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# Thermophysiological responses and work strain in fishermen on deep-sea fishing vessels

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## ABSTRACT

***Background:*** *Fishermen working on deep-sea vessels in the Barents and Norwegian Sea are exposed to low air temperatures, strong winds, high humidity, rain, snow and work at different intensities. Few studies have investigated the effect of environmental work factors on the physiology of this occupational group. The aim of the study was to investigate work strain and thermophysiological responses of fishermen on the trawl and factory decks of deep-sea vessels.*

***Materials and methods:*** *Twenty-five professional male fishermen (age 39 ± 13 years) were recruited to the study which was performed on three trawlers in the Norwegian Sea in April, June and August 2014. During a six-hour shift, heart rate (HR), core ($T_c$) and mean skin ($T_s$) temperatures were recorded, and questions about subjective thermal sensation and comfort were answered.*

***Results:*** *Short periods of hard (above 86% of $HR_{max}$) work raised $T_c$ by 0.8°C to 37.8°C and decreased $T_s$ by 2.3°C to 29.8°C during work on the trawl deck, and subjects reported being warm and sweaty. On the factory deck long periods of fairly light (between 52% and 66% $HR_{max}$) work, $T_c$ of 37.4°C and $T_s$ of 30.9°C were measured.*

***Conclusions:*** *Fishermen experience intermittent periods of heavy work on the trawl deck shown with elevated core temperature and HR. Work on the factory deck includes long periods of repetitive work with light to moderate work strain. A better understanding of work strain and environmental challenges during work on Norwegian deep-sea vessels will help identify exposure risks during work in the cold and heat.*

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**Key words: thermophysiological responses, work strain, fishermen, trawlers**

## INTRODUCTION

Working conditions on board fishing vessels include exposure to potential hazardous situations, low ambient temperatures [1], muscle stress (heavy lifting) [2], noise [3] and unusual and long working hours [4]. These may have undesirable health effects and diminished performance. Working on a fishing vessel is demanding and requires constant vigilance as human error can have significant consequences for both personnel and the environment. The fisherman occupation is described by the Food and Agriculture Organisation (FAO) as one of the most dangerous occupations that exists [5], so it is important to increase awareness of potential risk factors in order to reduce the high incidence of work-related injuries among fishermen [6].

Working in the Norwegian Sea and the Barents Sea exposes fishermen to low air and water temperatures, high winds, high air humidity, rain and snow, all of which increase the risk of heat loss. Such conditions, with air temperatures below 10°C [1, 7] affect the physiological state of the body and may lead to cold stress. Such conditions may affect thermoregulatory responses as well as thermal sensation and comfort during work. Cold environmental conditions may

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**Table 1**. Anthropometric data, body mass index (BMI) and heart rate (HR) of fishermen on the three trawlers

| Trawler | Age [years] | Height [cm] | Weight [kg] | BMI [kg/m$^2$] | $HR_{max}$ [bpm]$^{\$}$ | $HR_{max}$ [bpm]$^{\&}$ | Number of participants |
|---|---|---|---|---|---|---|---|
| 1 | 34 ± 12 | 179 ± 4 | 87 ± 10 | 27.0 ± 2.5 | 184 ± 8 | 171 ± 8 | 8 |
| 2 | 42 ± 14 | 179 ± 6 | 90 ± 15 | 28.1 ± 3.9 | 179 ± 9 | 166 ± 9 | 10 |
| 3 | 39 ± 10 | 185 ± 5 | 94 ± 9 | 27.4 ± 2.6 | 181 ± 7 | 168 ± 7 | 7 |
| Mean | 39 ± 13 | 181 ± 6 | 90 ± 12 | 27.5 ± 9.2 | 181 ± 8 | 168 ± 8 | |

No significant differences were found between fishermen on the three trawlers; $^{\$}$Age-estimated maximal heart rate in beats per minute; $^{\&}$Age-estimated maximal heart rate adjusted for upper-body work

lead to increased muscle activity compared to thermo-neutral conditions. As a consequence, earlier exhaustion and reduced functionality is expected [8, 9]. Repetitive muscular work is also negatively affected by low temperatures, as early onset of fatigue may increase attrition and overtaxing of the musculoskeletal system [9]. Repetitive work at low intensity in cold (5 °C) environments have a negative effect on muscle function and fatigue [9], that may lead to overuse injuries and in the long run musculoskeletal disorders [10].

