Annals of Work Exposures and Health, 2021, 649–658
doi: 10.1093/annweh/wxaa143
Advance Access publication 29 January 2021
Original Article

The Chartered Society for Worker Health Protection
OXFORD

Original Article

Effect of Long-Term Diving Exposure on Sleep of Male Occupational Divers in Southern Taiwan: A Cross-Sectional Study

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Submitted 14 July 2020; revised 10 December 2020; editorial decision 11 December 2020; revised version accepted 23 December 2020.

Abstract

Objective: Divers with a history of decompression sickness may be at high risk for sleep problems. However, limited studies have investigated the relationship between diving exposure and sleep problems of occupational divers. This study investigated the association between diving exposure and sleep quality and quantity among male occupational divers in southern Taiwan.

Methods: This descriptive, cross-sectional study included 52 occupational divers and 121 non-divers recruited from southern Taiwan in 2018. Survey data were collected using the Taiwanese version of the Hospital Anxiety and Depression Scale, Pittsburgh Sleep Quality Index, Epworth Sleepiness Scale, and a self-report questionnaire that included demographic variables, diving exposure/protocols, and factors associated with sleep quality.

Results: Among all participants examined, occupational divers were significantly more likely to have both poor sleep quality (adjusted odds ratio [OR] = 3.00; 95% confidence interval [CI] = 1.48–6.06; $P = 0.002$) and excessive daytime sleepiness (adjusted OR = 4.49; 95% CI = 2.12–9.52; $P < 0.001$). The diving exposure time, depth, ascent rate, and decompression table use showed no significant associations between poor and good sleepers in the divers group. However, a history of decompression sickness was associated with poor sleep quality among divers (adjusted OR = 2.20; 95% CI = 1.07–4.54; $P = 0.032$).

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What's important about this paper

Divers can develop nitrogen microbubbles that can contribute to brain damage even in the absence of decompression sickness. We surveyed male occupational divers and a control group of non-divers about sleep quality, anxiety and depression, diving history, and demographics. More divers experienced poor sleep quality and excessive daytime sleepiness than controls, and divers with poor sleep quality also reported insufficient sleep during the past month. Among diving-related factors, only history of decompression sickness was associated with poor sleep quality. The sleep quality of occupational divers should be monitored: Poor sleep can impact health and well-being, and may be associated with decompression sickness pathology.

Conclusions: Our results showed that occupational divers had poor sleep quality and more excessive sleepiness than non-divers. Decompression sickness likely contributes to poor sleep quality. Prevention and early detection of decompression sickness-related sleep problems should be an occupational health priority.

Keywords: decompression sickness; diving; occupational health; occupational injuries; sleep

Introduction

Sleep disorders affect sleep quality, health, safety, and quality of life. They are broadly classified into six major categories: insomnia, sleep-related breathing disorders, central disorders of hypersomnolence, circadian rhythm sleep–wake disorder, parasomnias, and sleep-related movement disorders (Sateia, 2014). Sleep disorders have a wide variety of causes, including medical and psychological conditions. Other factors that affect sleep may include age, drug use, nutritional intake, socioeconomic status, and environmental factors, such as noise, lighting, and shift work (Luo *et al.*, 2013; Matsumoto *et al.*, 2017).

Damage to the brain, such as traumatic brain injury (TBI), stroke, or carbon monoxide (CO) poisoning, is also associated with sleep problems (Ouellet *et al.*, 2015; Lin *et al.*, 2018; Gottlieb *et al.*, 2019). Although previous studies have shown there is no dose relationship between diving exposure and brain cognitive function (Ross *et al.*, 2013), recent studies have revealed that repeated dives may lead to micro-lesions of the white matter of the brain in a dose-dependent manner (Connolly and Lee, 2015; Coco *et al.*, 2019). These studies suggested that diving-related nitrogen microbubbles may be responsible for intracerebral lesions that lead to neuropsychological symptoms and nitrogen microbubbles related to dives performed in compliance with the current decompression tables (Coco *et al.*, 2019) or in individuals without a history of decompression sickness (DCS) (Connolly and Lee, 2015); this group of syndromes is caused by bubbles formed from dissolved gas in the blood and/or tissue due to a rapid reduction of environmental pressure (Pollock and Buteau, 2017). These nitrogen microbubbles are found in the majority of divers with no clinical signs of DCS after hyperbaric exposure; therefore, they are often termed 'silent bubbles' (Madsen *et al.*, 1994; Strauss and Borer, 2001). Some studies revealed that silent bubbles lead to endothelial dysfunction, which affects the integrity of the blood-brain barrier (BBB) in a linearly correlated manner (Brubakk and Møllerløkken, 2009). Therefore, silent bubbles may have a vital role in brain damage.

