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Predictors of Competitive Dynamic Apnea Performance in Elite Free Diving Athletes

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ABSTRACT

This study examined the predictors of the dynamic apnea performance of elite free diving athletes based on their actual championship performances as well as their speed in qualifications and finals. A total of 139 athletes' static apnea, dynamic apnea qualifications, and dynamic apnea finals performances in the 6th and 8th World, and the 3rd and 4th European Apnea Championships were examined in two studies. Study 1 was designed to test the role of static apnea performance in the dynamic apnea performance. In Study 2, the results of the 3rd European Championship were examined in detail to explore the relationship between the dynamic apnea performance and speed of the participants. Static apnea performance significantly predicted the dynamic apnea performance only among female athletes. Among male athletes the only significant predictor of the dynamic apnea final performance was their dynamic apnea qualification performance. Men performed better in static apnea and dynamic apnea finals but there was no sex difference in the dynamic apnea qualification performances. The speed of the athletes' dynamic apnea performance in the qualifications was higher than their speed in the finals. A detailed examination of speed of the participants during qualifications and finals revealed the importance of a balanced duration-distance relationship in competitive free diving. A sex difference obtained in terms of the static apnea–dynamic apnea relationship needs to be examined further to explore the possible goal achievement strategies that the athletes employ during the free diving competitions.

Keywords: Static Apnea, Dynamic Apnea, IElite Athletes, Sex, Speed

INTRODUCTION

Breath-hold or apnea diving, also known as free-diving is an in-water sports activity without self-contained or surface supplied breathing gas i.e. scuba. Free diving has become a popular

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individual sport in recent years. World and European as well as regional championships are organized and athletes from many different areas of the world participate in these competitions. This sport is also frequently on the news and media because of the adverse events, i.e. many athletes injure and some even pass away during the competitions or record trials. Increasing number of people who are interested in this sport join in sub-aqua teams and participate in the training programs. Parallel to its popularity, literature on the performance factors and training alternatives of this sport have been the subject of scientific inquiry in recent years. Two major organizations, The World Underwater Federation [CMAS, Confédération Mondiale des Activités Subaquatiques] and International Association for Development of Apnea [AIDA, Association Internationale pour le Développement de l'Apnée] govern and organize free diving competitions, promote scientific research and provide training.

There are currently several disciplines of apnea in CMAS all of which can be performed by both men and women. CMAS grouped these disciplines under two categories; pool disciplines and depth disciplines. Among these disciplines, static apnea involves resting and immersed breath-hold in controlled water, which is generally a shallow swimming pool. In dynamic apnea, on the other hand, athletes swim horizontally underwater in a swimming pool with the aim of covering the longest possible distance without any time limitation.

When the existing literature about the performance of free diving athletes was researched, a few empirical studies were found. Among these Jamin and colleagues examined the time estimation performance of free divers in relation to the athletes' heart rate during the apnea (Jamin et al., 2004a; Jamin et al., 2004b). Other studies focused on other physiological variables involved in static or dynamic apnea such as cardiovascular response and heart rate variability (Caspers, Cleveland & Schipke, 2011; Costalat, Pichon, Joulia & Lemaitre, 2015; Ferrigno et al., 1997; Foster & Sheel, 2005; Heusser at al., 2009; Joulia et al., 2002; Lemaitre et al., 2005; Lindholm, Nordh & Gennser, 2006); respiratory changes including oxygen level and saturation (Andersson & Evaggelidis, 2009; Andersson, Liner, Fredsted, & Schagatay, 2004; Andersson, Linér, Rünow & Schagatay, 2002) and heart rate changes (Caspers, Cleveland & Schipke, 2011; Costalat et al., 2015; Ferrigno et al., 1997).

This study reveals important insight about the competitive free diving performance. First, apnea performance involving depth, distance, and duration has been improving with the help of developing training methods, diving strategies, and dissemination of knowledge among the athletes (Pollock, 2008; Schagatay, 2009). Second, static apnea performance (duration) is a prerequisite for all other disciples of free diving and is determined by physiological capacity of an individual athlete. These physiological factors are total body gas storage in lungs, blood and tissues, tolerance to asphyxia, and metabolic rate (Schagatay, 2009). In terms of dynamic apnea, it was stated that, dynamic apnea with fins and without fins has different energy requirements, while in both disciplines the duration performances are similar; in dynamic apnea with fins, the distance performances are 15-25% longer. As well as the physiological factors being effective in static apnea, in dynamic apnea, other mechanisms are also involved because of the physical activity (swimming). One of the key issues here is balancing the speed and restricted energy during the performance. The spleen and lung volumes, and apnea performance in elite divers was also found to be positively correlated (Schagatay, Richardson & Lodin-Sundström, 2012).

