UNDERSEA & HYPERBARIC MEDICINE

Higher proportion of prematurely born adults in elite breath-hold divers

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ABSTRACT

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Introduction: Preterm birth may significantly impair the functional and anatomical development of the respiratory system and could be a background for various life-long medical sequelae. Prematurity has been recently connected to changes in hypercapnic reactions at adult age. Altered reactions to pCO_2 in premature-born subjects may impact breath-hold underwater exercises (freediving) results.

Methods: AIDA International provided the list of top-100 rankings freediving athletes for the years 2016-2021 with their personal best results. Data was collected using a subject questionnaire developed for the study (subject-reporting outcomes).

Period of data collection: March 2022 to June 2022.

Results: Within the sample of divers (n=146), 17.1% (n=25) were born prematurely. 13.7% (n=20) were moderate to late preterm, and 3.4% (n=6) were very preterm. The proportion of the athletes whose birth was premature was 18.1% for females and 16.2% for males. These figures are higher than the standardized estimated mean of the preterm birth rate of 8.5% calculated based on the geographical distribution of our sample. There was no difference in best personal results in freediving between the preterm and full-term elite freedivers.

Conclusions: The proportion of preterm within the elite freedivers is higher than could be estimated for the general population. There is no difference in best personal results between preterm and full-term elite freedivers.

Keywords: apnea; extreme environments; hypercapnia; lung function; physiology; prematurity.

INTRODUCTION

Preterm birth, defined as birth occurring before the 37th week of gestation [1], could significantly impair functional and anatomical development of the respiratory system and result in various life-long medical sequelae. Reduced resting pulmonary functions have been described in adults and children who were born prematurely [2].

Prematurity is connected to changes in hypercapnic reactions at adult age [3]. In particular, modulated ventilatory responsiveness to hypoxia and hypercapnia has been observed in this population [4].

Abnormal alveologenesis and pulmonary vasculogenesis likely contribute to a decrease in the resting lung diffusion capacity of carbon monoxide [5,6]. Whether preterm birth per se causes these effects remains unclear [4].

Supplemental oxygen is commonly applied in neonatal intensive care during premature birth management. New data suggested hyperoxia-induced alterations in the ventilatory response to hypoxia, likely due to failure in peripheral chemoreceptor development that persists with maturation but can be modulated by physical exercise [7]. Thus, prematurity impacts the physiological pathways of respiration regulation, and this effect likely persists throughout life.

Breath-hold (BH) diving relies on divers' ability to hold their breath until resurfacing. Substantial changes in intrapulmonary gas volume and pressure challenge the pulmonary system of the freedivers. While arterial pCO_2 increases during apnea, involuntary thorax and diaphragm contractions become unavoidable [8].

Increasing arterial pCO_2 could be a more significant limitation factor for freediving performance than hypoxia. Additionally, diaphragmatic and intercostal muscle spasms can induce the cessation of apne [9]. Altered reactions to pCO_2 in premature-born subjects may impact the results in breath-hold underwater exercises [3].

METHODS

Ethical And Official Aspects

No physiological/ medical examinations/ manipulations/ treatment(s) were planned. All experimental procedures for diving research were approved by the Human Sciences Ethics Committee, the Legal and Ethics Office, Vrije Universiteit Brussel (V.U.B.), Pleinlaan 2 - 1050 Brussel - Belgium (reference #B200-2020-088).

The study was conducted in accordance with the current revision of the Declaration of Helsinki, World Medical Association [16]. The informed consent to manage the personal data was obtained from the study subjects. The processing of personal data in the project was carried out in accordance with international laws regarding personal data protection. Transfer of the personal data to the Environmental, Occupational, Ageing (Integrative) Physiology Laboratory (ISEK) was carried out in an impersonal form, AIDA International depersonalization the personal data.

Study Design

Non-interventional study in routine settings (survey).

Research Question

Does the prevalence of prematurity (born before 38 weeks of pregnancy) in elite freedivers differ from the general population?

Study Objectives

Primary: To assess the proportion of subjects born before 38 weeks of pregnancy in a population of elite freedivers.

Secondary: (1) To assess the proportion of subjects born before 28 weeks of pregnancy (extremely preterm), weeks 28-32 (very preterm), and weeks 33-37 of pregnancy (moderate to late preterm).1 (2) To assess the best personal results of full-term and preterm elite freedivers in main freediving disciplines (STA, DNF, DYN-DYNB, CNF, FIM, CWT-CWTB).