In our previous study, we found that divers with a prior diagnosis of DCS were at increased risk for sleep disorders (Tseng *et al.*, 2019). A recent case–control study found that factors such as diving depths ≥30 m, diving durations ≥2 h, a history of loss of consciousness during diving, and more than one previous episode of DCS are associated with poor quality of life (as assessed by the 36-item short-form [SF-36]) of divers with DCS (Widyastuti *et al.*, 2019). However, whether diving itself is a risk factor for the development of sleep disorders remains unknown. There are few data regarding sleep disorders of occupational divers. We hypothesized that long-term diving exposure has a negative impact on sleep health. This study aimed to determine the relationship between diving exposure and sleep quality and quantity among male occupational divers in southern Taiwan.

Participants and methods

Ethics approval and consent to participate

The protocol of the study was approved by the Institutional Review Board of Kaohsiung Armed Forces

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General Hospital (no. KAFGH 106-037). Written informed consent was obtained from all individuals participating in the study (275 total participants).

Survey procedure and sampling

This cross-sectional questionnaire-based survey was conducted at Zuoying Branch of Kaohsiung Armed Forces General Hospital from March 2018 to December 2018. Participants who underwent health examinations at this hospital were recruited. Since there are few female occupational divers in southern Taiwan, we focused our study on male divers only. Inclusion criteria were age 20 years or older and willingness to participate in the study. Exclusion criteria were sleep problems due to the most common causes, which included brain defects, brain lesions, depression disorders, anxiety disorders, diabetes mellitus, narcolepsy, restless legs syndrome, periodic limb movements disorder, parasomnia, and obstructive sleep apnea. The experimental group included occupational divers with a diving history of more than 1 year according to their labor insurance status; the control group included non-divers without any prior diving experience. Some studies have revealed that anxiety and depressive symptoms have a significant association with poor sleep quality (Moalla *et al.*, 2016; Seun-Fadipe and Mosaku, 2017); therefore, to minimize the effects of depressive and/or anxiety symptoms on sleep, participants with Taiwanese version of the Hospital Anxiety and Depression Scale (HADS) anxiety subscale scores ≥9 and/or HADS depression subscale scores ≥8 were excluded from the data analysis.

Data collection

Data were collected using a self-administered survey based on three internationally validated and reliable questionnaires regarding anxiety, depression, sleep quality, and daytime sleepiness: HADS (Zigmond and Snaith, 1983), Pittsburgh Sleep Quality Index (PSQI) (Buysse *et al.*, 1989), and Epworth Sleepiness Scale (ESS) (Johns, 1991). These questionnaires had already been translated to Chinese (Chen *et al.*, 2002; Tsai *et al.*, 2005; Wang *et al.*, 2011). The duration of interviews ranged from 15 to 25 min.

Research tools

We collected demographic data (age, body mass index [BMI], education, and household income) and personal data, including occupational diving types, diving exposure (duration, depth, frequency), ascent rate, DCS history (DCS symptoms, such as muscle soreness and joint pain after a dive), decompression-table use (algorithm or tables allowing divers to ascend to the surface safely), and factors associated with sleep quality (history of brain concussion/contusion, living with children less than 12 years old, alcohol consumption, coffee/tea drinking, cigarette smoking, medication for pain release/insomnia, regular exercise > 90 min/week, regular afternoon nap > 10 min, and environmental noise while sleep).