As well as the physiological and training factors, psychological effects of training may also help to improve the performance of free diving athletes via improved tolerance and better coping with the respiratory distress, urge to breathe, and capacity to focus on the performance (Schagatay, 2010). In a relevant study where the psychological characteristics of free-diving athletes were compared with non-athletes, it was found that free diving athletes have less stress and anxiety levels, use more problem focused coping strategies, and have a balanced locus of control beliefs, all of which are positive psychological attributes that might affect their performance (Alkan & Akış, 2013).

With respect to the predictors of dynamic apnea performance, Schagatay presented a model depicting the related factors (see Figure 10 in Schagatay, 2010, p. 19 for all of the predicting factors). In the proposed model, as well as physiological variables that were summarized above, she presented a direct effect of static apnea duration on dynamic apnea performance (distance). It was concluded that "A successful diver in the dynamic apnea disciplines is likely to possess superior swimming skills and excellent work economy, balancing speed and restricted energy expenditure to achieve maximum distance within the limits set by maximized gas storage capacity and the tolerance of the brain to asphyxia" (Schagatay, 2010, p. 20).

Unfortunately, the empirical studies that examine the performance of free diving athletes focus largely on physiological and training factors. Furthermore, the numbers

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of participants in these studies were limited -varied between 11 and 38- making it difficult to make clearly generalizable conclusions.

Grounding on the findings of the dynamic apnea studies, the current study aims to examine the dynamic apnea final performance of elite free diving athletes in terms of their static apnea performance and dynamic apnea qualification performance with a large sample of participants as well as for exploring the pattern of speed and duration in dynamic apnea performances. In so doing, this research contributes to the free diving literature by providing real-life data with statistically driven results. Based on the available literature about the predictors of the dynamic apnea performance, we hypothesize that “Static apnea performance of elite free diving athletes predicts their dynamic apnea performance both in the qualifications and the finals”. Besides testing this hypothesis we explored the pattern of relationship between the speed and the dynamic apnea performance of elite free diving athletes. To this end, this research has examined the dynamic apnea (with fins) performances of the elite divers during qualifications and finals in four international championships. These are the 6th and 8th World, and the 3rd and 4th European Apnea Championships organized by CMAS.

According to Dynamic Apnea International Rules of CMAS (see CMAS, 2015 for the complete booklet), before the dynamic apnea final performance (competition) all athletes compete in qualifications. Eight female and eight male athletes, who ranked in top 8, compete in the dynamic apnea finals. Since static apnea performance is not an official requirement for dynamic apnea performance but an independent brench in competitions, as well as dynamic apnea qualifications and finals, some athletes can also compete in static apnea.

In the current paper, the findings of two studies were reported. In Study 1, the 6th and 8th World, and the 3rd and 4th European Apnea Championship results (static apnea, dynamic apnea qualifications and dynamic apnea finals performances) were examined to test the hypothesis of the study i.e., the role of static apnea performance on dynamic apnea qualification and final performance. In Study 2, the results of the 3rd European Championship were examined in detail, so as to explore the research question of the study by examining the duration of the dynamic apnea performances and speed of the participants in the qualifications and the finals.

Method

Data Analysis Strategy

Both between and within-participants designs were employed. Apnea performances across championships and sex were compared by one-way ANOVA. Athletes’ dynamic apnea qualification and final performances were compared by within-participants-repeated measures ANOVA. Hypothesis of the study was tested by hierarchical multiple regression analysis. In the within participants and hierarchical regression analyses, only the athletes who performed all three apneas; static apnea, dynamic apnea in qualifications and dynamic apnea in finals were included. Levene's test for homogeneity was employed for ensuring the equality of the samples. Before regression analysis, variance inflation factors (VIF) (Kutner, Nachtsheim, & Neter, 2004) and Box’s M test (Tabachnick & Fidell, 2007) were employed to ensure the suitability of the data for the analyses. Bonferroni Correction was applied to univariate tests. The number of the participants included in the analyses varied depending on the type of the analysis used in this research. In each of the analysis, the number of participants (n) was provided. Data were analyzed by using SPSS software.