There is a lack of knowledge regarding the interaction between work, working conditions and the health of fishermen. To the best of our knowledge, the importance of work strain and thermal responses on board fishing vessels in the Barents and Norwegian Seas has not previously been studied. Our aim was therefore to investigate work strain and the thermophysiological responses of fishermen on trawlers in the Barents and Norwegian Sea.

On a trawler two main working locations are found. On the trawl deck several sub-tasks are performed, many of which involve heavy physical work at low temperatures and wind. On the factory deck, the work positions includes operating the head-and-gut machine, sorting and cleaning the fish, and packing and pulling frozen blocks of fish out of the freezers. We hypothesised that there are differences in work intensity between work on the trawl and factory deck with short periods of intermittent work with heavy work strain on trawl deck and long periods of highly repetitive work with light work strain on factory deck. We also hypothesised that heavy work strain will lead to higher core and mean skin temperatures during work on trawl deck, whereas light work strain on factory deck will lead to unchanged core temperature and low mean skin temperature. Both heavy and light work strain in the cold will negatively affect perceived thermal sensation and comfort of the crew.

## MATERIALS AND METHODS

Studies were performed on board three deep-sea trawlers in the Norwegian Sea in April, June and August 2014.

### PARTICIPANTS

Twenty-five male fishermen were recruited to the study after an information meeting aboard each trawler before it commenced fishing. The test subjects were all professional fishermen who performed their regular work during the study. Their characteristics are presented in Table 1. The crew, captain and ship-owners approved participation before leaving port. The study was performed according to the Helsinki Declaration concerning human test subjects, and was approved by the Regional Research Ethics Committee in Medicine, Norway.

### PROTOCOL

Each fisherman participated in the physiological measurements during one of their work shifts between 08:00 and 14:00 or 14:00 and 20:00. During each shift, work was performed on both the trawl and factory decks or on only one of these. On both places work was divided into several sub-tasks. The fishermen were equipped with sensors 30–60 min before they started their 6-h work shift. After the shift, the sensors were removed and all subjects answered a questionnaire about thermal sensation and comfort. During the test, the fishermen used their regular work clothing including a work suit with buoyancy or oilskin with a lifejacket on the trawl deck, and a work suit together with oilskin trousers on the factory deck.

### MEASUREMENTS AND INSTRUMENTS

#### Heart rate and oxygen consumption

In order to measure work intensity the fishermen were equipped with a heart-rate recorder (Equivital EQ02 LifeMonitor, Hidalgo, Cambridge, UK). Oxygen consumption was estimated based on the percentage of predicted maximal heart rate ($HR_{max}$), according to Lounana et al. [11].

#### Core and skin temperatures

In order to quantify heat production during work, core temperature was measured using a gastrointestinal temperature pill (Vital Sense Jonah capsule ± 0.1 °C, Mini Mitter Inc, Bend, OR, USA). Skin temperatures were measured by attaching thermistors (YSI, Yellow Springs, OH, USA, ± 0.15 °C) at 6 locations (chest, upper back, upper arm, lower arm, front thigh and front leg) on the body. (On one of the trawlers, a thermistor was placed on the hand instead of the upper arm). Mean skin temperature ($T_s$) was estimated according to Teichner [12].

### Subjective evaluation

After the shift, participants were asked to evaluate their perceived thermal sensation and comfort by completing a questionnaire modified from Nielsen et al. [13].

### Ambient conditions

A hand-held thermometer (Testo 435, Testo, Lenzkirch, Germany, accuracy ± 0.3°C, ± 2% relative humidity) was used to measure ambient temperature ($T_a$, °C) and relative humidity (RH, %) on the trawl and factory decks of two of the trawlers.