The HADS was developed as a brief measure of generalized anxiety and depression symptoms (Zigmond and Snaith, 1983). It is a 14-item self-report questionnaire divided into anxiety (HADS-A, seven items) and depression (HADS-D, seven items) subscales. Each item was scored from 0 to 3, with total scores for each subscale ranging from 0 to 21. Higher scores indicated greater anxiety and/or depression. For the Taiwanese version of the HADS, scores of 9 and 8 were adopted as the optimal cutoffs for the HADS-A and HADS-D, respectively, because they yielded good sensitivity (84 and 73%, respectively) and specificity (72 and 86%, respectively) (Wang *et al.*, 2011). Cronbach's alpha values for the HADS-A and HADS-D were 0.84 and 0.76, respectively (Chen *et al.*, 2000).

The PSQI is a 19-item self-report questionnaire that evaluates sleep quality over a period of 1 month (Buysse *et al.*, 1989). This questionnaire contains 15 multiple-choice items about the frequency of sleep disturbance and subjective sleep quality and four write-in items about bedtime, sleep latency, wake-up time, and sleep duration. The surveys are categorized into seven components (sleep disturbance, overall sleep quality, sleep latency, duration of sleep, daytime dysfunction due to sleepiness, sleep efficiency, and need for medicine to sleep); each is graded on a scale of 0 to 3, with higher scores indicating poorer sleep quality. The total score ranges from 0 to 21. A score on the Taiwanese version of the PSQI >5 has sensitivity and specificity of 98% and 55% for sleep disturbance, respectively. Cronbach's alpha for the Taiwanese version of the PSQI was 0.79 (Tzeng *et al.*, 2012). Although it has low specificity, it can be a sensitive, reliable, and valid questionnaire for the evaluation of sleep disturbance in community-based studies (Tsai *et al.*, 2005).

The 8-item ESS is a self-administered questionnaire that evaluates an individual's degree of excessive daytime sleepiness (EDS). Each item is scored on a scale of 0 to 3, and the total score ranges from 0 to 24 (lowest to highest sleep propensity). A total score of >10 indicates that the participant requires medical evaluation (Johns, 1991). Validation of the Taiwanese version was performed by Chen *et al.*, and Cronbach's alpha was 0.81 (Chen *et al.*, 2002).

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Statistical analysis

Statistical analyses were performed using SPSS software (version 22; SPSS Inc., Chicago, IL, USA). Continuous variables with normal distribution were compared using Student's *t*-test and are presented as the mean ± standard deviation (SD); continuous variables with non-normal distributions were compared using the Mann–Whitney test and are presented as medians and interquartile ranges (IQR). Categorical variables were compared using the chi-square test and are presented as number (%). Education, household income, bedtime, wake-up time, PSQI global scores, ESS scores, and habit of using diving decompression tables were converted to categorical variables for the analysis. Comparisons were carried out by Student's *t*-test and the Mann–Whitney test according to distribution (normal and non-normal) determined by the Kolmogorov–Smirnov test. Chi-square test and Fisher's Exact test were utilized to assess significance among categorical variables. A backward stepwise binary logistic regression analysis was used to test the utility of the independent variables as predictors of poor sleep quality/EDS. The results are presented as adjusted odds ratios (OR) with 95% confidence intervals (CIs). Two-tailed $P < 0.05$ was considered statistically significant. Multicollinearity was assessed using the variance inflation factor (VIF) to support the validity of the regression results.

Results

As seen in Fig. 1, 275 participants were initially enrolled, including 82 divers and 193 non-divers. Of those in the divers group, 25 (25/82; 30.5%) had HADS-A scores ≥9, 11 (11/82; 13.4%) had HADS-D scores ≥8, and 6 (6/82; 7.3%) had both HADS-A scores ≥9 and HADS-D scores ≥8. Of those in the non-divers group, 55 (55/193; 28.5%) had HADS-A scores ≥9, 36 (36/193; 18.7%) had HADS-D scores ≥8, and 19 (19/193; 9.8%) had both HADS-A scores ≥9 and HADS-D scores ≥8. Therefore, 30 in the divers group and 72 in the non-divers group were excluded for greater anxiety and/or depression as assessed by the Taiwanese version of the HADS. Ultimately, we analyzed 52 divers (24 underwater construction workers, 16 diving instructors, 9 diving fishermen, and 3 marine researchers) and 121 non-divers (Fig. 1).