(STA = static apnea; DYN = dynamic apnea with fins; DYNB = dynamic apnea with bi-fins; DNF = dynamic apnea without fins; CNF = depth, constant weight without fins; FIM = depth, free immersion CWT = depth, constant weight with fins; CWTB = depth, constant weight with bi-fins).

Selection Of Study Subjects

Inclusion criteria: (1) Subjects from overall years 2016-2021 top-100 world ranking (Association Internationnale pour le Développement de l'Apnée, AIDA International) for any of the following freediving disciplines: STA, DNF, DYN-DYNB, CNF, FIM, CWT-CWTB. (2) Male and female athletes. (3) Signed informed consent on the processing of personal data.

Non-inclusion criteria: (1) Inability to obtain the reliable historical information necessary to complete the study questionnaire.

Number Of Subjects and Sample Size

This study is exploratory and non-comparative. The sample size was based on an assessment of feasibility (estimated number of target population - number of elite athletes presented in the AIDA database) rather than on statistical assumptions. The main limitation for assessing the sample size was the unknown magnitude of the influence of gestational age on breath-hold.

VARIABLES

Primary: Gestational age at birth (weeks).

Secondary: Personal best results in following freediving disciplines: STA (sec), DNF (m), DYN-DYNB (m), CNF (m), FIM (m), CWT-CWTB (m), according to worldwide ranking, AIDA International.

Characteristics of the population: Sex (male, female). Cesarean delivery (yes, no). Anthropometric data at birth (height, weight).

Medical history: Respiratory diseases in childhood and adolescence (before 18 years old), required continuous medical care and/or multiple hospitalizations (yes, no). Respiratory disease after 18 years old, required continuous medical care and/or multiple hospitalizations (yes, no). Other chronic diseases in childhood and adolescence (before 18 years old), required continuous medical care and/or multiple hospitalizations (yes, no). Other chronic diseases after 18 years old, required continuous medical care and/or multiple hospitalizations (yes, no).

See Attachment 1: The Questionnaire (Survey).

Data Collection

AIDA International provided the list of top-100 rankings athletes for the years 2016-2021 with personal best results.

Data was collected using a questionnaire developed for the study (Subject-reporting Outcomes), Attachment 1. Period of data collection: from March 2022 to June 2022.

The athletes were approached via e-mail or social media with the proposal to participate in the study. They were not informed about the purpose of the survey to avoid selection bias (if a higher proportion of prematurely born participants consent to participate). The athletes who agreed to participate in the survey were provided with the Questionnaire (Attachment 1) and the informed consent form.

The data about prematurity in the general population were obtained from the open sources.

Statistics

Eligibility. All subjects matching the selection criteria and having the following data: age, sex, and gestational age at birth, were included in the analysis.

Statistical analysis. Continuous data (height, weight, best personal results) are presented with the number of observations, mean, and standard deviation (M (SD)).

Discrete data (preterm birth rate, the proportion of subjects who required Cesarean delivery, and the proportion of subjects with relevant medical conditions in history) are presented with numbers and relative frequencies (percentage). When appropriate, the confidence interval of 95% (CI95%) is provided to present a range of estimates for an unknown parameter. Preterm prevalence in the study population also presented for different gestation periods (moderate to late preterm, very preterm, and extremely preterm).

A standardized estimated mean preterm birth rate based on the data calculated from Blencowe et al.10 This standardized estimated mean preterm birth rate represents the preterm birth rate that would have been expected in the study population considering the region of birth repartition in the sample.

Best personal results in different disciplines were compared between preterm and full-term athletes. The normality of distributions was assessed by the Shapiro–Wilk test for each variable (STA, DNF, DYN-DYNB, CNF, FIM, CWT-CWTB) as per gender and gestation status. If the data set did not follow the normal distribution, it was analyzed with the Wilcoxon rank-sum test. If the data set was parametrical, the homoscedasticity was assessed using the variance ratio with a threshold of 4. If the data were homoscedastic, we used the standard t-test. If the data were not homoscedastic, we used the Welch's t-test for unequal variances.

The alpha error was set at 0.05 for all statistical tests.

RESULTS

Disposition of Study Subjects

A total of 577 athletes were presented in the list of top-100 rankings for the years 2016-2021 (many athletes presented in more than one discipline). All (n=577) athletes were contacted via e-mail or social media with the proposal to participate in the study. There were 166 positive responses obtained. Each (n=166) signed the informed consent form and was provided with the questionnaire. Twenty athletes who initially agreed to participate did not return the completed questionnaire within the data collection period. One hundred forty-six completed questionnaires were returned , and all of them (n=146) were considered eligible for the analysis.