## DATA ANALYSES

Work intensity was calculated as a percentage of time spent within the intervals of %$HR_{max}$ corresponding to very light (< 52%), fairly light (52–66%), somewhat hard (67–85%) and hard (> 86%) on both factory and trawl deck [14, 15]. Work intensities are presented as the average value of the all participants (median ± 95% confidence interval). HR is adjusted for age [16], upper body work [17–19] and presented as percentage of $HR_{max}$. Heart-rate during work on factory deck is the mean HR of the entire work period. The data were collected 30 min after the start of each work period. Two representative averages of 10 min, separated by at least 30 min, were used to analyse $T_c$ and $T_s$ on factory deck. $HR_{max}$ and $HR_{min}$ are the highest and lowest measured values of HR. Highest and lowest $T_s$ and $T_c$ temperature were measured over three continuous minutes. Oxygen consumption was estimated from measured percentage of $HR_{max}$.

## STATISTICAL ANALYSIS

Normality was assessed by Shapiro-Wilk's test ($p > 0.05$). A Friedman test tested differences between the work intensity intervals on both decks on each trawler. Differences between $HR_{max}$ and $HR_{min}$ on the trawl deck and between HR and $HR_{min}$, $T_s$ and $T_c$ on the factory deck were analysed by Student's t-test for paired samples. Due to the small sample size, outliers and non-normality of the data, Student's t-test was not used on $T_s$ and $T_c$ from the trawl deck.

Differences between trawlers in HR, $T_s$ and $T_c$ were assessed by one-way analysis of variance (ANOVA). Differences in scores of thermal sensation and comfort between trawlers were analysed by a Kruskal-Wallis test. Repeated measures ANOVA was used to analyse differences between start, minimum, maximum and end values of $T_s$ and $T_c$, merged for all 3 trawlers during work on the trawl deck. Pairwise comparisons with Bonferroni correction for multiple comparisons were performed as *post hoc* tests. Data are presented as mean ± standard deviation (SD), unless otherwise stated. Statistical significance was accepted at $p < 0.05$. IBM SPSS Statistics v21 and Microsoft Excel 2013 were used as statistical software and SigmaPlot 13 as graphic design software.

# RESULTS

## AMBIENT CONDITIONS

On 2 of the 3 vessels, the temperatures on the trawl deck were 7 ± 2°C and 10 ± 4°C, respectively during the work shifts. Wind conditions ranged from light breeze (4–6 kt) to fresh breeze (17–21 kt). On the factory deck the ambient temperatures were 9 ± 1°C and 15 ± 2°C, and relative humidity 68 ± 9% RH and 79 ± 6% RH, respectively, on the 2 vessels.

## WORK INTENSITY

During the total work time on the trawl deck (40, 59 and 90 min on the 3 trawlers), short periods of hard work (> 86% $HR_{max}$) were measured. However, most of the time (approximately 80%) was spent working at fairly light (52–66% $HR_{max}$) and somewhat hard (67–85% $HR_{max}$) intensities. No differences between the time spent working at fairly light and somewhat hard intensity on the trawl deck were found (n = 19). Work on the factory deck (162, 168 and 291 min on the 3 trawlers) is mainly spent at fairly light intensities (approximately 62% of the time), and also included easy (10%; < 52% $HR_{max}$; $p = 0.001$), somewhat hard (18%; $p = 0.037$) and hard (0%; $p < 0.0005$) work intensities (n = 25).

## HEART RATE AND OXYGEN CONSUMPTION

A rise in mean HR of 38 ± 13% ($p < 0.0005$, n = 19) between lowest ($HR_{min}$) and highest ($HR_{max}$) was found on the deck of the 3 trawlers. An increase of 13 ± 6% ($p < 0.0005$, n = 25) between average HR and $HR_{min}$ were measured on the factory deck. No differences between trawlers were found for trawl or factory deck. $HR_{max}$ of 156 ± 20, 136 ± 23, 146 ± 3 bpm and $HR_{min}$ of 77 ± 8, 86 ± 12, 77 ± 11 bpm were measured during work on the trawl deck on trawlers 1, 2 and 3, respectively, corresponding to the percentages shown in Figure 1A. Figure 1B shows the percentages of HR and $HR_{min}$ during work on the factory deck (HR: 100 ± 10, 100 ± 9, 104 ± 7 bpm; $HR_{min}$: 83 ± 15, 76 ± 7, 77 ± 14 bpm).

