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Thermoregulatory Responses and Work Strain of Fishermen

A Field Study and a Laboratory Study

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MSc in Biology
Submission date: May 2015
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Preface

This master thesis is written at the Institute of Biology, at the Norwegian University of Science and Technology (NTNU), and SINTEF Technology and Society, department of Health Research. The thesis is a part of the project "Working environment and health in the Norwegian fishing fleet: challenges and health promoting factors" financed by the Research Council of Norway.

I want to thank my main supervisor and head of research Randi Eidsom Reinertsen for the opportunity to work with, and write my thesis at SINTEF Technology and Society, department of Health Research. I wish to thank her for excellent guidance and insight during these two years. I want to thank my supervisor and senior researcher Mariann Sandund for invaluable support during the entire process of this thesis, your support from the beginning of the field study to the last hours of writing the thesis have been without comparison. I also wish to direct a thanks to Øystein N. Wiggen for training in the laboratory, and Maria Suong Tjønnås and Julie Renberg for being helpful whenever needed and small pieces of advice along the way.

Cecile Thon Heidelberg deserves a lot of recognition for the completion of our field study. We literally made it through storms together. Thank you for the adventure, Cecile!

All fishermen on board the three trawlers we visited and the subjects who volunteered to the laboratory study deserves a lot of gratitude for their effort. Without you, this thesis would not have been possible to conduct.

A thank you to my family who have supported me along the way and helped with proof reading of the thesis towards the end.

Last, I wish to direct a message to my lovely girlfriend: Your weeks as a bachelorette is now over! Thank you for putting up with me for the last year, I know it has not been easy at times.

Erik Ulvolden Høye

Trondheim, May 2015

Abstract

Fishermen on board deep-sea trawlers in the Barents and Norwegian Sea are exposed to low air temperatures, strong winds, high humidity, rain, snow and work with varying intensities. No studies have investigated the effect of environmental work factors on selected physiological parameters of fishermen on board Norwegian deep-sea trawlers. This study was therefore performed to increase knowledge about work strain and environmental challenges on factory and trawl deck, by recording heart rate (HR), core (T_c) and mean skin (T_s) temperatures of 25 fishermen during work on deep-sea trawlers. Short periods of hard (above 86% of HR_{max}) work, increased T_c by 0.8°C to 37.8°C and decreased T_s by 2.3°C to 29.8°C were measured on trawl deck, together with subjective reports of being warm and sweaty. On factory deck long periods of fairly light (between 52-66% HR_{max}) work, T_c of 37.4°C and T_s of 30.9°C were measured. Fishermen endures short periods of intermittent work with heavy work strain on trawl deck and long periods of repetitive work with light to moderate work strain on factory deck. The present study characterizes work strain and environmental challenges endured by fishermen, and can help identify risk exposures during work in cold and warm environments.

Based on observations and measurements from the field study a laboratory study was conducted with the objective of studying the relationship between high (85%) and low (19%) relative humidity (RH) and sweat rate during inactive recovery after high intensity work in a warm environment (30°C). Ten male subjects volunteered to perform two 20-minute run-trials at 68 ± 4 % of maximal oxygen consumption followed by 36 minutes of upright inactive recovery. Regional sweat rate (RSR) was measured on the arm and back by technical absorbent pads at regular intervals and gross sweat loss was estimated from change in body weight. T_c, T_s, and HR were measured continuously during running and recovery. RSR were significantly ($p<0.05$) higher in high humidity, compared to low humidity conditions for both arm and back during running and inactive recovery. The highest sweat rates were observed on the back during the test in high humidity test with mean values of 1387 $g \cdot m^{-2} \cdot h^{-1}$ during the last five minutes of running and 1379 $g \cdot m^{-2} \cdot h^{-1}$ during the first five minutes of recovery. RSR showed weak to moderate correlations to local skin temperature during inactive recovery, but no correlations to local skin temperature during running. T_c continued to increase for three and seven minutes post-exercise in 19% RH and 85% RH respectively. HR was 11 bpm higher after running in 85% RH compared to 19% RH ($p=0.001$). Thermal load was higher during post-exercise recovery in high compared to low humidity conditions.

Sammendrag

Fiskere om bord på trålere i Barents- og Norskehavet er eksponert for lave lufttemperaturer, sterk vind, høy luftfuktighet, regn, snø og arbeid med varierende intensitet. Ingen studier har undersøkt effekten av omgivelsesfaktorer på utvalgte fysiologiske parametere hos fiskere på trål- og fabrikkdekk om bord på norske trålere til havs. Denne studien ble utført for å øke kunnskapen om arbeidsbelastning og utfordringer knyttet til omgivelsesforhold ved å måle hjerte frekvens (HR), kjernetemperatur (T_c) og gjennomsnittlig hudtemperatur (T_s) hos 25 fiskere under arbeid på havgående trålere. Korte perioder med hardt (over 85% HR_{max}) arbeid, 0,8°C økning i T_c til 37,8 °C og redusert T_s med 2,3°C til 29,8°C ble målt på tråldekk, samt subjektive tilbakemeldinger fra fiskerene om at de var varme og svette. Lange perioder med ganske lett (mellom 52-66% HR_{max}) arbeid, T_c på 37,4°C og T_s på 30,9°C ble målt på tråldekk. Fiskere arbeider korte perioder med periodisk høy arbeidsbelastning på tråldekk og lange perioder med repeterende arbeid ved lave til moderate arbeidsbelastninger på fabrikkdekk. Denne studien karakteriserer arbeidsbelastningen og utfordringer knyttet til omgivelsene hos fiskere og kan hjelpe til med å identifisere risiko relatert til arbeid i kulde og varme på havgående trålere.