Characteristics of the Population

The data from 146 study subjects (females n=72, males n=74) were analyzed for the purposes of this study. 9.0% (n=13) were born by Cesarean section: 8.3% females (n=6) and 9.5% males (n=7). Mean height at birth in total population was 51.0 (3.1) cm (females 50.7 (3.2) cm, males 51.4 (3.0) cm). The mean weight at birth in the total population was 3344 (688) g (females 3227 (528) g, males 3456 (800) g).

Primary Variable

Gestational age at birth. Within the sample of divers (n=146), 17.1% (n=25) were born prematurely. 13.7% (n=20) were moderate to late preterm, and 3.4% (n=6) were very preterm. The proportion of the athletes whose birth was premature was 18.1% for females and 16.2% for males (Table 1).

	N	n	Prevalence, % (CI95)
Prematurity, total population	146	25	17.1 (16.4-17.9)
Females	72	13	18.1 (17.3-18.8)
Males	74	12	16.2 (15.5-16.9)
Severity of prematurity			
Moderate to late (w33-37)	146	20	13.7 (13.0-14.4)
Very preterm (w28-32)	146	5	3.4 (3.1-3.8)
Extremely preterm (w<28)	146	0	-

Table 1. Prematurity Prevalence among breath-hold divers.

Secondary Variables

Freediving performance. There is no difference in best personal results between preterm and full-term elite freedivers in all freediving disciplines (Table 2).

Medical History

In the total population (n=146), 15.1% suffered from respiratory diseases that required continuous medical care and/or multiple hospitalizations in childhood and adolescence (before 18 years old), and 9.6% - after 18 years old. Other chronic diseases that required continuous medical care and/or multiple hospitalizations in childhood and adolescence (before 18 years old) occurred in 8.2% and in 10% after 18 years old.

	Preterm		Term			
	n	Mean (SD)	n	Mean (SD)	P-value	
Female	13	59				
Static						
STA (s)	11	345 (19.8)	50	334 (56.1)	0.26	◊
Distance						
DYN (m)	11	149 (33.1)	46	166 (33.0)	0.12	
DYNB (m)	8	147 (23.4)	28	153 (30.4)	0.61	
DNF (m)	9	124 (22.2)	50	122 (27.4)	0.87	
Depth						
CNF (m)	5	38 (7.6)	30	42 (12.3)	0.61	✦
CWT(m)	9	66 (22.0)	29	67 (18.6)	0.86	
CWTB (m)	6	60 (17.7)	23	63 (15.3)	0.78	
FIM (m)	9	64 (15.7)	35	57 (17.9)	0.29	
Male	12		62			
Static						
STA (s)	8	407 (103.1)	50	415 (92.6)	0.84	
Distance						
DYN (m)	8	189 (25.0)	44	200 (45.9)	0.34	◊
DYNB (m)	7	167 (31.3)	25	192 (44.4)	0.28	✦
DNF (m)	6	148 (17.3)	44	152 (43.7)	0.62	✦
Depth						
CNF (m)	6	50 (14.9)	43	57 (16.9)	0.29	
CWT (m)	7	79 (27.2)	45	80 (22.6)	0.96	✦
CWTB (m)	6	79 (18.7)	27	72 (18.4)	0.38	✦
FIM (m)	7	86 (23.1)	46	74 (26.3)	0.24	
TOTAL	25		121			

Per default, p-value were computed using the two-sample t-test.
◊ p-value were computed using Welch's t test for unequal variances.
✦ p-value were computed using Wilcoxon rank-sum test.

Table 2. Best personal results.

DISCUSSION

Within the study population (elite freedivers), 17.1% were born prematurely. These figures are higher than the standardized estimated mean of the preterm birth rate of 8.5% calculated based on the geographical distribution of our sample and the data from Blencowe and al. (Table 3) [10].

The observed phenomenon (higher proportion of premature-born athletes) still needs to be explained. On the one hand, babies born prematurely are more likely to develop complications such as respiratory distress syndromes [12,13], bronchopulmonary dysplasia, or hearing disorders that can represent a limitation on the exercise during breath hold activities [14]. On the other hand, the proven effect of prematurity on the respiratory system, including altered reactions to pCO_2, may contribute to freediving performance.