Oxygen consumption during one shift on trawlers 1, 2 and 3 was estimated at 35%, 37% and 38% $VO_{2max}$, respectively. For work on the trawl deck, oxygen consumption was estimated at 48%, 49% and 47% $VO_{2max}$, with peaks of 85%, 72% and 78% $VO_{2max}$ on trawlers 1, 2 and 3, respectively. Oxygen uptake during work on the factory deck was estimated at 41%, 44%, and 45% $VO_{2max}$ on trawlers 1, 2 and 3, respectively.

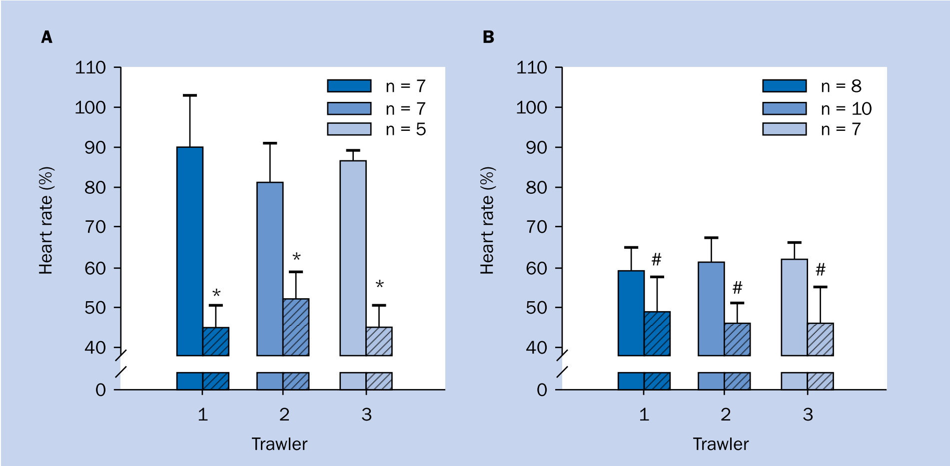


**Figure 1. A.** Maximum heart rate ($HR_{max}$, solid bars) and minimum heart rate ($HR_{min}$, hatched bars) recorded during work on the trawl deck on trawlers 1, 2 and 3; **B.** Average (solid bars) and minimum ($HR_{min}$, hatched bars) heart rate recorded during work on the factory deck on trawlers 1, 2 and 3. Percentage of age-estimated HR adjusted for upper body work; *Significant difference between $HR_{max}$ and $HR_{min}$ on trawl deck ($p < 0.05$). #Significant difference between average heart rate and $HR_{min}$ on factory deck ($p < 0.05$). Values are means ± standard deviation

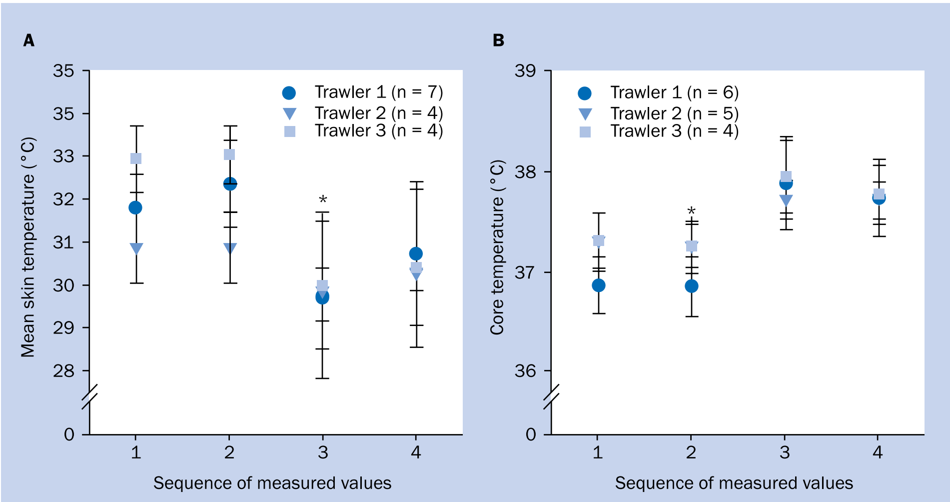


**Figure 2. A.** Mean skin temperature (°C) during work on the trawl deck on trawlers 1, 2 and 3. Sequence of measured values 1–4 represent mean skin temperatures at start (1), maximum (2), minimum (3) and end of the test (4); **B.** Core temperature (°C) during work on the trawl deck on trawlers 1, 2 and 3. Sequence of measured values 1–4 represent core temperatures at start (1), minimum (2), maximum (3) and end of the test (4); *Significant difference between lowest and highest mean skin and core temperature on the trawl deck ($p < 0.05$). Values are means ± standard deviation