Et laboratoriestudium basert på observasjoner og målinger fra felt ble utført for å studere forholdet mellom høy (85%) og lav (19%) relativ luftfuktighet (RH) og svetterate under en stillestående restitusjonsperiode etter arbeid ved høy intensitet i varme (30°C). Ti menn utførte to 20-minutters løpetester ved 68 ± 4% av maksimalt oksygenopptak etterfulgt av en 36 minutters stillestående restitusjonsperiode. Regional svetterate (RSR) ble målt på armen og ryggen med teknisk absorberende materiale ved regelmessige intervaller og totalt svettetap ble beregnet fra endring i kroppsvekt. T_c, T_s og HR ble målt kontinuerlig under løping og restitusjon. RSR var signifikant ($p<0,05$) høyere i høy fuktighet sammenlignet med lav fuktighet for både arm og rygg under stillestående restitusjon. Høyeste svetterate på ryggen ble målt ved høy fuktighet til 1387 $g \cdot m^{-2} \cdot h^{-1}$ under de siste fem minuttene av løping og 1379 $g \cdot m^{-2} \cdot h^{-1}$ under de første fem minuttene av restitusjon. RSR viste svak til moderat korrelasjon med lokal hudtemperatur under restitusjon, men ingen korrelasjon til lokal hudtemperatur under løping. T_c fortsatte å stige i tre og syv minutter etter løping i henholdsvis 19% RH og 85% RH. HR var 11 slag i minuttet høyere etter løping i 85% RH sammenlignet med 19% RH ($p=0,001$). Termisk belastning var høyere etter løping i omgivelser med høy luftfuktighet sammenlignet med lav luftfuktighet.

Abbreviations

Symbol	Description	Unit
A	Area	m^2
BF	Body fat	%
D	Density	$kg \cdot m^{-2}$
E_{res}	Respiratory evaporation	W
HR	Heart rate	bpm
HR_{max}	Highest recorded estimated maximal heart rate	bpm
HR_{min}	Lowest recorded estimated maximal heart rate	bpm
HR_{peak}	Highest measured heart rate	bpm
GSL	Gross sweat loss	$g \cdot h^{-1}$
MML	Metabolic mass loss	g
MR	Metabolic rate	W
P_a	Partial water vapour pressure	kPa
PTS	Perceived thermal sensation	
O_e	Fraction of oxygen in expired air	
RER	Respiratory exchange ratio	
RH	Relative humidity	%
RPE	Rating of perceived exertion	
RSR	Regional sweat rate	$g \cdot m^{-2} \cdot h^{-1}$
RWL	Respiratory water loss	g
T_a	Ambient temperature	°C
T_c	Core temperature	°C
T_s	Mean skin temperature	°C
V_E	Ventilation	$L \cdot min^{-1}$
VO_2	Oxygen consumption	$L \cdot min^{-1}$/ $ml \cdot kg^{-1} \cdot min^{-1}$
VO_{2max}	Maximum oxygen consumption	$L \cdot min^{-1}$/ $ml \cdot kg^{-1} \cdot min^{-1}$

Contents

1 Introduction

1.1 Background

The working conditions on board fishing vessels are complex, and with many elements of hazardous risks. Exposure to potential hazardous situations, low ambient temperatures (cold)(ISO 15743: 2008), muscle stress (heavy lifting) (Törner et al. 1988a), noise (Fulmer and Buchholz 2002) and unusual and long working hours (Törner et al. 1988b) may induce unwanted health effects, reduced work performance and also work participation. The fisherman occupation is described by The Food and Agriculture Organization of the United Nations (FAO) as one of the most dangerous occupations that exists (Turner 2012), so it is important to increase awareness of potential risk factors to reduce the high amount of work related injuries among fishermen (Aasjord et al. 2013).

Working in the Norwegian Sea and the Barents Sea exposes fishermen to low air- and water temperatures, strong winds, high air humidity, rain and snow all contributes to an increased risk of heat loss during cold exposure. Exposure to such conditions, with air temperatures below 10°C (BS EN 7915: 1998; ISO 15743: 2008) affect the physiological state of the body at and eventually leads to cold stress. Working on a fishing vessel is demanding and requires constant vigilance. Errors during work on board might have significant consequences for personnel and environment. Cold stress is an important factor and adds to the high risk of accidents since it increases the risk for work related accidents (Ramsey et al. 1983). In addition to the exposure to cold stress, fishermen on deep-sea trawlers perform work that change between high and low work intensity in varying work environments. Fishermen on board a deep-sea trawler are exposed to two main working conditions. Work on the trawl deck exposes fishermen to the outdoor weather conditions and intermittent high work intensity, while work on the factory deck exposes fishermen to cold, high humidity environment and low work intensity. These conditions affect thermal sensation and comfort during work as well as thermoregulatory responses. To increase our knowledge about the effect of the change from high to low work intensity in different environmental conditions we need knowledge about the thermal responses that are evoked when fishermen are exposed to the prevailing environmental conditions on board fishing vessels in the Barents and Norwegian Sea. Therefore, this study was carried out in two steps; an initial field study where the effect of

environmental work factors on selected physiological parameters were examined, followed by a laboratory study simulating a selection of some important environmental and work factors.

1.2 Thermoregulation

Humans are homeotherms which possess an internal body temperature between 36-40˚C throughout their lifetime. An important quality of homeothermy is the maintenance of a relative high body temperature compared to a low ambient temperature. This is achieved by producing metabolic heat and exchanging heat gradually to the environment, in that way the variation in body temperature rarely exceeds ±2˚C (Werner 1988; Jessen 2001). Changes in both core and peripheral body temperature is registered by thermo-sensors spatially distributed throughout the body (Werner 1988; Werner 2009). The temperature information gathered by the thermo-sensors is processed by two control centres, preoptic area in posterior hypothalamus and preoptic area in anterior hypothalamus (Simon et al. 1986; Romanovsky 2006). The preoptic area in the posterior hypothalamus is in control of the heat production of the body, while the preoptic area in the anterior hypothalamus supervises the body's heat dissipation (Simon et al. 1986; Mekjavic and Eiken 2006). Coordination between these two centres are suggested to regulate the body temperature by mutually inhibition, which would allow rapid adjustments to environmental conditions (Hensel 1973; Mekjavic and Eiken 2006)

1.2.1 Heat balance

The human body produces heat at a varying degree according to the needs of a person's activity level. To maintain the heat balance of the body, heat production have to equal heat loss (Webb 1995). Heat balance depends on several external factors such as ambient temperature (T_a), humidity, wind, radiative heat gain, thermal insulation of clothing and the internal factor of metabolic heat production (Werner 1988; Hassi et al. 2005). Skin and superficial muscle temperatures depends on the above mentioned external factors and may vary even when the body is in heat balance with a stable core temperature (Webb 1995; Blatteis 1998).