Table 1 shows the distribution of participant characteristics and factors affecting sleep among divers and non-divers. There were no significant differences in age or BMI. When compared with non-divers, divers exhibited significant associations with education ≤12 years (55.8% versus 21.5%), living without children younger than 12 years of age (71.2% versus 52.1%), alcohol consumption (28.8% versus 11.6%), and cigarette smoking (32.7% versus 16.5%). Mean PSQI global scores and ESS scores were higher for divers than for non-divers ($P < 0.001$ and $P = 0.017$, respectively), indicating more subjective sleep problems and daytime sleepiness among divers.

Backward stepwise binary logistic regression was used to analyze factors associated with poor sleep quality and EDS (Table 2). The values of VIF for the variables (being an occupational diver, age, BMI, history of brain concussion/contusion, education, household income, living with children younger than 12 years of age, alcohol consumption, coffee/tea consumption, cigarette smoking, medication for pain/insomnia, regular exercise/afternoon nap, environmental noise while sleeping, and bedtime) in the model ranged from 1.034 to 1.337 (data not shown) suggesting multicollinearity among the variables of the model is far below the critical thresholds and fairly tolerable (Salmerón *et al.*, 2018). After adjusting for these variables, being an occupational diver (adjusted OR = 3.00; 95% CI = 1.48–6.06; $P = 0.002$), and low household income (≤400 000 NT$/year) (adjusted OR = 2.85; 95% CI = 1.41–5.75; $P = 0.004$) were significantly correlated with a higher incidence of poor sleep quality. Using the ESS scores as the results, being an occupational diver (adjusted OR = 4.49; 95% CI = 2.12–9.52; $P < 0.01$) was significantly associated with EDS.

Table 3 presents the sleep pattern in participants which are classified into four groups by divers/non-divers and poor/good sleepers (poor sleepers and good sleepers in the divers group, poor sleepers, and good sleepers in the non-divers group). The poor sleepers in the divers group had a tendency to go to sleep late and had longer sleep latency and shorter sleep duration when compared to other groups.

Table 4 shows the diving pattern between poor and good sleepers and the results of our backward stepwise binary logistic regression analysis of the association between diving variables and sleep quality among divers in this study. Because there were no significant differences in age, BMI, history of brain concussion/contusion, education, household income, living with children younger than 12 years of age, alcohol consumption, coffee/tea consumption, cigarette smoking, medication for pain/insomnia, regular exercise/afternoon nap, environmental noise while sleeping, and bedtime between poor and good sleepers in the divers group (data not shown), only five variables including estimated exposure time of diving, diving depth, ascent rate, history of DCS,

