The influence of wetsuit thickness (≥ 7 mm) on lung volumes in scuba divers

Graham Stevens[1], David R Smart[2]

[1] *Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital, Hobart, Tasmania, Australia*
[2] *Private Consultant. Formerly: Clinical Professor, School of Medicine, University of Tasmania and Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital, Hobart, Tasmania, Australia*

Corresponding author: *Dr Graham Stevens, Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital, Hobart, Tasmania 7000, Australia*
ORCiD: *0009-0001-3341-108X*
graham.stevens@ths.tas.gov.au

Keywords
Diving research; Equipment; Fitness to dive; Lung; Respiratory; Spirometry

Abstract
(Stevens G, Smart DR. The influence of wetsuit thickness (≥ 7 mm) on lung volumes in scuba divers. Diving and Hyperbaric Medicine. 2025 31 March;55(1):27–34. doi: 10.28920/dhm55.1.27-34. PMID: 40090023.)
Introduction: We hypothesised that although thicker (≥ 7 mm) wetsuits delay hypothermia and allow divers to dive in cooler waters, they may hinder pulmonary function. The aim of this study was to investigate whether thicker wetsuits worn by Tasmanian divers affected lung volumes, primarily the forced vital capacity (FVC) and forced expiratory volume, one second (FEV_1).
Methods: Sixty-two volunteer active divers were recruited from recreational dive clubs and Tasmania's occupational diving industry. After confirming fitness and that the divers were currently active, spirometry testing was performed with and without the divers' usual wet suits, in a controlled dry environment. Suits were of varying thickness, but all were ≥ 7 mm thickness.
Results: All divers had significantly reduced lung volumes when wearing ≥ 7 mm wetsuits. Recreational divers had greater decrements (-7% FVC and -5% FEV_1), compared to occupational divers (-3% FVC, -3% FEV_1). Males' lung volumes declined -4% FVC and -4 % FEV_1, whereas females declined -7 % FVC and -6 % FEV_1. Female recreational divers experienced the greatest negative impact from thicker wetsuits (up to 15% reduction in FVC), and this group also demonstrated an inverse relationship between increasing wetsuit thickness and declining lung volumes.
Conclusions: Wearing thicker wet suits aids in thermal protection in temperate water diving but this study suggests it has negative effects on lung volumes. The real-life impact of this negative effect may be minor in fit healthy divers but might add additional risk to a less fit, recreational diving population with medical comorbidities.

Introduction

Wetsuits are worn by divers for thermal protection to prevent conductive heat loss in the subaquatic environment and may offer some protection from marine hazards. Wetsuit thicknesses vary from 1 mm (or less) in tropical waters to 18 mm or more in colder waters. Previous authors have shown a detrimental effect from wearing wetsuits < 7 mm thickness on performance in spirometry in fit 'active' recreational divers.[1] The effect of thicker wet suits which are commonly used in colder waters on pulmonary function are, as far as we are aware, unknown.

In Tasmania, Australia, sea temperatures range from 9–21°C which are consistent with temperate waters in other countries.[2] To prevent hypothermia, divers routinely use ≥ 7 mm (single layer and sometimes double layer) neoprene wetsuits, or dry suits. Double layer suits are in 'long john' (singlet shoulders) and vest with attached hood configuration. The double layer covers the thorax, abdomen and pelvis. Tasmania has more than 20,000 divers among its 570,000+ population, including recreational and occupational divers; the latter supporting multi-million-dollar seafood and aquaculture industries and offshore work.[3,4] Occupational divers are subject to legislated higher level commercial training, annual full diver health assessments, and they dive all year round. Recreational divers have minimal governance over health assessments, and tend to dive less frequently. Based on the above it is possible that there may be a difference between these diver groups.

A previous study demonstrated reduced forced vital capacity (FVC) of 4% and forced expiratory volume in one second (FEV_1) of 3.6% in recreational divers wearing thinner wetsuits of mean thickness 3.8 mm.[1] We hypothesised that wetsuits of ≥ 7 mm thickness may have a greater negative impact on pulmonary function.

The aim of this study was to investigate whether (≥ 7 mm thickness) wetsuits worn by Tasmanian divers affected lung volumes, primarily FVC and FEV_1. Secondary aims were to assess the influence of body mass index (BMI), age, sex, and recreational versus occupational status of the diver on lung volumes.