1.2.2 Heat exchange

The body releases energy as heat that increases T_c when activity levels increase, which promotes heat loss mechanisms. For heat dissipation the produced heat need to be transferred to the skin, where heat exchange with the environment is takes place through conduction,

convection, radiation and evaporation (Jessen 2001). The direction and rate of heat exchange (gain or loss) is dependent on the difference in temperature between body and environment, conductance of the mediums (air, water, skin), and distance and size of the area of exchange (Gagge and Gonzalez 1996). Transfer of heat to or from (or within) an object or an organism takes place in the form of conduction. Conduction always occurs in the direction of the temperature gradient (from low to high) and contributes to 3% of total heat loss in comfortable room temperature (Wendt et al. 2012). Convection is heat transfer by moving liquid or gas. Heat loss by convection always occurs due to the heating of the air around the body. This causes warm air to rise and be replaced by cooler air, which leads to a constant heat sink around the body (Gagge and Gonzalez 1996). Radiation is the net heat gain or loss of objects through infrared heat. When the body is warmer than the objects in its surroundings, it will lose heat from radiation, and if the surroundings is warmer than the body it will gain heat through radiation (Gagge and Gonzalez 1996). Evaporation is the mechanism of heat loss through insensible water loss or sweating. Insensible water loss is the no controllable loss of water through diffusion and ventilation (Werner 1988; Wendt et al. 2012). Sweating is the main heat loss mechanism during exercise or in warm environments when the body gains heat through conduction, convection and radiation. Heat loss by sweating works through evaporation of secreted sweat and provides for an effective mechanism to avoid hyperthermia (Gagge and Gonzalez 1996).

1.2.3 Work in cold environments

When exposed to cold conditions the body core consisting of brain, spinal marrow, chest cavity and abdominal region will reduce its circumference by vasoconstrictions in the peripheral parts of the body in order to reduce heat loss (Åstrand and Rodahl 1986). The peripheral parts of a cold exposed body are defined to be the skin-surface and muscles (Jessen 2001). When first exposed to cold, the initial response of temperature regulation is achieved by vasoconstriction in the peripheral skin and musculature. Vasoconstriction leads to a lower skin blood flow, which results in lower skin temperature (Webb 1995; Jessen 2001) and a reduced temperature gradient to the environment (Gagge and Gonzalez 1996). This response will prevail until the ambient temperature reach the thermos neutral zone or the capacity of the vasoconstriction to maintain a steady core temperature is exceeded (Werner 1988; Mekjavic and Eiken 2006). When the capacity of vasoconstriction is exceeded, shivering is

initiated as an effector mechanism. Shivering is a mechanism to increase metabolic heat production in response to peripheral cold stimuli (Webb 1995; Mekjavic and Eiken 2006).

When exposed to environmental factors as low ambient temperature, wind and rain the body heat content, and thus body temperature will be affected both globally and locally. This may lead to changes in several physiological parameters as nerve conduction, muscle power, mobility and tactile sensitivity (Heus et al. 1995). Studies show that cold environmental conditions leads to increased muscle activity compared to thermo-neutral conditions. As a consequence earlier exhaustion and reduced functionality is expected (Oksa et al. 1995; Oksa et al. 2002). Repetitive muscular work is negatively affected by cold temperatures, as early onset of fatigue may increase attrition and overtaxing of the musculoskeletal system. Therefore it is important to avoid additional fatigue by maintaining a normal core temperature (Oksa et al. 2002).

1.2.4 Work in hot environments

When the human body is exposed to ambient temperatures above the thermoneutral zone, ranging from 28 to 35°C (Savage and Brengelmann 1996; Færevik et al. 2001), a vasomotor response will initiate vasodilatation (Mekjavic and Eiken 2006). Vasodilatation effectively increases blood flow to the skin, which results in an increased skin temperature (Åstrand and Rodahl 1986). Once the capacity of vasodilatation to defend a stable T_c within the interthreshold zone is exceeded. Sweating is initiated as the autonomic effector mechanism of heat loss (Mekjavic and Eiken 2006).

Several physiological challenges are connected to working or performing exercise in hot environments (González-Alonso et al. 2008). During heavy work or exercise in a hot environment there is an increased strain on the cardiovascular system. This increased strain on the cardiovascular system results from an enhanced thermoregulatory demand of skin blood flow (Wyss et al. 1975; González-Alonso et al. 2008). At the onset of work or exercise in hot environments, vasoconstriction limits the skin blood flow. If the activity continues body temperature rises and vasodilatation is initiated (Fortney and Vroman 1985; Kenny and Jay 2007). The activation of the vasodilatation response at the start of exercise or work in hot environments is delayed. This modification results from two mechanisms. Firstly, an increase in the internal temperature threshold at which skin blood flow begins to increase (Kellogg et al. 1991), which leads to an delayed initiation of active vasodilatation. Secondly, as the T_c

continues to rise during work in the heat, skin blood flow reaches an upper limit at a T_c around 38°C (Brengelmann et al. 1977). Another well-established consequence of exercise in heat is a reduced stroke volume and increased heart rate leading to a lower cardiac output (Rowell et al. 1966; González-Alonso et al. 2000). This reduction in stroke volume has been attributed to the increased skin blood flow during exercise and work in heat (Rowell 1974), but is more likely a combination of elevated internal temperature acting on heart rate and skin blood flow (González-Alonso et al. 2000).

When vasodilatation is no longer sufficient to defend a stable T_c within the interthreshold zone, sweating is initiated as an effector mechanism to increase heat loss (Nadel et al. 1971; Werner 1988; Mekjavic and Eiken 2006). Sweating is a very powerful mechanism for heat loss, and the only available when environmental temperature is higher than the body temperature (Nadel et al. 1971; Torii 1995; Havenith et al. 2008b). When heat gain exceeds the capacity for heat loss during exercise or work in hot environments, T_c will continue to rise and result in increased heat stress of the body (Parsons 2014). Heat stress during work can have many severe implications. Mental confusion, behavioural changes, muscular failure, fainting and eventually death due to denaturing of proteins are all some of the potential results of severe heat stress (Parsons 2014).