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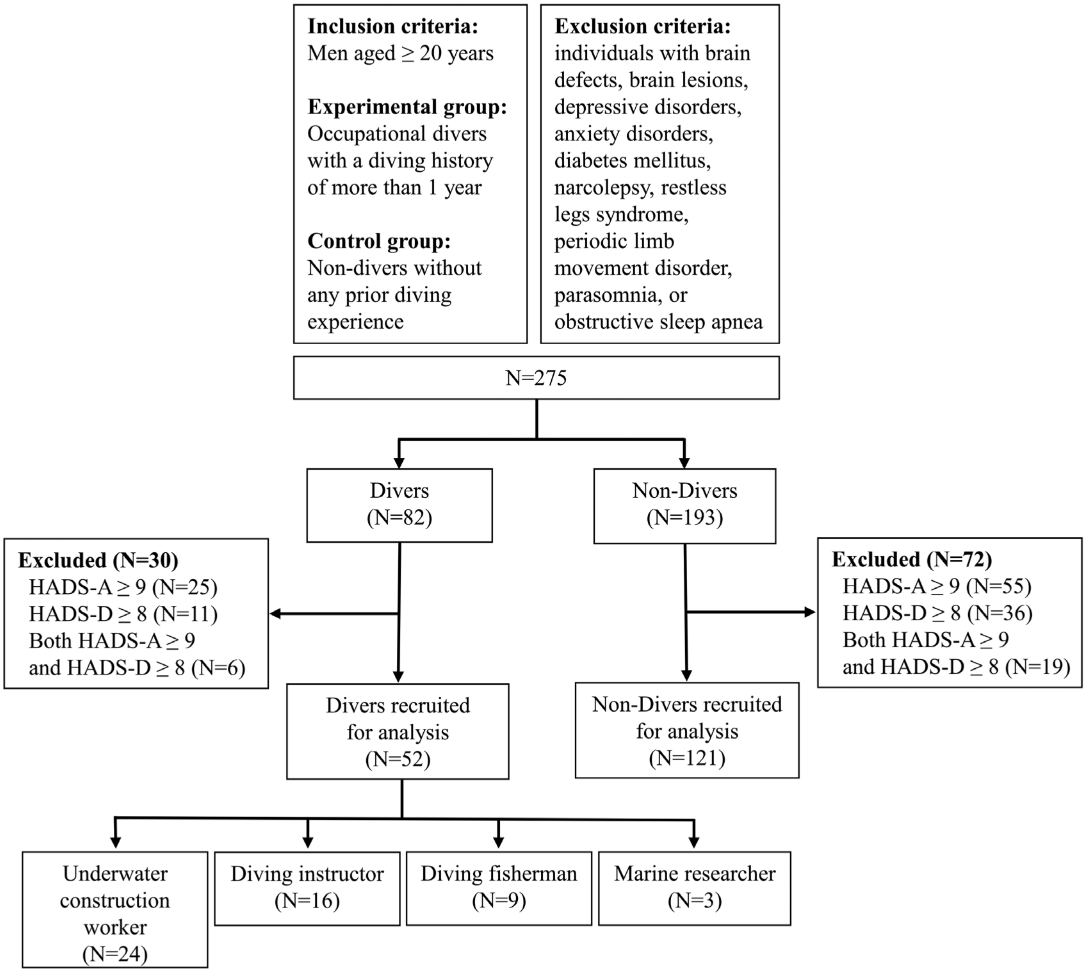

Figure 1 Participant flowchart.

and habit of using diving decompression tables were adjusted in this regression model. The values of VIF for these five variables ranged from 1.040 to 1.340 (data not shown) suggesting multicollinearity among the variables of the model is far below the critical thresholds and fairly tolerable. After adjusting for these five diving-associated variables, a history of DCS was associated with poor sleep quality among divers (adjusted OR = 2.20; 95% CI = 1.07–4.54; P = 0.032).

Discussion

We found that the prevalence of poor sleep quality and EDS among divers was two- to three-times higher than that among non-divers (50.0% versus 24.0% and 42.3% versus 14.0%, respectively) and also higher than that of the general population in Taiwan (Tai *et al.*, 2015). After adjusting for sociodemographic and environmental characteristics, household income was associated with poor sleep quality among all participants. This finding is consistent with those of previous studies of the general population (Roehrs and Roth, 2001; Mezick *et al.*, 2008).

A case–control study revealed that there is no difference between the divers and offshore workers in scores of depression or anxiety (Macdiarmid *et al.*, 2004). We found that the rates of anxiety and depressive symptoms (divers: 30.5 and 13.4%, respectively; non-divers: 28.5 and 18.7%, respectively) in our population were similar to the rates (anxiety: 16.4–41.7%; depression: 10.1–26.7%) reported in previous studies (Andruskiene *et al.*, 2016; Moalla *et al.*, 2016; Seun-Fadipe and Mosaku, 2017). These findings suggest that our sample was similar to the general population. However, the rate

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Table 1. Characteristics of divers and non-divers in this study.