Methods

Ethics approval was obtained from the University of Tasmania Human Research Ethics Committee (UTasHREC) and the Department of Health Research Governance Office [Protocol number H0024772]. The study was registered with the Australian and New Zealand Clinical Trials Registry (382180).

Volunteer active divers were recruited through poster advertising in dive shops, dive clubs and via occupational dive companies over 15 months from 21 July 2021 to 24 October 2022. Study exclusions were pregnancy, age < 18 years, respiratory illness less than four weeks prior (including COVID-19), symptomatic cardiovascular disease, dived < 24 hours before evaluation and non-active divers. Active divers were defined as performing ≥ 20 dives per year and as having dived in the last three months. Included divers then provided written consent to enter the study.

Divers were asked to complete a basic health triage questionnaire (developed by the authors) to confirm absence of major illnesses affecting fitness to dive. The results of the triage questionnaire were not further analysed in this study. Data for each diver were recorded: age, height, weight, sex, body mass index (BMI), number of total dives, recreational qualification or occupational qualification, and wetsuit(s) thickness.

Divers were assessed in the Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital, at the workplace or dive site (pre-dive) by the first author. Subjects were assessed when wearing their personal wetsuit(s) in a dry room or office. It was assumed that these personal wetsuits were appropriate 'fit' as they had been self-selected, and were in regular use by the subjects. Ages of the wetsuits were variable and not documented. Wetsuit thicknesses were recorded as stated from the manufacturer label. Wetsuits of 14 mm and 18 mm thickness had double layers covering the thorax and abdomen.

Randomisation of the order in which measurements were performed (in wetsuit, out of wetsuit, thicker suit first) was generated using R Software (R Foundation for Statistical Computing, Vienna, Austria) just prior to the measurement to mitigate potential learning effect.[5] The assessor was blinded to the order of testing until just before the test was performed.

The Spirolab III spirometer (MIR, Rome, Italy) was calibrated in accordance with manufacturer's instructions. Each test was performed with subjects exhaling through disposable mouth pieces. The device was cleaned fully between subjects. Individual subjects completed all their tests in a single session, same day. It was initially planned to complete testing when subjects achieved three category A quality spirometry samples (assessed by the spirometer internal algorithm) for each of the wetsuit states: wetsuit off, wetsuit on (thick or thin).[6,7] Subjects were expected to require multiple blows to achieve each quality A sample (minimum two). For a full data set, subjects with one wetsuit therefore provided six samples to the database (three with wetsuit on and three with wetsuit off, and subjects with two wetsuits (thick and thin) had nine samples taken. Allowances were made if some subjects became exhausted and were unable to achieve the three samples of acceptable quality. On that basis two samples were regarded as acceptable.[6,7] Spirometry included: forced vital capacity (FVC), and forced expiratory volume in one second (FEV_1), as measures of pulmonary function, previously used by other authors.[1] Full spirometry curves were available for each subject but not analysed in this study.

Spirometry and anonymised biometric data (sex, height, weight, BMI, number of dives, and diver status – recreational or occupational) were extracted from our data pool and analysed. Wetsuit thickness was stratified into three groups for analysis: ≤ 7 mm, > 7 mm but < 14 mm, and ≥ 14 mm.

STATISTICS

R software was used, and a sample size of 60 was calculated to provide 95% power to detect a 4% difference in FEV_1 or FVC at alpha = 0.05 by two-tailed *t*-test.[5] The estimates were based on previously published data.[1,5] To investigate the relationship between lung volumes (FEV_1 and FVC) and suit thickness, a linear mixed-effect model was also used in R Software.[5] This modelling approach enabled us to account for population level variance using the random effects of the subject, and fixed effects of suit-type. Additional fixed effects that may influence pulmonary function (age, sex, height, weight, BMI, and recreational vs occupational diving background) were also included which enabled us to control for these variables and avoid confounding changes in pulmonary function due to suit effect interaction with other variables. Additional data analysis was performed using GraphPad Prism software (version 7.03) for tests of normality (Shapiro-Wilk and Kolmogorov-Smirnov), paired Student *t*-testing, contingency tables with Chi-square analysis and Bland-Altman analysis.[8]

Results

Recruitment was hampered by the COVID-19 pandemic. We recruited 62 divers over a 15-month period, who provided 364 samples. Five divers provided samples in two different wetsuit thicknesses, which meant the ideal sample number should have been 387. Thirteen divers were unable to provide more than two category A samples for their assigned wetsuit states (off, on ± thin or thick). Because they produced a minimum of two samples of sufficient quality, their data was accepted for analysis. In our 62 subjects, 47% were female, and 47% were occupational divers (of these 14/29 were female, Table 1). Samples were collected mostly (71%) in the morning and less (29%) in the afternoon. The distribution of sampling times was not significantly different for occupational versus recreational samples (P = 0.58 Fishers exact test).