Sweating in heat and high humidity

Sweating is the main mechanism for heat loss during work at high ambient temperatures (Wyndham et al. 1965; Åstrand and Rodahl 1986). Both the production of sweat and regulation of sweating have been object of many studies (Nadel et al. 1971; Nadel and Stolwijk 1973; Cotter et al. 1995; Machado-Moreira et al. 2008; Havenith et al. 2008a; Smith and Havenith 2010). Aerobic fitness, acclimation, environmental conditions, clothing and evaporative efficiency are all important modifiers of sweat production (Candas et al. 1979; Shapiro et al. 1982; Havenith et al. 2008b), which is the main factor of evaporative cooling power. Sweating facilitates heat loss through evaporation of sweat on the skin (Gagge and Gonzalez 1996). The evaporative power available through sweating in a hot environment is highly dependent on humidity, or the water vapour pressure of the surrounding air (Candas et al. 1979). Several studies have historically been conducted on total sweat loss, or gross sweat loss (GSL), of the whole body during varying conditions and activities. In recent years differences in regional sweat rates (RSR) have gained attention because of the research within design of clothing, thermophysiological modelling and thermal manikins (Fiala et al. 1999;

Havenith 2001; Havenith et al. 2008b; Smith and Havenith 2010). It has become well established that RSR varies greatly depending on body location. RSR is highest on the back along the lumbar spine and is greatly reduced in the extremities (Cotter et al. 1995; Smith et al. 2007; Machado-Moreira et al. 2008; Havenith et al. 2008a). A study by Smith and Havenith (2010) mapped the RSR of the entire body of male athletes during mild exercise and showed that the highest sweat rates were observed on the central back and lowest on the hands and feet.

Exercise or work in hot and humid environments is especially challenging for the thermoregulatory capacity of the body (Werner 1988; Wendt et al. 2012). Maughan et al. (2012) showed a significant decrease in exercise capacity at high humidity compared to low humidity. The decreased performance in hot humid environments can be linked to reduced efficiency of sweat evaporation as the gradient between ambient water vapour pressure and skin decreases (Candas et al. 1979; Wendt et al. 2012). A hot and humid environment may therefore exceed the capacity of the evaporative heat loss mechanism (Wendt et al. 2012). The decrease in heat loss capacity is further reduced during prolonged sweating, profound sweating or high humidity conditions due to the effect of hidromeiosis. Hidromeiose is the effect of skin hydration, which results in a decline in sweating when the skin is saturated (Nadel and Stolwijk 1973; Candas et al. 1983). The thermoregulatory responses of passive, inactive and active and nonthermal effects on post-exercise recovery have been investigated in earlier studies (Carter III et al. 2002; Wilson 2004; Jay et al. 2008). There is a need to increase the current knowledge about effects of high humidity during exercise and post-exercise recovery, especially in connection with occupations where these conditions may occur.

1.3 Study objective, hypotheses and predictions

The first objective of this study is to investigate and increase knowledge about work strain, and work-related environmental challenges and thermophysiological responses of fishermen on deep-sea trawlers in the Barents and Norwegian Sea. Humid environments may be especially challenging for the thermoregulatory capacity of the body. Based on observations and measurements from the field study, we therefore want to study the effect of humidity on the thermoregulatory responses of the fishermen on deep-sea trawlers in a laboratory study. The second objective is therefore to study the relationship between high (85%) and low (19%) relative humidity and sweat rate during inactive recovery after work with high intensity in a warm (30°C) environment.

1.3.1 Hypothesis of the field study

The changing levels of work strain that fishermen endures in cold work environments on board deep-sea trawlers, will result in 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.

Predictions

1. There are differences in work intensity, measured as heart rate, between work on trawl and factory deck. Heart rate will vary during work on trawl deck with high peaks of heart rate and be stable at low heart rates, while working on the factory deck.

2. In cold environments, light work strain on factory deck will lead to unchanged core temperature and a low mean skin temperature compared to thermoneutral conditions. Heavy work strain will lead to increasing core and mean skin temperature during work on trawl deck.

3. Both heavy and light work strain in cold ambient conditions will negatively affect thermal comfort and perceived thermal sensation of fishermen working on board deep-sea trawlers.

To test the hypotheses and predictions the following parameters were measured: Heart rate, skin temperatures, core temperature, perceived thermal sensation and thermal comfort.

1.3.2 Hypothesis of the laboratory study

Thermal load during post-exercise inactive recovery is higher in a high humidity (85% RH) environment, compared to a low humidity (19% RH) environment at 30°C.

Predictions

1. Gross sweat loss ($g \cdot h^{-1}$) will be higher in a high humidity compared to a low humidity environment and show a positive correlation to the metabolic rate.

2. Regional sweat rate will be higher ($g \cdot m^{-2} \cdot h^{-1}$) in high humidity compared to a low humidity environment. Furthermore a low humidity environment will lead to a quicker decrease in regional sweat rates ($g*m^{-2}h^{-1}$) and the slope of the gradient will be larger.

3. High humidity will lead to a higher mean skin temperature during exercise compared to exercise in a low humidity environment. Mean skin temperature will decrease faster during inactive recovery in a low humidity environment.

4. Core temperature will remain unchanged between high and low humidity during the exercise period, but reach a higher value during inactive recovery in high humidity.

5. High humidity will negatively affect perceived thermal sensation, thermal comfort and perceived exertion compared with a low humidity environment.

To test the hypotheses and predictions the following parameters were measured: Sweat rate, heart rate, skin temperatures, core temperature, change in body mass, oxygen consumption, perceived thermal sensation, thermal comfort and ratings of perceived exertion.

2 Methods

This master thesis is a part of the project Working environment and health in the Norwegian fishing fleet: challenges and health promoting factors at SINTEF Technology and Society, SINTEF Fisheries and Aquaculture and University Hospital North Norway. This project is financed by the Research Council of Norway. The thesis was conducted in two parts. The first part was a field study on board three deep-sea trawlers fishing in the Barents and Norwegian Sea, where physiological parameters of fishermen were measured during work. The second part was a laboratory study, with ten healthy men participating. The laboratory study was performed at the Work Physiology Laboratory at SINTEF Technology and Society, Department of Health Research. The regional ethical committee for medical and health research (REK) approved protocols for field and laboratory studies.

2.1 Field study

The field study was conducted on board three deep-sea trawlers during three separate sailings (Fig 2-1). The first trawler (69.8 x 15.6 m, 19 crewmembers) disembarked from Ålesund the 12th of April 2014. Physiological measurements started on the 14th and ended on the 18th of April. The second trawler (53.1 x 10.2 m, 15 crewmembers) disembarked from Tromsø the 10th of June 2014. Physiological measurements started 12th and ended on the 17th of June. The third trawler (48.4 x 13.2 m, 17 crewmembers) disembarked from Tromsø the 12th of August 2014. Physiological measurements started the 14th and ended the 18th of August 2014.