Study 1

Participants

One hundred and thirty nine elite free-diving apnea athletes who competed in four international championships; the 3rd and, 4th European, the 6th and 8th World Apnea Championships constituted the participants of this study. The athletes’ static apnea, dynamic apnea qualification, and dynamic apnea final performances which were obtained from CMAS’s web page (www.cmas.org) were used in data analysis. Seventy five of the participants were female and sixty four of them were male. The participants were from 17 countries (Algeria, Argentina, Austria, Belgium, Check Republic, Croatia, Ecuador, France, Greece, Italy, Mexico, Morocco, Russia, Serbia, Spain, Turkey, and Venezuela).

Variables used in Study 1

The following three variables were used in the analyses. Static apnea performance (SAP): the total duration of immersed apnea in seconds; dynamic apnea qualification performance (DAQP): the total distance recorded during the qualifications

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in meters; dynamic apnea final performance (DAFP): the total distance recorded during the finals in meters.

Results of Study 1

Means and standard deviations of three apnea performances by sex and championship are presented in Table 1.

Table 1: Means and Standard Deviations of the Apnea Performances of the Athletes across Four Championships.

Championship		SAP (S)			DAQP (M)			DAFP (M)		
		Female	Male	Total	Female	Male	Total	Female	Male	Total
3rd European	*M*	315.67	358.32	341.81	158.20	156.43	157.10	187.51	221.60	204.56
	n	12	19	31	14	23	37	7	7	14
	SD	*45.41*	*111.32*	*92.94*	*28.26*	*71.64*	*58.53*	*26.31*	*11.93*	*26.42*
4th European	*M*	328.38	469.78	403.24	176.79	183.36	181.09	193.84	223.66	208.75
	n	8	9	17	9	17	26	8	8	16
	SD	*85.82*	*82.69*	*109.24*	*21.11*	*52.99*	*44.16*	*34.57*	*66.70*	*53.58*
6th World	*M*	304.17	353.21	334.22	151.52	178.51	166.05	187.35	221.04	202.89
	n	12	19	31	18	21	39	7	6	13
	SD	*61.51*	*102.34*	*90.89*	*41.41*	*30.29*	*37.90*	*15.68*	*15.35*	*22.95*
8th World	*M*	321.30	365.69	346.39	147.35	177.58	163.36	200.50	216.07	208.28
	n	10	13	23	16	18	34	8	8	16
	SD	*108.37*	*84.68*	*96.03*	*51.24*	*59.75*	*57.16*	*28.44*	*48.96*	*39.51*
Total	*M*	316.14	375.02	350.77	155.98	172.92	165.82	192.62	220.53	206.34
	n	42	60	102	57	79	136	30	29	59
	SD	*74.04*	*104.85*	*97.44*	*39.64*	*56.16*	*50.44*	*26.62*	*42.34*	*37.65*

Note. SAP (S) =Static apnea performance in seconds, DAQP(M)= Dynamic apnea qualification performance in meters, DAFP(M) = Dynamic apnea final performance in meters.

In order to test the difference in the participants' performance across championships, one-way ANOVA was conducted. The results indicated no significant difference in the SAP, $F(3, 98) = 2.11$, $p = .104$, DAQP $F(3, 132) = 1.20$, $p = .314$, or DAFP $F(3, 55) = .08$, $p = .97$ across championship. One-way ANOVA revealed a significant difference between males and females in SAP, $F(1, 100) = 9.81$, $p = .002$ and DAFP results $F(1, 57) = 9.25$, $p = .004$. However, men and women did not differ in their DAQP $F(1, 134) = 3.80$, $p = .053$.

In order to test the difference in the two dynamic apnea performances by sex, 2 x 2 within-participants repeated-measures ANOVA (Performance type: DAQP and DAFP x Male and Female) was conducted. The analysis revealed a significant main effect of sex, $F(1, 27) = 239.47$, $p = .00$, but not a performance type, or interaction effect. Follow-up comparisons showed that female athletes' DAQP (M = 180.81, SE = 1.95, 95% CI = 176.81- 184.81) and DAFP (M = 185.99, SE = 4.34, 95% CI = 177.08- 194.89) were significantly shorter than male athletes' DAQP (M = 218.17, SE =2.03) and DAFPs (M = 223.05, SE = 7.72).

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Because of the sensitivity of the correlation and regression analysis to the variance differences, to examine the possible differences of variance covariance matrices between male and female athletes, Box's M test was conducted (Tabachnick & Fidell, 2007). Box's M was significant with M = 9.55, F (3, 608297.7) = 3.06, p = .03. Consequently, a correlation analysis and the regression analysis which was conducted to explore the predictors of the final performance were run separately for male and female athletes.

