids are positive in the first function for the groups CT and AT and negative for CG. Therefore, the first function classifies as a control the individuals with the lowest score in the variables STA2 and DNF2, whereas individuals with higher scores would be classified in the CT group and, to a lesser extent, in the AT group. In the second function, we have opposite sign coefficients and similar values for the discriminant variables. Because the centroids that are the most distant are those that correspond to the groups CT and AT, those of opposite sign, the function classifies the participants with greater scores in STA2 and smaller scores in DNF2 within the AT group. In contrast, the participants with a lower score in STA2 and a higher score in DNF2 are classified in the CT group (Fig. 2).

3.2. Physiological variables

The post-hoc analysis determined that the CT group was the only group in which the difference of means was significant before and after training for the VC and VO_{2max} variables. We found a significant increase in VC and VO_{2max} after training (see Table 2). Mean of HR_{min} significantly decrease after training for CT and AT (see Table 2). Analyzing this variable by pairs of training groups, significant differences were found between the control group and the rest of the groups, being the mean of HR_{min} higher in the CG than in the others (see Table 2).

4. Discussion

There is current interest in the role of physical training on apnea performance. Previous research (Schagatay, 2000) analyzed the effects of physical training and apnea training separately. In the current study, after the discriminant analysis, we concluded that training groups can be distinguished in two areas: isolated apnea training appears to be the most suitable for STA, whereas cross-training appears to be best for DNF. Regarding DYN performance, although there were no significant differences between the training groups (AT vs. CT), there was a trend

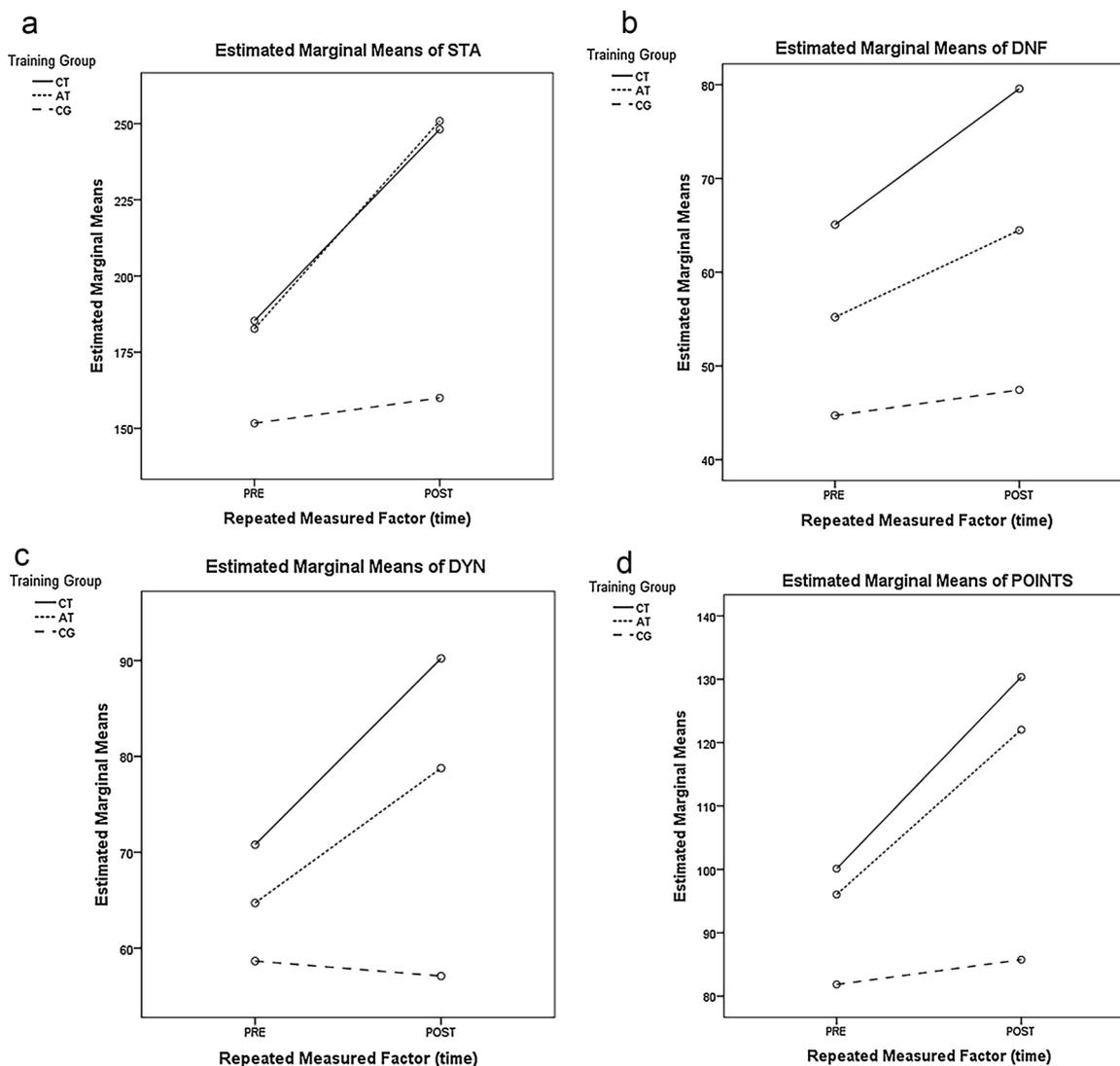


Fig. 1. a–d Profile plots of the static apnea – STA (1a) -, dynamic apnea no fins- DNF (1b) -, dynamic apnea with fins – DYN (1c) – and the global performance indicator–POINTS (1d)-. The estimated marginal means of each performance variable are the mean responses of the performance variable for each combination of level pairs of both factors: training group and time measure.