Figure 2-1. Approximate fishing positions of trawler 1 (T1), trawler 2 (T2) and trawler 3 (T3) during the field study. T1 disembarked from Ålesund. T2 and T3 disembarked from Tromsø. Modified from Google Maps (2015). https://www.google.no/maps/@69.9992877,-2.15332,3z?hl=no (accessed 01.05.2015)

2.1.1 Subjects

The fishermen were recruited to the field study after an information meeting aboard each trawler before it commenced fishing activities. Twenty-five fishermen, whose characteristics are presented in Table 2-1, voluntarily accepted to participate in the study. The test subjects were all professional fishermen who performed their regular work during participation. The crew, captain and ship owners approved participation before leaving port. All participants

were informed about the study goal, the test protocol and their rights to terminate the experiment according to the Helsinki declaration including human test subjects.

Table 2-1. Summary of anthropometric data, heart rate (HR) and body mass index (BMI) on the three trawlers. Age estimated maximal heart rate in beats per minute (bpm). [1)] Indicates age estimated maximal heart rate adjusted for upper-body work in beats per minute (bpm). No significant differences were found between the three trawlers.

Trawler	*Age (yrs.)*	*Height (cm)*	*Weight (kg)*	*HR_{max} (bpm)*	*[1)]HR_{max} (bpm)*	*BMI ($kg \cdot m^{-2}$)*	*Number of participants (n)*
1	34 ± 12	179 ± 4	87 ± 10	184 ± 8	171 ± 8	27.0 ± 2.5	8
2	42 ± 14	179 ± 6	90 ± 15	179 ± 9	166 ± 9	28.1 ± 3.9	10
3	39 ± 10	185 ± 5	94 ± 9	181 ± 7	168 ± 7	27.4 ± 2.6	7

2.1.2 Protocol

Each fisherman participated in the physiological measurements once during the field study. The measurements took place between 08:00 and 14:00 or 14:00 and 20:00. One shift usually had a 30-minute pause in the middle of the shift, but this could vary depending on the amount of fish caught. With back to back large catches fishermen often skipped breaks and they rotated working overtime. Work were divided into two main locations, factory or trawl deck. Work on factory and trawl deck were divided into several work positions or sub-tasks. On the factory deck, the different work positions included operating the head-and-gut machine, sorting and cleaning the fish, and packing and pulling frozen blocks of fish out of the freezers. Work on trawl deck was divided into several sub-tasks during fishing, many of which were heavy physical work. Fishermen could work on both factory and trawl deck or just one of them during a shift.

Measuring equipment was attached to the fishermen 30-60 minutes prior to the start of their six-hour work shift and was removed directly after the end of the shift. After the work shift, all subjects answered a questionnaire about thermal sensation and comfort.

2.1.3 Clothing

The standard clothing used by most of the fishermen consisted of cotton underwear, pants, t-shirts and socks. The outerwear depended on whether the subject was working on factory or trawl deck. The most used clothing on factory deck was a cotton work suit and a pair of waterproof oilskin pants, sometimes with a waterproof oilskin jacket. Some also used a cap together with hearing protection. On trawl deck a work survival suit or oilskin with a floating

vest were observed as primary outerwear. Helmets were also mandatory. Insulated protective rubber boots were used on both factory and trawl deck.

2.1.4 Measurements and equipment

Heart rate and oxygen consumption

The fishermen were equipped with an Equivital EQ02 LifeMonitor (Hidalgo, Cambridge, UK, 25-240 bpm) to measure heart rate during work. The sample interval was set to 1 minute.

Oxygen consumption was estimated from Eq. 1 based on the percentage of predicted maximal heart rate (HR_{max}) (Lounana et al. 2007).

$$\% VO_{2max} = (\%HR_{max} - 30.14) \cdot (0.706)^{-1} \quad (1)$$

Core and skin temperature

To measure core temperature during work a gastrointestinal temperature pill (Vitalsense Jonah capsule ±0.1°C, Vitalsense) were ingested. Skin temperatures were measured by attaching skin thermistors (YSI, Yellow Spring Instruments, Ohio, USA, ±0.15°C) on six different locations (chest, upper back, upper arm, lower arm, front thigh and front leg) on the body. Four of these (chest, upper arm, front thigh and front leg) were used for estimating T_s. Placement of one skin thermistors differed on trawler 1 compared to trawler 2 and 3 and this thermistor was placed on the hand instead of the upper arm. The skin thermistors were attached with waterproof surgical tape. Core and skin temperatures were registered at 1-minute intervals. Mean skin temperature (T_s) was calculated using Eq.2 (Teichner 1958)

$$T_s = 0.34 \cdot T_{chest} + 0.15 \cdot T_{lower\ arm} + 0.33 \cdot T_{thigh} + 0.18 \cdot T_{leg} \quad (2)$$

Subjective evaluation

After the work shift, fishermen were asked to evaluate their own perceived thermal sensation (PTS) and comfort answering a questionnaire (A.1). The questionnaire were modified from Nielsen et al. (1989).

Ambient conditions

A hand-held thermostat (Testo 435, Testo, Lenzkirch, Germany, accuracy ± 0.3°C, ± 2% RH) was used to measure ambient temperature (T_a, °C) and relative humidity (RH, %) on factory and trawl deck. During the work shifts on trawler 2, T_a and RH were measured to 8.6 ± 0.7°C and 79 ± 6% RH on the factory deck. The outdoor air temperature was 7 ± 2°C and wind conditions ranged between a light breeze (4-6 kn) to moderate breeze (11-16 kn) during

sailing. During work shifts on trawler 3, T_a and RH were measured to 14.5 ± 2.0°C and 68 ± 9% RH on the factory deck. The outdoor temperature 10 ± 4°C and wind conditions ranged between light breeze (4-6 kn) to fresh breeze (17-21 kn) during sailing. No ambient temperature or weather data is available for trawler 1.

2.2 Laboratory study

2.2.1 Subjects

Ten healthy young males volunteered to participate in the study. Table 2-2 shows the subjects characteristics. All participants were informed about the study goal, the test protocol and their rights to terminate the experiment according to the Helsinki declaration of experiments including human test subjects before delivering a written consent. Research subjects were recruited from among students at NTNU. To be included in the study the subjects had to be male, between 20 and 30 years old and pass a medical examination. Test abortion criteria's was the following: T_c reached 35.0 or 39.5 °C, one of the skin temperatures reached 8°C or was below 10°C for 20 minutes, abortion by the test subject or by evaluation from project staff.