## CORE AND SKIN TEMPERATURE

### Trawl deck

Fishermen on the three trawlers entered the trawl deck (start) with an average $T_s$ of 31.9 ± 1.1°C. The average $T_s$ rose to a maximum (max) of 32.1 ± 1.2°C before it decreased significantly to the lowest value (min) of 29.8 ± ± 1.6°C ($p < 0.0005$, n = 15) (Fig. 2A). No significant changes in $T_s$ from the start until the highest values, were found (p = = 0.475). However, from the highest to the lowest values a significantly reduced $T_s$ ($p < 0.0005$) of 2.3°C was measured.

The average $T_c$ on all three trawlers increased significantly during work on the trawl deck ($p < 0.0005$, n = 15) to 37.8 ± ± 0.4°C (max) (Fig. 2B). No changes between start (37.1 ± ± 0.4°C) and minimum (37.1 ± 0.3°C) $T_c$ were found on any of the trawlers (p = 0.499). During work on trawl deck $T_c$ increased by 0.8°C (95% CI, 0.5 to 1.0, $p < 0.0005$) to 37.8°C.

### Factory deck

The lowest $T_s$ measured on the factory decks of the trawlers (29.5 ± 1.5°C) differed significantly from the average (30.9 ± 1.2°C) temperature ($p < 0.0005$) (Fig. 3A).

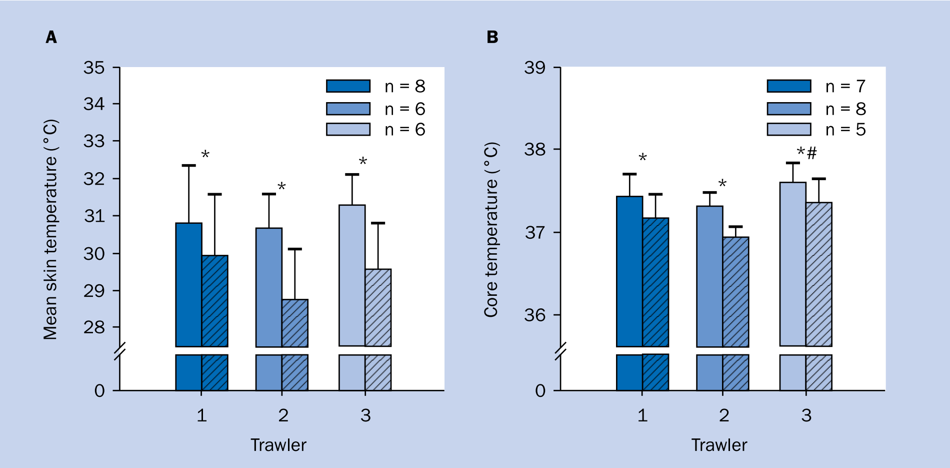


**Figure 3. A.** Average (solid bars) and lowest (hatched bars) mean skin temperature during work on the factory deck on trawlers 1, 2 and 3; **B.** Average (solid bars) and lowest (hatched bars) core temperature during work on the factory deck on trawlers 1, 2 and 3; *Significant difference between minimum and average mean skin and core temperature ($p < 0.05$); #Significant difference in core temperature between trawlers 2 and 3 ($p < 0.05$). Values are means ± standard deviation

On trawler 1, $T_s$ rose by 0.8 ± 0.6°C ($p = 0.006$) from 30.0 ± ± 1.6°C. On trawlers 2 and 3 $T_s$ rose by 1.9 ± 0.7°C ($p = = 0.001$) from 28.7 ± 1.5°C and by 1.7 ± 1.3°C ($p = 0.023$) from 29.6 ± 1.3°C, respectively. $T_c$ on the factory decks of the trawlers showed a small but significant increase from 37.1 ± 0.3°C to 37.4 ± 0.2°C during work ($p < 0.0005$) (Fig. 3B). The $T_c$ of fishermen on trawlers 1, 2 and 3 showed a significant increase of 0.3 ± 0.2°C ($p = 0.013$), 0.4 ± 0.1°C ($p < 0.0005$) and 0.3 ± 0.1°C ($p = 0.008$) from 37.2 ± 0.3°C, 36.9 ± 0.1°C and 37.3 ± 0.3°C, respectively. The average and minimum $T_c$ were significantly higher on trawler 2 than 3.