Height, weight, BMI, FEV_1 and FVC data were normally distributed, but age was not (skewed by a small group of older recreational divers). Mean BMI of all the divers was 25.1 kg·m^{-2}. The BMI in occupational and recreational divers was not different (P = 0.67, two-tailed unpaired t-test). Wetsuit thicknesses were 7 mm, 8 mm, 10 mm, 14 mm (double thickness 7 mm) and 18 mm (double thickness 9 mm). Median thickness for recreational divers was 10 mm (range 7–14 mm), and for occupational divers 14 mm (range 7–18 mm).

Occupational divers had significantly greater diving experience compared to recreational divers, Figure 1 (P = 0.0002, χ^2 test). Table 1 summarises baseline data for the divers. Occupational and female divers were generally younger in this study. Lung volumes were not significantly different when occupational and recreational divers were compared in this sample (P = 0.29 for FEV_1, and P = 0.10 for FVC (two tailed t-test)).

Table 1 also documents the reductions in FVC and FEV_1 when wearing any thickness of wetsuits. All diver groups demonstrated statistically significant reductions in lung volumes when wearing a wetsuit versus no wetsuit (t-test). Recreational divers had greater reductions when wearing a wetsuit compared to occupational divers; recreational divers exhibited a reduction of FVC and FEV_1 by 0.350 L (7%) and 0.210 L (5%) respectively in comparison to occupational divers where the reduction was 0.140 L (3%) and 0.100 L (3%) respectively. Occupational divers generally were wearing thicker wetsuits (Table 1). For males, FVC

Figure 1
Distribution of diving experience for the study cohort

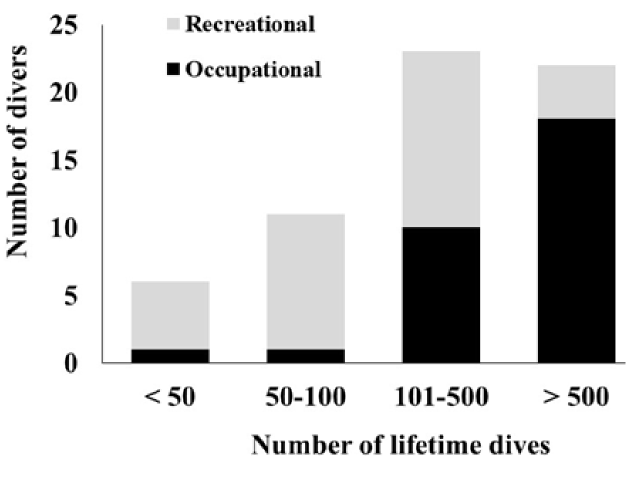


Table 1
Diver age, height, body mass index (BMI) and mean reductions of forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) by diver sub-group; F – female; IQR – interquartile range; M – male; SD – standard deviation

Diver group	Median (IQR) age (y)	Mean (SD) height (cm)	Mean (SD) BMI (kg·m^{-2})	Median wetsuit thickness (mm)	Mean (SD) Baseline FEV_1 (L)	Mean (SD) Baseline FVC (L)	Mean reduction FEV_1 wearing any wetsuit			Mean reduction FVC wearing any wetsuit		
							L	%	P-value	L	%	P-value
All (n = 62)	31.5 (26.0, 46.5)	173.9 (9.1)	25.1 (3.5)	10	4.2 (1.0)	5.4 (1.4)	-0.16	-4	< 0.001	-0.25	-5	< 0.001
Male (n = 33)	36 (28.0, 50.0)	180.7 (4.6)	26.3 (3.4)	14	4.8 (0.7)	6.1 (0.8)	-0.16	-4	< 0.001	-0.25	-4	0.0019
Female (n = 29)	28 (22.5, 35.0)	166.6 (5.9)	23.8 (3.3)	10	3.3 (0.5)	4.1 (0.7)	-0.17	-6	0.0052	-0.26	-7	0.0126
Occupational (M = 15, F = 14)	30 (26.0, 37.0)	173.3 (9.8)	24.9 (3.6)	14	4.1 (1.0)	5.0 (1.3)	-0.10	-3	0.0068	-0.14	-3	0.0044
Recreational (M = 18, F = 15)	32 (26.5, 48.5)	174.1 (8.2)	25.3 (3.5)	10	4.3 (1.0)	5.6 (1.5)	-0.21	-5	< 0.001	-0.35	-7	0.0017