Hierarchical multiple regression analyses predicting the dynamic apnea final performance

In both of the regression analyses, the dynamic apnea final performance (DAFP) was the dependent variable. The predictor variables were the static apnea (SAP) and dynamic apnea qualification performances (DAQP). Before regression analysis, the bivariate correlation analyses between the variables were conducted. The variables moderately correlated with each other and coefficients varied between .04 and .58. The bivariate correlation matrix of the variables used in the analyses is available upon request. The results of the regression analyses, ΔR^2 and β's are presented in Table 2.

Table 2: Hierarchical Multiple Regression Analyses Predicting the Dynamic Apnea Performance in the Competitions.

	Female			**Male**		
Predictor	ΔR^2	β	*t*	ΔR^2	β	*t*
Step 1	**.29**			.00		
Static apnea performance (SAP)		.44	2.39*		.06	-.31
Step 2	**.22**			**.35***		
Dynamic apnea qualification performance (DAQP)		.48	2.56*		.60	2.90*
n	18			19		
Total *R*²	.51			.35		

Note. *p < .05

The hierarchical multiple regression analyses showed that the hypothesized model was significant. However, there was a difference between male and female athletes in terms of the significant predictors of the dynamic apnea final performance. In men, both static apnea and dynamic apnea qualification performances significantly predicted the dynamic apnea final performance. Two variables accounted for approximately 50% of dynamic apnea final performance. In women, on the other hand, two variables accounted for the 35% of the total variance and only dynamic apnea qualification performance was the significant predictor. When the correlation coefficient of study variables were taken into consideration, due to a moderate correlation between SAP and DAQP (.17) in male athletes, a moderation analysis was conducted by applying hierarchical multiple regression analysis. When SAP x DAQP product was entered in the third step of regression analyses, the interaction variable was not significant in predicting DAFP neither in men, t = 1.18, p = .25, β = 1.45 with .05 ΔR^2; nor in women, t = .51, p = .62, β = .44 with .009 ΔR^2.

Study 2

Participants

Forty elite free-diving athletes who took part in the 3rd CMAS European Apnea Championship in 2012 in Antalya, Turkey, constituted the participants of the study. Seventeen of the athletes were female and 23 of them were male. The participants were from 9 different countries (Austria, Croatia, France, Greece, Italy, Russia, Serbia, Spain, and Turkey). No additional information regarding the participants was obtained.

Procedure

The authors used the official results of the 3rd CMAS European Championship Static Apnea Final Results, Dynamic Apnea Qualification Results, and Dynamic Apnea Final Results, which were announced at CMAS's web page (www.cmas.org). In addition to these data, the authors obtained the video recordings of the performances, which were recorded

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individually for each of the participants during the dynamic apnea qualifications and the finals. The authors of the current study watched the videos independently and recorded the durations of the performances in seconds.

Variables used in Study 2

In addition to three variables used in Study 1, namely, static apnea performance (SAP), dynamic apnea qualification performance (DAQP), and dynamic apnea final performance (DAFP), the following variables were used in Study 2. Dynamic apnea qualification duration (DAQD): the duration of the apnea performance during qualifications in seconds; Dynamic apnea final duration (DAFD): the duration of the apnea performance during finals in seconds; Speed of the participants in qualifications: a derived variable obtained as time/distance ratio; Speed of the participants in finals: a derived variable obtained as time/distance ratio.

Results of Study 2

In order to test the difference in the duration and distance across qualification and final performances, 2 x 2 within-participants repeated measures ANOVA with sex being a between-subject variable (Dynamic apnea qualification performance and Dynamic apnea final performance X Dynamic apnea qualification duration and Dynamic apnea final duration) was conducted. The results indicated a significant main effect of duration, $F(1, 13) = 26.88$, $p = .00$, $\mu^2=.67$, main effect of performance, $F(1, 13) = 16.03$, $p = .002$, $\mu^2=.55$ and interaction, $F(1, 13) = 26.04$, $p = .00$, $\mu^2 = .66$. Neither performance-sex $F(1, 13) = .52$, $p = .49$, $\mu^2 = .04$; nor duration-sex interaction $F(1, 13)=1.04$, $p = .33$, $\mu^2 = .08$ was significant. The pairwise comparisons showed that the estimated marginal means of the duration in the qualifications (M = 165.93, SE = 9.39) was significantly shorter than the duration in the finals (M = 200.40, SE = 6.02). Similarly, performance in the qualifications was shorter (M = 175.87, SE = 7.16) than the performance in the finals (M = 190.46, SE = 7.60).