### SUBJECTIVE EVALUATION OF THERMAL SENSATION AND COMFORT

At the end of their shifts 11 (46%) fishermen reported their body to be "neutral" whereas 7 (29%) described their body to be "warm". The answers ranged from "slightly chilly" to "extremely hot". During work on the trawl deck and when pulling blocks of fish out of the freezers on the factory deck, the fishermen answered they were rarely cold, but hot, very hot or extremely hot. Twenty-one (88%) fishermen reported that they felt thermally comfortable during their work shift. Answers ranged from comfortable to uncomfortable.

## DISCUSSION

### WORK INTENSITY AND HEART RATE

Our findings supported our hypothesis of a difference in work intensity between work on the trawl and factory decks. On the trawl deck, the fishermen spent a few minutes above 86% of $HR_{max}$ and a long period above 67% of $HR_{max}$. A study by Åstrand et al. [20] of Norwegian coastal fishermen measured $VO_{2max}$ peaks up to 80% of $VO_{2max}$ during fishing, which is in accordance with the heart rates of fishermen working on the trawl deck of deep-sea trawlers. In accordance with previous findings from Norwegian costal fishing [21], work on trawl decks can be characterised as intermittent activity with average levels of work strain, as shown by the distribution of time within the work intensities fairly light and somewhat hard. That work was performed within all four work intensity classifications indicates a work situation with changing intensities classified as intermittent work.

We found that fishermen spent more than 60% of their time working on the factory deck between 52% and 66% $HR_{max}$. In contrast to the intermittent character of work on the trawl deck, work on the factory deck is highly monotonous and repetitive, as also observed by Törner et al. [2]. The ambient temperatures inside the factory deck were 9°C and 15°C in two of the trawlers, and can be described as cold and cool work environments [1, 7]. Repetitive work at low intensities in cold (5°C) environments have a negative effect on muscle function and fatigue [9] that may lead to overuse injuries and in the long run, musculoskeletal disorders [10]. Several studies have been performed on the incidence of work-related musculoskeletal disorders from cold indoor work [21–23], especially among workers in the fish-processing industry [24–27]. Our findings of prolonged low-intensity highly repetitive work in a cold environment is a factor that may explain that fishermen are at higher risk of developing musculoskeletal symptoms, which is in accordance with previous studies [2, 27, 28] and recent findings among Norwegian fishermen on deep-sea fishing vessels (Sandsund et al. in prep.).

Heart rate reached peaks above 86% of $HR_{max}$ during work on the trawl deck and averaged 60% of $HR_{max}$ on the factory deck. The World Health Organisation (WHO) classifies HR below 100 bpm as light, between 100 to 125 bpm as moderate and above 125 as heavy cardiac strain [29]. During work on the factory deck, fishermen on the trawlers had average HR of 100–104 bpm. Work on factory deck on deep-sea trawlers induced light to moderate cardiac strain in accordance with the classification by Andersen et al. [30]. The maximal HR measured during work on trawl deck varied between 136 and 156 bpm on the 3 trawlers. Average cardiac strain experienced by the fishermen on trawl deck can be classified as moderate, but we measured a high incidence of heavy cardiac strain shown as time spent at somewhat hard and hard work intensities.

The WHO classification of cardiac strain [30] does not consider the relevance of the age or physical fitness of workers. A HR of 100 bpm does not imply the same work intensity or cardiac strain for a 20- and a 50-year-old man. In our study the youngest and oldest participants were 19 and 60 years old, respectively. This range of ages makes HR, presented as beats per minute, a poor measure to describe work intensity or cardiac strain in our sample. Rodahl et al. [20] and Rodahl and Vokac [31] present cardiac strain and work load in terms of HR reserve, with corresponding oxygen uptake equivalent. Heart rate reserve is a method to estimate exercise intensity, but it does not correlate well with $VO_{2max}$ [11]. We present our data in terms of percentage of age-estimated $HR_{max}$, as this has a well-established linear relationship with $VO_{2max}$ [32, 33].