Table 2
Reductions in forced vital capacity (FVC) in the female recreational diver group

Suit	FVC (L)	% baseline in sample	% negative change
Baseline	4.26	100	0.0
7 mm	3.99	93.7	-6.3%
7–14 mm	3.78	88.7	-11.3%
> 14 mm	3.63	85.2	-14.8%

Table 3
The effect of suit type, sex, age, and height on forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1); the parameter estimates for the optimum (AICc selected) model;[9–11] M – male

Variable	FEV_1			FVC		
	Estimate change (L)	95% confidence interval	*P*-value	Estimate change (L)	95% confidence interval	*P*-value
Intercept (includes baseline, i.e., no suit)	-0.20	-4.26, 3.86	0.923	-0.75	-5.96, 4.45	0.776
Suit (7 mm)	-0.16	-0.24, -0.07	< 0.001	-0.27	-0.40, -0.13	< 0.001
Suit (7 to14 mm)	-0.19	-0.29, -0.09	< 0.001	-0.48	-0.64, -0.32	< 0.001
Suit (> 14 mm)	-0.17	-0.23, -0.11	< 0.001	-0.19	-0.29, -0.10	< 0.001
Sex (M)	1.42	0.99, 1.86	< 0.001	1.86	1.30, 2.42	< 0.001
Age centre	-0.03	-0.04, -0.02	< 0.001	-0.02	-0.03, -0.01	0.002
Height cm	0.02	-0.00, 0.04	0.104	0.03	-0.00, 0.06	0.075
Random Effects						
σ^2	0.05			0.12		
Number of subjects	62			62		
Observations	364			364		
Conditional R^2-Marginal R^2	0.95 – 0.72 = 0.23 (23%)			0.93 – 0.71 = 0.22 (22%)		

and FEV_1 declined 0.240 L and 0.160 L respectively, a 4% fall for both compared to females where FVC and FEV_1 declined 0.258 L (7%) and 0.165 L (6%) respectively. Although absolute values of the male vs female FVC and FEV_1 reductions were similar, the percentage decrements for females were greater due to smaller baseline spirometry values in females.

Female recreational divers had reductions of almost 15% in FVC when wearing 14 mm or greater wet suits (Table 2). Even the 7–14 mm and 7 mm suits recorded FVC decrements of 11.3% and 6.3% respectively. For this subset of our study population, there was an inverse relationship of declining lung volumes as wetsuit thickness increased. The same relationship was not confirmed for other diver subsets.

Controlling for other variables such as age, sex and height, the reduction in lung volumes was statistically significant in our multivariate analysis (Table 3). This model, using Akaike Information Criterion, (AIC)c, provided the best fit for analysis of small groups with multiple variables.[9–11] Our multivariate analyses confirmed that there was a negative effect on FEV_1 and FVC when wearing a wetsuit, which was statistically significant in all categories. The reduction in FEV_1 was greatest in the 7 to 14 mm suit thickness category, followed by > 14 mm thickness, then 7 mm thickness suits. The reduction in FVC was greatest for 7–14 mm wetsuits, followed by ≤ 7 mm wetsuits and ≥ 14 mm thickness. These results are depicted graphically in Figures 2 and 3.

Effect of suit type, age, sex, and height were treated as explanatory variables. Males had significantly greater FEV_1 and FVC in this population; a known characteristic which is incorporated into normative spirometry databases. Lung volumes reduced significantly with age in all categories. The effect of BMI was not significant as an independent variable (Bland-Altman analysis, $P = 0.48$ for FEV_1 and $P = 0.80$ for FVC). There was a trend towards statistical significance for height as an independent variable (also a known effect incorporated into spirometry databases).