The comparison of preterm rates between the general population and the study population has several limitations. We compare the prevalence of athletes born prematurely in an adult population to the incidence of preterm infants among live births of newborns in a particular year. Although prevalence is related to incidence, it is not equivalent to it and depends on the average life expectancy. A baby born prematurely has a lower life expectancy than a baby born at term. Thus, if we had access to the average prevalence of non-diving adults of the same age as those in our sample, we would probably observe a lower prevalence than the standardized incidences mentioned above. Therefore, this comparison between incidence and prevalence tends to underestimate the actual difference in the prevalence of prematurity between divers and non-divers.

Region of birth	n of divers in sample	Estimated mean preterm birth rate, % (CI95)
Developed regions	112	8.6 (8.3-9.4)
Eastern Asia	16	7.2 (5.4-9.0)
Latin America	9	8.4 (6.8-11.4)
Southeastern Asia	4	13.6 (9.3-18.6)
Oceania	3	7.4 (4.5-15.6)
Caribbean	1	11.2 (7.8-20.8)
Western Asia	1	10.1 (6.9-14.3)
Stand. est. mean preterm birth rate*		8.5 (7.9-9.7)

*Standardized estimated mean of preterm birth rate based on data from Blencowe, H. and al. (2012). National, regional, and worldwide estimates of preterm birth rates in the year 2010 with time trends since 1990 for selected countries: a systematic analysis and implications. Lancet (London, England), 379(9832), 2162–2172.

Table 3. Standardized estimated mean preterm birth rate.

Available data in terms of prematurity rates are not for the years of birth of the study subjects. Therefore, comparing these rates is anachronistic and may produce a statistical cohort effect. The rate of live birth of premature children has tended to increase in recent years thanks to advances in health. Thus, according to data from Zeitlin et al., all European countries tended to see their preterm birth rates increase between 1996 and 2008 (except Finland, the Netherlands, Spain, and Sweden) [15]. This cohort effect also tends to underestimate the actual difference in the prevalence of prematurity between divers and non-divers.

Thus, although these two main biases may affect the observations' accuracy, they influence it in the direction of underestimating the observed difference.

There is no difference in best personal results between preterm and full-term elite freedivers. Prematurity may not affect the breath-hold diving performance at the top sport level. These suggestions correspond with the finding that regular physical activity may change ventilatory response in preterm-born adults [7]. This adaptive change may be related to different brain excitability elicited from peripheral muscle signals [16]. This path can also be related to respiratory control [9]. Moreover, at this highest level of the sport, predisposing factors, training models, and psychological techniques may be of primary importance.

Major confounding factors might be the diver's age, specifically when an athlete sets the personal record. Aging leads to deceleration of the resting metabolism, which could lead to better performance in static apnea at a greater age. On the other hand, aging may have a negative impact on the performances in CWT-CWTB disciplines [17,18].

LIMITATIONS

1. Possible selection bias (if a higher proportion of prematurely born participants consent to participate in the survey).
2. Historic control of prematurity rate in the general population.

Additional analysis of the age when personal best results were achieved, as well as other possible confounders like neurologic and biochemical respiratory control, could contribute to a better understanding of the possible impact of prematurity on freediving performance.

CONCLUSIONS

There is a significant proportion of preterm within the professional freedivers. That proportion is higher than could be estimated for the general population.

There is no difference in best personal results between preterm and full-term elite freedivers.

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	Question	Values
1.	What is your gestational age at birth?	weeks
2.	Were you born with Cesarean delivery?	yes, no
3.	What were your anthropometric data at birth?	height (g), weight (cm)
4.	Did you suffer with respiratory disease(s) in childhood and adolescence (before 18 years old), required continuous medical care and/or multiple hospitalizations?	yes, no if yes, what was the diagnosis?
5.	Did you suffer with respiratory disease(s) after 18 years old, required continuous medical care and/or multiple hospitalizations?	yes, no if yes, what was the diagnosis?
6.	Did you suffer with other chronic disease(s) in childhood and adolescence (before 18 years old), required continuous medical care and/or multiple hospitalizations?	yes, no if yes, what was the diagnosis?
7.	Did (do) you suffer with other chronic disease(s) after 18 years old, required continuous medical care and/or multiple hospitalizations?	yes, no if yes, what was (is) the diagnosis?
8.	Have (had) you any other medical conditions, that you want to report (e.g.: gastric reflux, allergies, dysbiosis)?	Not formalized

Attachment 1: The Questionnaire (Survey).