Table 2-2. Test subject characteristics. Measurement values gained from pre-tests. HR_{peak} and VO_{2max} is highest measured heart rate and oxygen consumption during the VO_{2max} test. ND: No data.

Subject	*Age*	*Weight*	*Height*	*Body fat*	HR_{peak}	VO_{2max}	VO_{2max}
	years	kg	cm	%	bpm	$L \cdot min^{-1}$	$mL \cdot min^{-1} \cdot kg^{-1}$
1	27	59.1	175	7.8	191	3.61	61.1
2	26	89.1	182	16.4	197	4.64	52.2
3	27	64.9	179	10.2	191	3.70	57.0
4	22	72.5	175	10.2	207	5.17	71.4
5	22	70.9	183	10.5	188	4.74	66.8
6	23	74.5	176	12.4	191	4.38	58.7
7	22	76.7	177	12.4	203	4.46	58.2
8	23	65.1	184	5.9	197	4.77	73.4
9	20	98.6	188	17.5	201	4.87	49.4
10	20	75.3	190	13.5	ND	4.09	54.5
Mean	23	74.7	181	11.7	196.2	4.44	60.3
SD	2	11.1	5	3.4	6.1	0.48	7.6

2.2.2 Protocol

All test subjects attended a pre-test to define VO_{2max}, HR_{peak}, body measurements and familiarize themselves with the main test procedures. T_a during the pre-tests was 20.4 ± 0.7°C and the relative humidity was 38 ± 5%. The pre-test measurements was used to define individual running speeds and area of sweat pads for the main tests.

Each test subject performed two main tests, one in a low humidity (19 ± 2% RH) environment and another in a humid (85 ± 2% RH) environment. T_a during the main tests were 30.1 ± 0.2°C and 30.0 ± 0.2°C (T_a hereafter referred to as 30°C) for high and low humidity conditions respectively. Test subjects were exposed to the two environments in a counterbalanced order to reduce any effects of the order of exposure. Each test subject performed the tests on the same time of day, with minimum of 48 hours between each test. The subjects were asked to refrain from alcohol consumption and smoking 24h before testing. They were also asked not to drink coffee and tea, or eat chocolate 2h before the test started. Limitations on exercise before the main tests were set to 24 h for hard exercise. All subjects were encouraged to stay well hydrated before the tests.

Upon arrival to the laboratory, the test subjects were weighed without clothes. The subjects inserted a rectal probe after weighing. After the subjects were dressed in shorts and shoes, six thermistors, a heart rate recorder and frames for sweat sampling pads were attached to the subjects. The main test started with a 20-minute rest at room temperature (22.8 ± 0.9°C) and RH of 24 ± 3 %. Sweat sampling pads were applied during the last five minutes of rest and the subjects were asked to evaluate their thermal comfort and sensation. After the initial rest, the subjects moved directly into the climatic chamber.

Inside the climatic chamber, the test subjects started to run on a treadmill (PPS 55 sport-1 climatel, Woodway, Weil am Rhein, Germany) at 68 ± 4% VO_{2max} and 6° incline for 20 minutes. Oxygen consumption were measured during the first and last five minutes of running. After 15 minutes of running, test subjects stopped and sweat-sampling pads were applied during the last five minutes of the run. Recovery in an upright position were initiated as the running ended. Sweat sampling pads were changed every five minutes during recovery. Every change of sweat pads took approximately one minute, making the total recovery time 36 minutes. VO_2 were measured after 15 minutes of recovery. Evaluations of thermal sensation and comfort were answered after five minutes of running, directly after the run, 10

minutes into the recovery and directly after the recovery. Water (30.6 ± 2.1°C) was available at five, 15, 20, 30, 40 and 50 minutes after the start of the run. Subjects were encouraged to drink as much as they wanted. Naked body weight were re-measured directly after the end of the recovery period.

2.2.3 Clothing

During pre-tests subjects wore underwear, shorts, t-shirt and running shoes. Main test clothing consisted of underwear, shorts and running shoes. The same type of underwear and the same shorts were used in the two main tests. A compression bandage (Comprilan 8 cm x 5 m, 100% cotton, BSN Medical AB) were wrapped around the abdomen to keep the back sweat pad in place. A tube compression bandage were used on the right arm (Tubifast 7.5 cm x 1 m, Mölnlycke Health Care).

2.2.4 Measurements and equipment

Climatic chamber

Both main tests were performed in a heat chamber at the Work Physiology Laboratory at the department of Health Research at SINTEF Technology and Society. Temperatures in the heat chamber can be regulated from 5°C to 50°C (± 0.5°C). Relative humidity can be regulated from 10 to 90 % (± 3%). Temperature and relative humidity were measured four times during the test with a hand-held thermostat (Testo 435, Testo, Lenzkirch, Germany, accuracy ± 0.3°C, ± 2%). Average T_a during the laboratory study were calculated from measurements taken after 5 and 20 minutes of running, and 15 and 30 minutes of recovery.

Gross sweat loss

Subjects were weighed (ID1, Mettler Toledo, Albstadt, Germany, accuracy ±0.006 kg) before and after each test. Gross sweat loss (GSL) was calculated (Eq. 3) based on the weight loss of each participant (ΔM) and corrected for ingested water (WI) during the test, respiratory water loss (RWL) and metabolic mass loss (MML) (Cheuvront et al. 2002).

$$GSL = \Delta M + WI - RWL - MML \quad (3)$$

RWL was calculated from respiratory evaporation (E_{res}) by Eq. 4 and converted into RWL by Eq. 5 (Smith and Havenith 2010).

$$E_{res} = 1.27x10^{-3} \cdot MR \cdot (59.34 + (0.53 \cdot T_a) - (11.69 \cdot P_a)) \quad (4)$$

$$RWL = E_{res} \cdot t \cdot 2430^{-1} \quad (5)$$

Where E_{res} is the evaporative heat loss (W). MR is the metabolic rate (W). T_a is the air temperature. P_a is the partial water vapour pressure (kPa). RWL (g). t is the duration of the experiment (sec). 2430 is the latent heat of 1g of water ($J \cdot g^{-1}$). MR were calculated from the simple equation of metabolic rate (Eq. 6) by McIntyre (1980).

$$MR = 20600 \cdot V_E \cdot (0.2093 - O_e) \quad (6)$$

Where V is the ventilation rate ($L \cdot s^{-1}$) and O_e is the fraction of oxygen in the expired air.