Variable	Divers (N = 52)	Non-divers (N = 121)	P value[a]
Age (years)	45.1 ± 9.21	42.1 ± 9.32	0.052[b]
BMI (kg/m^2)	26.4 ± 3.30	25.6 ± 3.66	0.215[b]
History of brain concussion/contusion			0.094
Yes	5 (9.6)	4 (3.3)	
No	47 (90.4)	117 (96.7)	
Education (years)			<0.001**
≤12	29 (55.8)	26 (21.5)	
>12	23 (44.2)	95 (78.5)	
Household income (NT$/year)			0.100
≤400 000	20 (38.5)	33 (27.3)	
>400 000	32 (61.5)	88 (72.7)	
Living with children less than 12 years old			0.014*
Yes	15 (28.8)	58 (47.9)	
No	37 (71.2)	63 (52.1)	
Alcohol consumption			0.006**
Yes	15 (28.8)	14 (11.6)	
No	37 (71.2)	107 (88.4)	
Coffee/tea drinking			0.308
Yes	42 (80.8)	103 (85.1)	
No	10 (19.2)	18 (14.9)	
Cigarette smoking			0.016*
Yes	17 (32.7)	20 (16.5)	
No	35 (67.3)	101 (83.5)	
Medication for pain release/insomnia			0.248
Yes	1 (1.9)	7 (5.8)	
No	51 (98.1)	114 (94.2)	
Regular exercise >90 min/week			0.412
Yes	13 (25.0)	34 (28.1)	
No	39 (75.0)	87 (71.9)	
Regular afternoon nap >10 min			0.196
Yes	18 (34.6)	52 (43.0)	
No	34 (65.4)	69 (57.0)	
Environmental noise while sleep			0.483
Yes	21 (40.4)	51 (42.1)	
No	31 (59.6)	70 (57.9)	
Bedtime			0.509
20:00–23:00	23 (44.2)	61 (50.4)	
23:00–10:30	29 (55.8)	60 (49.6)	
PSQI global score (mean ± SD)	6.0 ± 2.89	4.1 ± 2.34	<0.001**
PSQI, no (%)			0.001**
Good sleepers ≤5	26 (50.0)	92 (76.0)	
Poor sleepers >5	26 (50.0)	29 (24.0)	
ESS score (mean ± SD)	8.4 ± 4.28	6.8 ± 3.64	0.017*
ESS, no. (%)			<0.001**
Normal ≤10	30 (57.7)	104 (86.0)	
Excessive daytime sleepiness >10	22 (42.3)	17 (14.0)	

BMI, body mass index; NT$, New Taiwan Dollar; PSQI, Pittsburgh Sleep Quality Index; ESS, Epworth Sleepiness Scale; SD, standard deviation. Categorical data are presented as number (%); continuous data are expressed as mean ± standard deviation.

[a]Chi-square test: *P < 0.05, **P < 0.01.

[b]Student's t-test.

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Table 2. Factors associated with poor sleep quality and excessive daytime sleepiness measured by PSQI and ESS scores, respectively.

Response variable	Predictor variables	*N* (%)	Adjusted OR (95% CI)	*P* value[a]
Poor sleep quality (PSQI > 5)	Occupational diver			0.002*
	No	121 (69.9)	1	
	Yes	52 (30.1)	3.00 (1.48 – 6.06)	
	Household income (NT$/year)			0.004*
	> 400 000	120 (69.4)	1	
	≤ 400 000	53 (30.6)	2.85 (1.41–5.75)	
Excessive daytime sleepiness (ESS > 10)	Occupational diver			<0.001**
	No	121 (69.9)	1	
	Yes	52 (30.1)	4.49 (2.12–9.52)	

PSQI, Pittsburgh Sleep Quality Index; ESS, Epworth Sleepiness Scale; OR, odds ratio; CI, confidence interval; NT$, New Taiwan Dollar.
[a]Variables including age, BMI, history of brain concussion/contusion, education, household income, living with children less than 12 years old, alcohol consumption, coffee/tea drinking, cigarette smoking, medication for pain release/insomnia, regular exercise/afternoon nap, environmental noise while sleep, and bedtime were analyzed by backward stepwise binary logistic regression. All significant associations between predictor and response variables are shown and non-significant associations are omitted for brevity and clarity.
*$P < 0.05$, **$P < 0.01$.