Table 3 also provides marginal R2/conditional R2 values for the two parameters. The marginal is the variation explained by the model fixed effects and conditional is the variation

Figure 2
Wetsuit thickness effect on mean forced expiratory volume in one second (FEV_1); error bars represent mean (2 standard deviations)

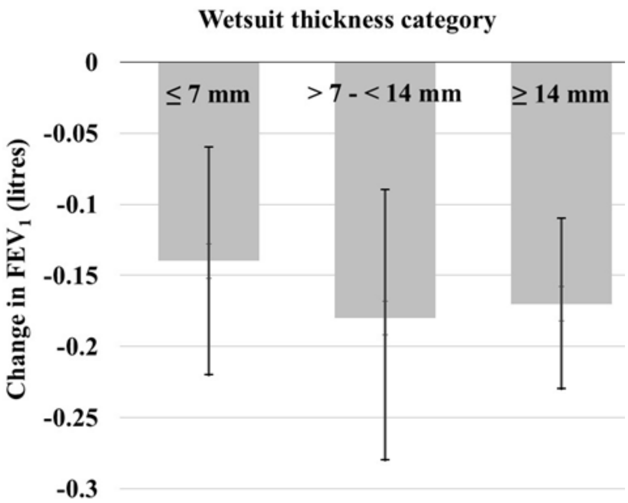
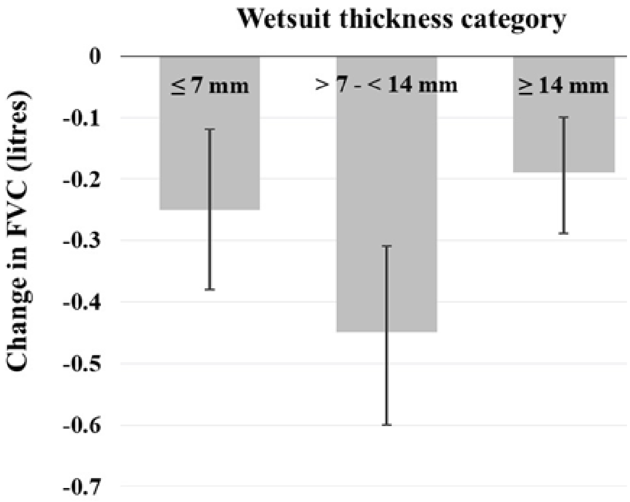


Figure 3
Wetsuit thickness effect on mean forced vital capacity (FVC); error bars represent mean (2 standard deviations)



explained by the random and fixed effects. The random effect demonstrates some variance not specified in the fixed effects. Hence, some of the study population variance is not fully explained by our chosen parameters. Using a mixed effects model such as this, we had the opportunity to account for greater population-level variability than a standard (fixed effect) linear model. In the fitted models, the inclusion of a random effect of subject increased the variability explained (calculated as conditional R2 minus marginal R2) in pulmonary function 23% for FEV_1 and by 22% for FVC.

Discussion

We have shown that there is a statistically significant reduction in lung volumes when wearing temperate water wetsuits, but what does this mean in the real world? Is a 3–7% reduction in FVC and FEV_1 physiologically significant? In a young, fit, healthy population of divers, free of medical illness, we would assert that this order of decrement is unlikely to have any functionally consequential effect on physical performance when diving.

An earlier study demonstrated that tropical thickness wetsuits have negative effects on measurable lung volumes in recreational divers.[1] Mean suit thickness in our study was greater than in that study, and our recreational diver subset had a greater decrement in lung volumes.[1] The largest reductions of FVC (greater than 10%) were observed in female recreational divers. This may be explained by a smaller baseline FVC and FEV_1 in females, but could also be related to suit fit, baseline physical fitness or technique. This effect was independent of other variables and our data model correlated well with previous work on age and pulmonary function.[12]

It is possible that specific diver groups could experience greater negative physiological effects from wetsuits. Increasing age can be associated with reduced fitness, obesity, hypertension, underlying cardiac and pulmonary disease. These effects may also evolve without detection in recreational divers who dive less frequently. Recreational divers in Australia have no mandated health monitoring. This contrasts with occupational divers who have mandatory annual medical assessments. Medical assessments are likely to detect and correct heath issues, weight gain, and ensure fitness in this group. In addition, regular diving may improve occupational divers' adaptation and strength when wearing wetsuits.[13]

An individual sustaining weight gain but still using the same wetsuit, could experience greater impaired pulmonary function. All divers in our study were in relatively good physical condition and BMI did not influence lung volumes. Our population mean BMI was 25.1, within a narrow range. Our data showed insufficient variance in BMI to accurately detect relevant effects.