When the bivariate correlation coefficients of the variables were examined, it was seen that dynamic apnea final duration was significantly correlated with all other variables. When the correlation coefficients between the independent variables were examined, it was seen that although all predictor variables except speed were correlated with each other, none of the coefficients exceeds .85, which indicates the suitability of the data for multiple regression analysis. Therefore, the speed of the participants in dynamic apnea qualifications and finals were not included in the regression analysis. The bivariate correlation coefficients matrix of the variables is available upon request from the authors.

In order to rule out the possible multicollinearity problem which may arise due to small sample size, the variance inflation factors (VIF) were also calculated (Kutner, Nachtsheim, & Neter, 2004). The VIF values for the study variables; DAQD, DAQP, DAFD and SAP were 1.00, 2.56, 7.36, and 2.18, respectively and ensured the absence of multicollinearity. To examine the possible differences of variance covariance matrices between male and female athletes, Box's M test was conducted (Tabachnick & Fidell, 2007). Box's M was non-significant with M = 18.719, F (10, 688.446) = 1.17, p = .31. Consequently, data were collapsed across sex. Due to the significant sex difference in terms of apnea performances, in the hierarchical multiple regression analysis, the sex was added in the equation as a dummy variable (male = 0, female = 1). The results of the regression analyses, ΔR^2 and β's are presented in Table 3.

Table 3: Hierarchical Regression Analyses Predicting the Dynamic Apnea Performance in the Finals.

Predictor	**ΔR^2**	**β**	***t***
Step 1	**.44***		
Dynamic apnea qualification duration (DAQD)		-.73*	-3.44
Step 2	**.33***		
Dynamic apnea qualification performance (DAQP)		.92*	3.36
Step 3	**.17***		
Dynamic apnea final duration (DAFD)		.53**	4.14
Step 4	**.00**		
Static apnea performance (SAP)		-.04	-.20
Step 5	**.06***		
Sex (dummy)		1.27*	5.23
Total R^2	**.97***		

Note. **p < .005. *p < .05.

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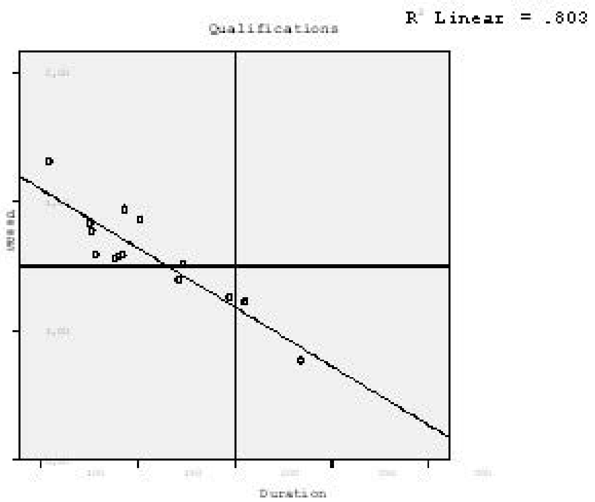
The results of the regression analysis indicated that five variables accounted for the 97% of the total variance in the dependent variable. While three study variables: Dynamic apnea qualification duration (.44), Dynamic apnea qualification distance (.33) and Dynamic apnea final duration (.17) were significant in predicting the dynamic apnea final distance, Static apnea performance (.01) was not a significant predictor. Sex, on the other hand, was a significant predictor variable (.06).

Although the speed of the participants during both qualifications and finals were calculated, since they are derived variables (distance/duration), they were not used in the multiple regression analysis. However, as it can be of relevance in terms of the final apnea performance, they were examined across two conditions and by sex. A paired sample t-test result showed that the speed during the qualifications was significantly higher ($M = 1.29$, SD = .18) than the speed in the finals ($M = 1.17$, $SD = .15$), $t(1, 13) = 5.60$, $p = .00$). One-way ANOVA results did not reveal any sex difference of the speed neither in the qualifications $F(1, 29) = .128$, $p = .723$, nor in the finals $F(1, 13) = 1.404$, $p = .259$.