Table 3. Sleep pattern in participants categorized by divers/non-divers and poor/good sleepers.[a]

Variable[b]	Divers		Non-divers	
	Poor sleepers (*N* = 26)	Good sleepers (*N* = 26)	Poor sleepers (*N* = 29)	Good sleepers (*N* = 92)
Wake-up time				
04:00–06:00	7 (26.9)	13 (50.0)	10 (34.5)	27 (29.3)
06:01–09:00	18 (69.2)	13 (50.0)	18 (62.1)	65 (70.7)
16:00–20:00	1 (3.9)	0 (0.0)	1 (3.4)	0 (0.0)
Bedtime				
20:00–23:00	8 (30.8)	15 (57.7)	14 (48.3)	47 (50.5)
23:00–10:30	18 (69.2)	11 (42.3)	15 (51.7)	45 (48.4)
Real time of sleep latency (min)	30.0 (10.0–30.0)	10.0 (5.0–10.0)	20.0 (10.0–30.0)	10.0 (5.0–15.0)
Real time of sleep duration (h)	6.0 (5.0–6.0)	7.0 (6.9–8.0)	7.5 (6.5–8.3)	7.0 (6.6–7.5)

[a]Participants with a Pittsburgh Sleep Quality Index global score >5 were classified as 'poor sleepers', and with a score of ≤5 were classified as 'good sleepers'.
[b]Continuous variables with non-normal distributions are presented as medians and interquartile ranges. Categorical variables are presented as number (%).

of poor sleep quality in our non-divers group (24.0%) was lower than the rates previously reported in the USA (35%) (National Sleep Foundation, 2014) and Taiwan (46.6%) (Tai *et al.*, 2015). This discrepancy may be related to differences in assessment tools.

We also found that being an occupational diver was associated with both poor sleep quality and EDS. An analysis of factors associated with sleep quality revealed no significant differences in age, BMI, history of brain concussion/contusion, education, household income, living with children younger than 12 years of age, alcohol consumption, coffee/tea consumption, cigarette smoking, medication for pain/insomnia, regular exercise/afternoon nap, and environmental noise while sleeping when poor sleepers in the divers group were compared to good sleepers in the dives group and poor sleepers in the non-divers group (data not shown). However, poor sleepers in the divers group tended to report insufficient sleep during the past month. The median sleeping time at night of poor sleepers in the divers group was only 6.0 h, which was 1–1.5 h less than that of other groups. This sleep duration is even lower than the lower limit of the sleep duration recommendation for adults (7–9 h) (Hirshkowitz *et al.*, 2015). The short sleep duration reported by poor sleepers in the divers group may have been because some of them fished at night, thus leading to late bedtimes but wake up times that were the same or similar

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Table 4. Statistical comparison of diving pattern between poor and good sleepers among divers.[a]

Variable[b]	Poor sleepers (PSQI global score > 5) (*N* = 26)	Good sleepers (PSQI global score ≤ 5) (*N* = 26)	*P* value	Adjusted OR (95% CI)	*P* value
Estimated exposure time of diving[c] (h)	3780.0 (1395.0–5880.0)	3600 (1425.0–6216.0)	0.666		
Diving depth (meters)	20.0 (17.3–27.0)	19.0 (14.8–30.0)	0.427		
Ascent rate (m/min)	1.9 (0.8–3.3)	3.0 (1.6–5.0)	0.054		
History of DCS (times)	0.0 (0.0–2.0)	0.0(0.0–1.0)	0.178	2.20 (1.07–4.54)	0.032[d]
Without	15 (57.7%)	19 (73.1%)			
With	11 (42.3%)	7 (26.9%)			
Habit of using diving decompression tables			0.668		
Without	2 (7.7%)	4 (15.4%)			
With	24 (92.3%)	22 (84.6%)			