Median wetsuit thicknesses were greater in the occupational group. This was counter-intuitive, particularly when considering the lesser impact on FVC (Figure 3). Occupational divers may have had better quality wetsuits, fitted specifically for work, more flexible due to frequent use, and their wetsuits may be replaced more frequently. In addition, occupational divers are likely to be fitter and stronger, physically compensating for the restrictive effect of the wetsuit. Wetsuits which are used less frequently may become stiff and less flexible.

An additional important factor could be the wetsuit 'fit' which was not independently assessed in this study. Subjects were all assessed when wearing their personal wetsuits.

We made an assumption that these wetsuits would be close to ideal 'fit' because they were personally selected, and in regular use. This may be valid for occupational divers who dive regularly at work. Recreational divers in this study dived less frequently and had less overall experience than occupational divers. It is possible that recreational divers may not update their wetsuit if the wetsuit ages or stiffens, they gain weight or fail to maintain their fitness levels.

Other than for the female recreational diver subset, our data did not confirm a stepwise inverse relationship between wetsuit thickness and lung volumes. For the total cohort, there were smaller reductions in FEV_1 and FVC when wearing wetsuits > 14 mm thickness. There are some possible explanations for this:

(1) A significantly greater proportion of occupational divers were wearing wetsuits ≥ 14 mm thickness.Occupational divers as a group had lesser reductions in pulmonary function when wearing wetsuits. For the reasons outlined above, the impact of wetsuit thickness may have been attenuated for that sub-group, reducing the effect in the whole cohort wearing wetsuits ≥ 14mm thickness. We had insufficient numbers to investigate subgroups in this study.

(2) The lack of consistency across subgroups makes it possible that the chosen statistical model has over-fitted the data from an insufficient number of samples. In a mixed effects linear model with six explanatory variables, and 22–23% random effects, this is possible.

(3) The effect was greater on FVC than FEV_1. This could have resulted from individuals not inhaling fully when wearing the thickest wetsuit, due to impaired thoracic expansion. Hence the inspired vital capacity was reduced, and subsequently the measured expired FVC and FEV_1.

Males and females were almost equally distributed in both occupational divers, and recreational divers; hence this cannot be implicated in causation. The sampling times for occupational and recreational divers were not significantly different (morning vs afternoon), so diurnal variation was not a factor. A practice effect for individual samples was minimised by randomisation.

Tasmania has recently observed a trend towards older divers being more represented in fatalities.[3] Other authors have confirmed this trend.[14] The reduction in pulmonary function from wetsuits could further add to negative impacts from cold water immersion, in particular the effects on cardiovascular physiology, hypothermia and wetsuit compression, buoyancy and any concomitant health issues. Adding more neoprene helps delay hypothermia but at a cost of decreased pulmonary function.

Despite a publicly available medical risk assessment, Australian recreational divers have no mandatory regular medical fitness assessments.[15] This means recreational divers may accumulate health and fitness risks over many years without medical assessment or intervention, and the sum of these risks could compromise their safety in the water. For these individuals, detailed medical assessments and achievement of high levels of fitness might help offset the pulmonary effects of wearing wetsuits. It could be argued that diving fitness and medical requirements should be greater for cold water versus warm water diving. We are concerned that negative effects on pulmonary function from thicker wet suits may impact more on older divers and could represent a further safety factor to consider when appraising fitness to dive.

Some of the risk factors in a recent review of immersion pulmonary oedema (IPO) were female sex, fifty years or older, diving in cold water and tight-fitting wet suits.[16] In addition, female open water swimmers had a much greater risk of developing IPO, but wetsuit tightness was not considered in the study or 30-month follow-up.[17,18] Our study has identified a relationship between reduced lung volumes and thicker suits in recreational female divers and this could be explored further in future studies of IPO.

LIMITATIONS

This study was limited by several factors. A key confounder was that we had no method of assessing wet suit 'fit'. We relied on the divers to provide their own suits, and confirmation that they were active, regular divers. Wetsuit thickness was not directly measured but assumed as per manufacturer stated labelling. In addition, we did not record the age of subjects' wetsuits. It is possible that older wetsuits were thinner, due to wear and tear, or stiffer due to neoprene collapse. Both factors could have influenced lung volumes. Our inclusion of occupational divers who used thicker wetsuits may also have biased against detecting greater effects on lung volumes in subjects with the thickest wetsuits.