(favorable to CT).

As hypothesis, the inclusion of physical training could have triggered an improvement in the diver’s underwater swimming economy; however, this variable has not been measured in our study. Another study (Nadel, 1974) proposed that trained swimmers use less oxygen than those not trained to swim at the same speed. Also, a previous review (Schagatay, 2010) concluded that a high proportion of ex-swimmers represent the elite in the apnea dynamic discipline.

According to the correlation shown between physiological variables studied, groups were defined into: lung storage, body composition, metabolic rate, and individual tolerance to asphyxia. The difference in means after training interventions was significant only in the CT group for the VC and VO_{2max} variables.

Maximal aerobic capacity is closely related to performance in endurance sports (Bassett, 2000). Expected benefits, after physical training, would be an increased storage of oxygen before apnea, a decreased heart rate during apnea and increased motivation or stamina. According to the results in this study, the increased aerobic capacity did not result in a lower heart rate during apnea, which is consistent with the findings of Schagatay (Schagatay, 2000). On the other hand, the test for assessing maximum aerobic capacity (incremental test on treadmill) was no specific (swimming); thus, muscular fatigue could produce

limitation on aerobic and anaerobic performance during the incremental test on treadmill.

Physical training resulted in an increased VC; thus, the inclusion of physical activity in the apnea training plan could be considered appropriate for increasing divers’ total O_2/CO_2 lung storage. Glossopharyngeal insufflation was not allowed during training or spirometry test; thus, there was no any improvement or adaptation produced by this breathing technique. Whittaker noted in his study (Whittaker, 2007) that after a specific training consisting of thoracic stretching with glossopharyngeal insufflation divers could increase total lung capacity up to 2 liters. However, the proposed training was insufficient to cause long-term adaptations in hematological values. In addition to hypoxia training, it would be advisable to include hypoventilation training in low lung volume instead of the traditional training in hypercapnia, mentioned in our study. A study conducted in 2010 (Woorons, 2010) showed that hypoventilation training in low lung volume produced both an increase in CO_2 concentrations (hypercapnic effect) and a decrease in O_2 (hypoxic effect) in the blood and muscles.

No tendency was found regarding body composition after training programs, suggesting that AT or CT was insufficient to cause significant long-term changes in body composition. Previous study (Sarang and

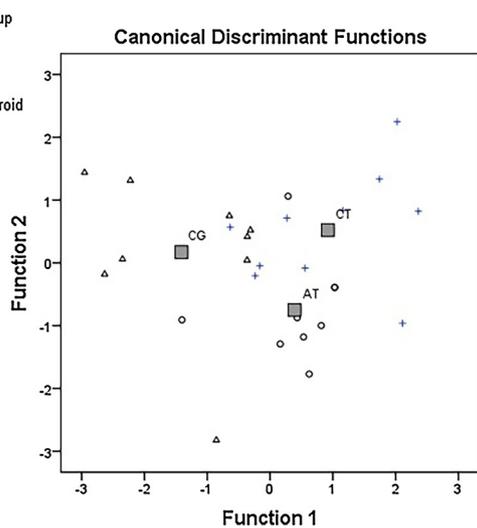


Fig. 2. The graph depicts the subjects' scores on both discriminant functions (Function 1 and Function 2 over X- and Y-axis respectively) as well as centroids of each group. The centroid are calculated by averaging all subjects' scores belonging to the same training group.

Telles, 2006) proposed a decrease greater than 30% in O_2 consumption after the application of relaxation techniques; however, achieving the concentration that enables breath-hold divers to reduce their metabolic rate during apnea requires many hours of deliberate practice and years of experience.

Decreased HR_{min} after AT and CT, compared with the CG, is probably due to a pronounced bradycardia induced by increased hypoxia during the static apnea in dry conditions; i.e., breath-hold divers who followed periodized training achieved greater tolerance to asphyxia and consequently an increase in apnea time. On the other hand, there was no trend for the HR_{min} between experimental groups, suggesting a lack of cardiac adaptation produced by physical exercise proposed. Physical and psychological tolerance to effort have aspects in common during the struggle phase of apnea or physical exertion; thus, a intensive physical training, as performed through HIIT, could trigger an increased tolerance to the asphyxia produced during apnea. According to results showed in our study, oxygen saturation reached during dry static apnea were far from limits, i.e.; hypoxic syncope (50% SO_2 in amateurs and 30% in trained freedivers (Andersson, 2004). In this way, an increase in tolerance to asphyxia in our divers could dilute the effect (on Apnea Indoor performance) of other factors such as: total storage of O_2/CO_2 , metabolic rate or underwater swimming economy. A limitation of the present study was that O_2 consumption and CO_2 release rates were not

calculated during the breath-hold; moreover, there are no data on the partial pressure of O_2 and CO_2 in the alveolar air before the apnea and at the end of the apnea. The availability of these data would provide a more detailed analysis of the identified correlations.

5. Conclusions

The inclusion of physical activity in apnea training increased VC and VO_{2max} in breath hold divers; in addition, divers who followed a mixed training, physical training and hypoxic training, achieved increased DNF performance.

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