Operating fishing gear and fish-processing machines is heavily reliant on upper body work [2, 3]. We therefore decided to adjust the age estimates of $HR_{max}$ for upper body work. The adjustment by 13 bpm [17–19] was applied to heart rate during work on both factory and trawl deck. Åstrand et al. [20] and Rodahl et al. [34] showed that coastal fishermen and Norwegian trawler crew had an average energy expenditure during all activities corresponding to about 39% of $VO_{2max}$, which is in agreement with the estimated oxygen consumption in our findings. WHO recommends that the metabolic strain of a normal workday including pauses should not exceed 50% $VO_{2max}$ [30]. A study of open-cast miners in Finland and Sweden by Oksa et al. [35] found an average metabolic strain of around 35% of $VO_{2max}$, which is very similar to our findings of a metabolic strain of about 37% $VO_{2max}$. Neither our findings nor those of Oksa et al. [35] exceeded WHO's recommendations.

## CORE AND SKIN TEMPERATURE

We predicted that high work strain on the trawl deck would lead to an increased core and mean skin temperature. We measured a drop in mean skin temperature and an increase in core temperature during work on the trawl deck, in agreement with previous studies on high-intensity work in cold environments [36–38].

The fishermen reported that they were warm and sweaty after working on the trawl deck, which may be in contradiction to the drop in mean skin temperature. Sparks et al. [37] measured mean skin temperature to about 29°C in an ambient temperature of 10°C, similar to results of Sandsund et al. [38], and in accordance with the lowest mean skin temperature during work on the trawl deck in our study. Skin temperature falls in cold environments in response to vasoconstriction, which reduces skin blood flow. In our study the ambient temperatures were 7°C and 10°C on trawlers 2 and 3, respectively, and in combination with wind exposure between light and fresh breeze this gives a significant lower effective temperature. No differences between the lowest mean skin temperatures were measured on the 3 trawlers.

In accordance with previous findings [36, 37], we observed an increase in core temperature during work in a cold (10°C) environment. Our results show an average rise of 0.8°C in core temperature on all 3 trawlers during work on the trawl deck. This increase is in agreement with core temperatures measured during duathlons in 10°C [37]. Fishermen reported that they were warm and sweaty during work on trawl deck in spite of their lower mean skin temperature. This can be explained by higher core temperature leading to an enhanced central drive towards sweating, as shown by Kondo et al. [39].

We also hypothesised that low work strain on the factory deck would lead to low mean skin temperature and unchanged core temperature. The mean core temperature on all 3 trawlers was 37.4°C and the lowest was 37.1°C. The core temperature measured on the factory deck is within the interthreshold zone of thermoregulation [40] and does not contribute to any particular thermal stress. This finding is further supported by the subjective evaluations of thermal comfort, as the fishermen did not report any shivering during work on factory deck. The mean skin temperature of fishermen on trawler 1, 2 and 3 was 30.9°C at ambient temperatures of 9°C and 15°C on the factory decks of trawlers 2 and 3 during work, respectively. These finding is in accordance with previous studies on exercise in similar ambient temperatures [36, 37]. Neither the average or lowest mean skin temperature on any of the trawlers indicate an uncomfortable thermal environment according to the relationship between mean skin temperature and thermal comfort and sensation [41, 42]. This also corresponds well with the crew-members' subjective evaluations of thermal comfort and perceived thermal sensation.

Since all field measurements took place during spring and summer, the participants were not exposed to any extreme weather or sub-zero temperatures. Therefore, this study is limited to circulatory and thermoregulatory responses in ambient temperatures of about 10°C.

However, during repetitive work at low intensity in cold environments during winter months, one may expect a negative effect on muscle function and fatigue.

## CONCLUSIONS

This study confirms that workers on deep-sea fishing vessels are periodically exposed to high levels of work strain, manifested as raised core temperature and heart-rate when working on the trawl deck. On the factory deck, fishermen endure long periods of light to moderate repetitive work, unchanged core temperatures and a small but significant reduction in mean skin temperature. A better understanding of work strain and environmental challenges during work will help identify risk exposures, and may be useful in future studies aimed at reducing symptoms of musculoskeletal disorders in fishermen.

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## CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

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