Testing of non-immersed divers may not accurately reflect performance during immersion. Further limitations include the fact that good technique is required to produce accurate spirometry. Thirteen divers (21%) were unable to provide three samples for each of their wetsuit states due to exhaustion. All produced a minimum of two 'A' quality samples for each state, and hence their available data were used. This should not have biased the results, and should have been compensated for by randomisation. We did not standardise the time of day that data was collected, which could have influenced measurements because there is a significant diurnal variation in spirometry.[19] There was however, no significant difference between sampling times for recreational and occupational divers.

It is likely that we had insufficient numbers to adequately assess the relationship of incremental wet suit thickness and lung volumes, at a more detailed level. Our initial power study was undertaken for a single variable, wetsuit versus no wetsuit, and we achieved the required sample size. We stratified the wetsuits into three thickness groups for statistical analysis. It does appear that occupational divers and recreational divers are different with respect to impact on lung volumes from wetsuits when diving, and future studies will need to separate these groups, with sufficient numbers for statistical analysis. To assess this greater detail using a multivariate model, may require upwards of 1,000 subjects for adequate power (depending on numbers of variables analysed).

This study has raised areas for future research. Measuring body metrics, respiratory parameters and effect on inspiratory pressures at rest and when exercising might be useful in assessing wetsuit 'fit'. Precise tailoring of wetsuits may further improve 'fit'. A recent paper reported that 3-dimensional printed polycarbonate panels in a 3 mm neoprene wetsuit had superior thermal properties when compared to a 7 mm neoprene wet suit. Future technologies may reduce wetsuit effect on pulmonary function.[20]

This study could be repeated with divers immersed in a pool; potential volunteers wearing (or not wearing) a wetsuit, or when wearing dry suits. All options are technically possible using smart device-based spirometers.[21] Wearing full scuba gear including buoyancy control device and weights would also add realistic variables to the data collection.

Conclusions

Scuba diving has many variables that create an additional risk for the diver. This study has found that thicker temperate water wetsuits produce significant reductions in pulmonary function and that the effect was greater on recreational divers than occupational divers. Female divers had a greater percentage decrement from their wetsuits, than male divers. The real-life impact of this negative effect may be minor in fit healthy divers but might add additional risk to a less healthy, unfit, older recreational diving population in deeper and colder waters. For dive physicians, an awareness of the increased demands of cold-water diving, and the negative effect on lung volumes when wearing a thicker wetsuit is relevant to providing advice about the health risks to each individual diver.

References

1 Schellart NAM, Sterk W. Influence of the diving wetsuit on standard spirometry. Diving Hyperb Med. 2016;46:138–41. PMID: 27723013. [cited 2024 May 20]. Available from: https://dhmjournal.com/images/IndividArticles/46Sept/Schellart_dhm.46.3.138-141.pdf.

2 Sea temperature analysis. Bureau of Meteorology. Australian Government. Australian climate and variability. Australian Government. [cited 2021 Mar 26]. Available from: http://www.bom.gov.au/oceanography/forecasts/idyoc300.shtml?region=ETAS&forecast=SST.

3 Ascencio-Lane JC, Smart D, Lippmann J. A 20-year analysis of compressed gas diving related deaths in Tasmania, Australia. Diving Hyperb Med. 2019;49:21–9. doi: 10.28920/dhm49.1.21-29. PMID: 30856664. PMCID: PMC6526051.

4 Tuynman H, Cao A, Dylewski M, Curtotti R. 2023, Australian fisheries and aquaculture statistics 2022. Canberra: Fisheries Research and Development Corporation, ABARES; 2023. doi: 10.25814/pnm2-9714 CC BY 4.0. [cited 2024 Jan 1]. Available from: https://daff.ent.sirsidynix.net.au/client/en_AU/search/asset/1035343/0.

5 R Core Team. R: A language and environment for statistical computing. Version 4.1.1. Vienna, Austria: R Foundation for Statistical Computing; 2021.

6 Medical International Research. Spirolab User Manual 2.1. Spirolab User Code MIR 980067. Rome, Italy: MIR. [cited 2022 Sep 23]. Available from: https://www.gimaitaly.com/DocumentiGIMA/Manuali/EN/M33521EN.pdf.