MML were calculated using Eq. 7 from Mitchell et al (1972).

$$MML = VO_2 \cdot (RER \cdot (\rho CO_2 - \rho O_2) \quad (7)$$

Where VO_2 is the oxygen consumption ($L \cdot min^{-1}$). RER is the measured respiratory exchange ratio. ρCO_2 and ρO_2 are the densities of carbon dioxide (1.96 $g \cdot L^{-1}$) and oxygen (1.43 $g \cdot L^{-1}$).

Regional sweat rate

Sweat were sampled with a technical absorbent material (Air Laid 2240CW1+, Meditas, Grimsby, United Kingdom). The technical absorbent material were fitted into pads for each individual test subject. Sweat sampling pads (hereafter, sweat pads) sizes were calculated following the method of Smith and Havenith (2010). Sweat pad area were estimated using exact measures of pre-cut outlies following the method described in Morris et al. (2013). Eight sweat pads for both arm and back were weighed (Saerorius AG, Sartorius, Goettingen, Germany, accuracy ± 0.01 g) and stored in air tight zip-lock bags before each test. Posterior lower arm and central mid back were chosen as sweat pad locations based on existing literature (Havenith et al. 2008a; Smith and Havenith 2010; Morris et al. 2013). To ease application and removal of sweat pads on the arm, these were scaled down by 50% compared to Smith and Havenith (2010).

Sweat production was measured in 5-minute intervals. Each sweat pad took an average of 56 ± 5 seconds to change. Sweat pads were applied during the last five minutes of initial rest and

running period, and every 5 minutes during recovery. Sweat were measured in the following time intervals: 5-10, 25-30, 31-36, 37-42, 43-48, 49-54, 55-60 and 61-66 minutes after 10 minutes of initial rest. Hereafter referred to as sample 1, 2, 3, 4, 5, 6, 7, 8.

Regional sweat rate (RSR, $g \cdot m^{-2} \cdot h^{-1}$) were calculated from Eq. 8 based on work by Smith and Havenith (2010).

$$RSR = (60 \cdot \Delta M) \cdot (t \cdot A)^{-1} \quad (8)$$

Where ΔM is the difference in weight of the sweat pad before and after application (g); t is the application time (min); A is the measured area of the sweat pad (m^2).

Heart rate

Heart rate (HR) was continuously measured during initial rest, running and recovery with a Polar RS800 HR recorder (Polar Electro, Oy Kempele, Finland, accuracy ± 1 bpm). HR were registered every 15 seconds.

Oxygen consumption

Ventilation (V_E), oxygen consumption (VO_2) and fraction of oxygen in expired air (O_e) were measured with an Oxycon Pro® apparatus (JCAB 5.x, Jaeger, Germany, accuracy 0.05 $L \cdot min^{-1}$). Data were registered every 20 seconds during the first and last five minutes of running, and after 15 minutes of recovery.

Core and skin temperatures

Skin temperatures were measured with skin thermistors (YSI 400, Yellow Spring Instruments, Ohio, USA, ±0.15 °C). Skin temperatures were registered on six locations: posterior lower arm, upper arm, chest, back, anterior thigh and anterior calf. All thermistors were controlled in a water bath before use. Thermistors were fastened to the skin with waterproof surgical tape. Core temperature (T_c) was measured with a rectal probe placed 10 cm into rectum (YSI 400, Yellow Spring Instruments, Ohio, USA, ±0.15 °C). Core and skin temperatures were continuously registered with a 20-second interval during the test. Mean skin temperature (T_s) was calculated from Eq. 9 (Teichner 1958).

$$T_s = 0.34 \cdot T_{chest} + 0.15 \cdot T_{lower\ arm} + 0.33 \cdot T_{thigh} + 0.18 \cdot T_{leg} \quad (9)$$

Subjective evaluation

Subjects were asked to evaluate their perceived thermal sensation (PTS) and comfort of their body during initial rest, running and inactive recovery (A.2). Questions are modified from Nielsen et al. (1989) and are scaled from -5 to 5, where -5 is extremely cold, 0 is neutral and 5 is extremely hot. A 15-point Borg's scale, where 6 is no exertion and 20 is maximal exertion, was used to evaluate perceived exertion (RPE) (Borg 1985).

Body fat

Body fat percentage was measured with a Harpender Skinfold Caliper at the pre-test. Four points of measurements were used: m. biceps brachii, m. triceps brachii, m. subscapularis and m. suprailiac. These values were used to estimate the body fat percentage (BF, %) by Eq. 10 (Durnin and Womersley 1974).

$$BF = (4.95 \cdot (D - 4.5)^{-1}) \cdot 100 \quad (10)$$

Where D ($kg \cdot m^{-2}$) is density given by Eq. 11.

$$D = c - (m \cdot \log \Sigma Sf) \quad (11)$$

Where Sf are the skinfolds measured with the Harpender Caliper. For men of 20-29 years c = 1.1631 and m = 0.0632 (Durnin and Womersley 1974).

2.3 Data analysis

IBM SPSS Statistics v21 and Microsoft Excel 2013 were used as statistical software and SigmaPlot 13 as graphic design software.

2.3.1 Field study

All variables are presented for factory and trawl deck. Work intensities were 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 (Borg 1985; McArdle et al. 2014). Work intensities are presented as the average of the fishermen (medians ± 95% CI). HR is adjusted for age (Gellish et al. 2007), upper body work (McArdle et al. 1977; Gergley et al. 1984; Franklin 1989) and presented as percentage of HR_{max}. Heart rate during work on factory deck is the mean heart rate of the entire work period. To analyse T_c and T_s on factory deck two representative averages of ten minutes were used. The data were collected 30 minutes after start of the two work periods. In cases with one

long work period, data was separated by 30 minutes. HR_{max} and HR_{min} values are the highest and lowest measured values of HR. Highest and lowest T_s and T_c temperature were measured over three continues minutes. Oxygen consumption was estimated from measured % of HR_{max}.

2.3.2 Laboratory study

The number of subjects differ between parameters due to loss of data or erroneous measurements during the tests.

HR, T_c and T_s are presented as one-minute running averages. RSR are presented for each sample of 5 minutes. The last two minutes of each sweat sample interval were used for statistical analyses of HR, T_c and T_s. Only the last 10 minutes of the initial resting are presented in figures. The running period lasted for 20 minutes and 17 seconds (±20 seconds), hereafter presented as 20 minutes. The recovery period lasted for 35 minutes and 37 seconds (±29 sec), hereafter presented as 36 minutes.