PSQI, Pittsburgh Sleep Quality Index; OR, odds ratio; CI, confidence interval; DCS, decompression sickness.
[a]No significant differences in age, BMI, history of brain concussion/contusion, education, household income, living with children less than 12 years old, alcohol consumption, coffee/tea drinking, cigarette smoking, medication for pain release/insomnia, regular exercise/afternoon nap, environmental noise while sleep, and bedtime between poor and good sleepers in our divers.
[b]Continuous variables with non-normal distributions were compared using the Mann–Whitney test and are presented as medians and interquartile ranges. Categorical variables were compared using the chi-square test and are presented as number (%).
[c]Estimated exposure time of diving = diving years × 12 × diving times a month × diving hours per work day.
[d]Statistical significance was tested with backward stepwise binary logistic regression after adjusting for estimated exposure time of diving, diving depth, ascent rate, and habit of using diving decompression tables.

to those of other groups (data not shown). It is known that a late bedtime is a risk factor for diabetes mellitus (Yan *et al.*, 2019) and smaller hippocampal volumes (Kuperczkó *et al.*, 2015), and that short sleep duration increases the risk of depressive symptoms (Sakamoto *et al.*, 2013), hypertension (Gangwisch *et al.*, 2006), coronary heart disease (Chandola *et al.*, 2010), and all-cause mortality (Heslop *et al.*, 2002). Lack of sleep is also a risk factor for DCS (Brandt *et al.*, 2009). There may be a reciprocal relationship between insufficient sleep and DCS.

The backward stepwise binary logistic regression analysis revealed that diving-related factors were not significantly associated with sleep quality, with the exception of a history of DCS, in the divers group. This result is consistent with those of previous studies that reported that divers with a history of DCS are at increased risk for sleep disorders (Tseng *et al.*, 2019). Recent studies suggested that DCS-induced nitrogen microbubbles could impair the BBB and cause axonal injury to the brain, especially white matter regions (Connolly and Lee, 2015; Coco *et al.*, 2019). Furthermore, chronic exposure to the hyperbaric condition of diving is thought to be associated with a higher incidence of low-stage atherosclerotic changes in brain arteries that lead to cerebral ischemic events and decreased blood flow to the brain, which might be caused by immersion-induced low volemia and nitrogen microbubbles (Fereshtehnejad *et al.*, 2012). Damage to the brain white matter regions could lead to sleep problems, poor visuoconstruction, and visual episodic memory (Connolly and Lee, 2015; Ergen *et al.*, 2017; Coco *et al.*, 2019; Tseng *et al.*, 2019). However, the exact mechanism of these brain lesions has not been clearly established.

Limitations

This study had several limitations that should be noted. First, this was a cross-sectional study. All sleep quality components that were assessed are subjective and rely on the respondent's self-assessment. We were unable to completely exclude participants with sleep disorders, such as periodic limb movement disorder or parasomnia, which may be easily ignored by the public and need to be confirmed by clinical tests, and their sleep-associated variables could not be evaluated precisely. We suggest that screening tools (e.g. polysomnography) should be used in future research to enable a more detailed evaluation of sleep stages and other variables after long-term diving. Second, we did not assess the timing or intensity of exercise before or during diving. These two factors might have had positive or negative effects on the formation of silent bubbles (Dujic *et al.*, 2008). Third, because all participants were male, we did not collect data to determine the effects of long-term diving on the sleep quality of female occupational divers.

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Conclusion

Our results demonstrate that occupational divers had poor sleep quality and higher excessive sleepiness than non-divers. DCS likely has an important role in the deterioration of sleep quality of these individuals. DCS pathology might be an under-recognized risk factor for poor sleep quality among occupational divers. Therefore, further studies are warranted to validate our findings.

Under safe circumstances, occupational divers can continue diving for many more years without the risk of a negative impact on their sleep. However, clinicians, as well as divers themselves, should regularly monitor and evaluate sleep quality of those with a history of DCS to ensure early detection of any issues and to prevent the development of diseases associated with poor sleep quality. Therefore, clinicians who care for these divers should be aware of the importance of sleep quality and the prevention of DCS.

Funding

This study was supported by a grant from Zuoying Branch of Kaohsiung Armed Forces General Hospital Research Program (ZBH 107–16), Taiwan.

Conflicts of Interest

The authors have no conflicts of interest relevant to this article.

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