7 Graham BL, Steenbruggen I, Miller MR, Barjaktarevic IZ, Cooper BG, Hall GL, et al. Standardization of spirometry 2019 update. An official American Thoracic Society and European Respiratory Society Technical Statement. Am J Respir Crit Care Med. 2019;200(8):e70–e88. doi: 10.1164/rccm.201908-1590ST. PMID: 31613151. PMCID: PMC6794117.

8 Prism by GraphPad. Version 7.03. San Diego: GraphPad Software; 2017.

9 Ishiguro M, Sakamoto Y, Kitagawa G. Bootstrapping log likelihood and EIC, an extension of AIC. Annals of the Institute of Statistical Mathematics. 1997;49:411–34. doi: 10.1023/A:1003158526504.

10 Burnham KP, Anderson DR. Multi-model inference: understanding AIC and BIC in model selection. Sociological Methods and Research. 2004;33:261–304. doi: 10.1177/0049124104268644.

11 Hurvich CM, Tsai C-L. Regression and time series model selection in small samples". Biometrika. 1989;76:297–307. doi: 10.1093/biomet/76.2.297.

12 Thomas ET, Guppy M, Straus SE, Bell KJL, Glasziou P. Rate of normal lung function decline in ageing adults: a systematic review of prospective cohort studies BMJ Open. 2019;9:e028150. doi: 10.1136/bmjopen-2018-028150. PMID: 31248928. PMCID: PMC6597635.

13 Australian New Zealand Standards 2299.1:2015. Occupational diving operations. Standards Australia/New Zealand. Sydney: Standards Australia Limited; 2015.

14 Peddie C, Watson J. BSAC National Diving Committee diving incident report 2019. [cited 2021 Mar 26]. Available from: https://www.bsac.com/safety/diving-incidents/annual-diving-incident-report/.

15 South Pacific Underwater Medicine Society guidelines on medical risk assessment for recreational divers. 5th ed. Melboune: South Pacific Underwater Medicine Society; 2020. [cited 2022 Sep 23]. Available from: https://spums.au/index.php/diving-medicals/spums-full-medical.

16 Edmonds C. The evolution of scuba divers pulmonary edema. Undersea Hyperb Med. 2016;43:83–91. PMID: 27265985.

17 Hårdstedt M, Kristiansson L, Seiler C, Braman Eriksson A, Sundh J. Incidence of swimming-induced pulmonary edema: a cohort study based on 47,600 open-water swimming distances. Chest. 2021;160:1789–98. doi: 10.1016/j.chest.2021.06.034. PMID: 34186036. PMCID: PMC8628172.

18 Kristiansson L, Seiler C, Lundeqvist D, Braman Eriksson A, Sundh J, Hårdstedt M. Symptom duration, recurrence, and long-term effects of swimming-induced pulmonary edema: A 30-month follow-up study. Chest. 2023;164:1257–67. doi: 10.1016/j.chest.2023.06.041. PMID: 37414334. PMCID: PMC10635841.

19 Medarov BI, Pavlov VA, Rossoff L. Diurnal variations in human pulmonary function. Int J Clin Exp Med. 2008;1:267–73. PMID: 19079662. PMCID: PMC2592592.
20 Demers A, Martin S, Kartalov E. Proof of concept for a segmented composite diving suit offering depth independent thermal protection. Diving Hyperb Med. 2021;51:295–8. doi: 10.28920/dhm51.3.295-298. PMID: 34547781. PMCID: PMC8608442.
21 Zhou P, Yang L, Huang Y-X. A smart phone based handheld wireless spirometer with functions and precision comparable to laboratory spirometers. Sensors (Basel). 2019;19:2487. doi: 10.3390/s19112487. PMID: 31159155. PMCID: PMC6603793.

Acknowledgements

The authors acknowledge the following for their support of this study: Dr Martin Cox (statistics), Associate Professor Dr David Cooper, Dr Viet Tran, Technicians Karl Price, Shane Dennis, Stuart Bumford, Jason Pepper, Combined Dive Clubs weekend organising committee, CSIRO and UTAS divers, Tasmanian Diving Group and Go Dive.

Conflicts of interest and funding

In kind support for spirometry disposable mouth pieces came from the Department of Diving and Hyperbaric Medicine, Royal Hobart Hospital. No conflicts of interest were declared.

Submitted: 26 May 2024
Accepted after revision: 19 November 2024