In order to better depict the nature of the difference of speed in the qualifications and the finals, the scatterplots of the speed and the duration are presented in Figure 1. As the figure indicates, the relationship between the speed of the participants and the total duration of the performance during the qualifications was stronger. Although a similar linear trend was also seen and statistically significant during the finals, the strength of the relationship was not as high as it is observed in the qualifications; $R^2 = .47$ and .80, respectively.

a)



b)

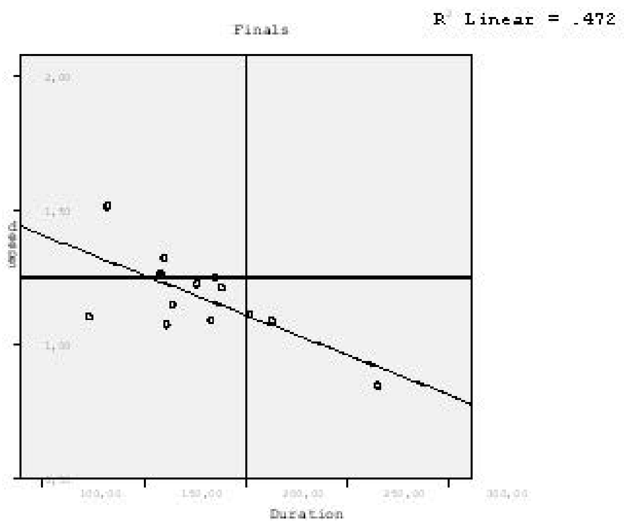


Figure: Scatterplot of the relationship between speed and the durations of athletes during (a) qualifications (b) finals.

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DISCUSSION

The aims of the present study were to examine the predictors of the dynamic apnea performance of elite free diving athletes based on their actual championship performances. Furthermore, this research examined the pattern of relationship between duration of the dynamic apnea performances and speed of the participants in the qualifications and the finals. Our hypothesis was partially supported by the current data. In Study 1, we found out that static apnea performance of elite female athletes was a significant predictor of dynamic apnea final performance. In the male athletes, on the other hand, dynamic apnea qualification performance was a significant predictor of final performance. Study 2 confirmed Study 1; static apnea performance of the athletes was not a significant predictor of their dynamic apnea performances.

Besides determining the role of static apnea on dynamic apnea performances, this research produced some important information about elite free diving athletes' dynamic apnea performances. In both Study 1 and Study 2, cross-sectional analyses revealed that female athletes' static apnea and dynamic apnea final performance scores were significantly smaller than that of male athletes. Their dynamic apnea qualification performances, on the other hand, was not different from the male athletes. This finding, together with the results obtained from multiple regression analysis, suggests that men and women might utilize different strategies during dynamic apnea qualifications. Although we did not examine in the current study, one possible explanation of these findings is the possible sex difference in performance goals and achievement motivations of the participants (Duda, 2005). Although the performance goal and achievement motivation literature suggest inconsistent results in terms of sex difference in achievement goal orientation (Hanrahan & Cerin, 2008), due to the nature of dynamic apnea qualifications, such a difference might be observed among free diving athletes. Because there is no published research regarding the achievement goal orientations of free diving athletes, it is not possible to compare our findings with others.

In a related vein, it can also be argued that perceived competence of the athletes may also contribute to the possible strategy difference between males and females. It is known that high perceived competence orients individuals to possibility of success and facilitates endorsement of approach goals, low perceived competence orients individuals to possibility of failure and to facilitate the adoption of avoidance goals (Elliot & McGregor, 2001).

In the current study, it is possible that depending on their performance in the qualifications, men and women might have experienced different mood states (Bar-Haim et al., 2007; Beedie, Terry, & Lane, 2000), adopted different coping strategies (Hoar et al., 2006) and achievement goals leading in significant sex difference in the final performance.

The final contribution of this study to the existing competitive apnea literature is the detailed exploration of the speed in the qualifications and finals. We found that that the relationship between participants' speed and duration of the performance in the qualifications were stronger showing that the participants who swam faster also stayed longer under the water. In the finals, although the final dynamic apnea performance of the participants was better as compared to the qualifications, their speed was not as high as in the qualifications. This finding strengthen our suggestion that, during the finals, athletes adopted different strategies such as balancing their speed according to the total distance they perform. In other words, they optimized their speed in order to perform better in the finals.

LIMITATIONS AND FUTURE DIRECTIONS

This study utilized data of four international competitive apnea championships' official results. No additional information regarding the participants was obtained. The role of other factors such as the average training of the athletes and the number of years in this sport need to be included in future studies regarding the predictors of dynamic apnea performance. Future studies also need to be designed in order to unfold the sources of the performance difference between male and female athletes. These might include the examination and comparison of performance goals and strategies of the elite free diving athletes.

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