In calculation of GSL, initial resting phase are considered to have no impact of the total GSL and are not included in the analysis. GSL are calculated for the total testing time (running + inactive recovery). Due to differences in work intensity between running and recovery, metabolic rate (MR) was weighted based on total heat production. Estimated total heat production included 80 ± 3 % heat from running and 20 ± 3% from recovery. Constants of 0.8 and 0.2 were used to calculate a weighted absolute mean MR for the total test time.

RSR values were $\log_{10}$ transformed to achieve normality of data distribution and assumed positive. VO_2, V_E , O_e and RER were calculated from the last two minutes of each measurement. In testing of correlation between RSR and local skin temperature, the data were kept untransformed. Two minutes of local skin temperature corresponding to sample two to eight were used on correlation analyses.

2.4 Statistics

For all statistical analyses, corresponding assumptions were tested. Outliers and distributions of data were inspected by boxplot or studentized residuals (±3 SD). Normality were assessed with Shapiro-Wilk's test ($p>0.05$) and equality of variances were checked with Levene's test ($p>0.05$). If a test showed non-sphericity, a Greenhouse-Geisser adjustment was applied.

Linear and monotonic relationships were assessed by visual inspection of scatterplots. Pairwise comparisons with Bonferroni correction for multiple comparisons were performed as post hoc tests.

Data is presented as mean ± standard deviation (SD), unless otherwise stated. Statistical significance accepted at $p<0.05$.

2.4.1 Field study

A Friedman test was applied to test differences between the work intensity intervals on both factory and trawl deck. Differences between average HR and HR_{min} on trawl deck and between HR_{max} and HR_{min}, T_s and T_c on factory deck were analysed by a Student's t-test for paired samples. Differences between trawlers in HR, T_s and T_c were assessed by one-way analysis of variance (ANOVA). Differences between start, minimum, maximum and end values in T_s and T_c on trawl deck were analysed by repeated measures ANOVA. T_s and T_c on trawl deck did not pass the assumption of sphericity ($p=0.001$ and $p<0.0005$), assessed by Mauchly's test of sphericity, and a Greenhouse-Geisser adjustment was applied ($\varepsilon=0.648$ and $\varepsilon=0.0426$).

In case of outliers, the ANOVA was run with and without the outliers. The outlier was kept in the analysis if the conclusion of the tests were equal. Due to the low sample size, outliers and non-normality of the data, no statistical analyses were used on the parameters T_s and T_c from trawl deck. Alternative tests and transformations were found inadequate due to the low sample sizes.

Differences in scores of thermal sensation and comfort between trawler 1, 2 and 3 were analysed by a Kruskal-Wallis test. Differences in the scores on question 1 (A.1) were assessed with a Friedman test.

2.4.2 Laboratory study

Two-way repeated measures analysis of variance (Within-within ANOVA) was used to examine interactions of the parameters RSR, HR, T_c and T_s between and within high and low humidity environments. If statistical significant interactions were found, simple main effects (SME) were analysed with a Student's t-test between environments. Significance levels with Bonferroni adjustments are presented in table 3-2 and 3-3. Significance levels for RSR values with Bonferroni adjustment are only presented in text due to its strict nature (Perneger 1998).

Pearson correlation coefficient (r) was calculated for the relationship between GSL and MR. No outliers were found by checking deviation from the regression line. Spearman's correlation coefficient (r_s) was calculated for the relationship between GSL and T_s, and RSR and local T_s for both arm and back. Spearman's rank-order correlation was used instead of a Pearson correlation because of presence of outliers.

Differences in the slope of the regression lines between high and low humidity environments for parameters RSR, HR, T_c and T_s were analysed with Student's t-test for paired samples. Student's t-test for paired samples was also used to analyse differences in oxygen consumption.

Friedman's test was used to analyse differences in the ratings of PTS and RPE between rest, after 5 and 20 minutes of running, and after 10 and 30 minutes of inactive recovery. Differences in ratings of PTS and RPE between 19% RH and 85% RH were analysed with a Wilcoxon signed-rank test.

3 Results

3.1 Field study

3.1.1 Work intensity

Work intensities on trawlers shows that short periods of hard work (>86% HR_{max}) was measured during work on trawl deck (Table 3-1). However, most of the time is spent working at fairly light (52-66 % HR_{max}) and somewhat hard (67-85% HR_{max}) intensities. Work on factory deck is mainly spent working at fairly light intensity. No differences were found between the time spent working at fairly light and somewhat hard (p=1.0) intensity on trawl deck. On factory deck the time spent at fairly light work intensity differed from easy (<52% HR_{max}) (p=0.001), somewhat hard (p=0.037) and hard (p<0.0005) work intensities.

Table 3-1. Percentage of time fishermen spent working at the intensities easy (<52% HR_{max}), fairly light (52-66% HR_{max}), somewhat hard (67-85% HR_{max}) and hard (86-% HR_{max}) during work on factory or trawl deck. HR_{max} is age estimated maximum heart rate adjusted for upper-body work. a, b, c and d indicates significant differences between the work intensities easy, fairly light, somewhat hard and hard respectively (p<0.05). Values are median ± 95% CI

	Fishing vessels	*Easy (%)*	*Fairly light (%)*	*Somewhat hard (%)*	*Hard (%)*	*Total work time (min)*
Trawl deck	Trawler 1 (n= 7)	15 ± 8	42 ± 7	33 ± 12	4 ± 7	59 ± 25
	Trawler 2 (n=7)	7 ± 8	55 ± 18	33 ± 18	0 ± 4	40 ± 14
	Trawler 3 (n=5)	15 ± 16	43 ± 14	34 ± 28	0 ± 1	90 ± 20
	Significance	b	a, d	d	b, c	
Factory deck	Trawler 1 (n=8)	7 ± 22	66 ± 19	8 ± 11	0 ± 1	162 ± 41
	Trawler 2 (n=10)	6 ± 12	68 ± 13	23 ± 14	0 ± 1	291 ± 19
	Trawler 3 (n=7)	16 ± 11	51 ± 15	23 ± 21	0 ± 0	168 ± 56
	Significance	b, d	a, c, d	b, d	a, b, c	

3.1.2 Heart rate and oxygen consumption

Heart rate

For all three trawlers working on trawl deck resulted in an increase in HR by 38 ± 13 % ($p<0.0005$, n=19) between lowest (HR_{min}) and highest (HR_{max}). An increase of 13 ± 6 % ($p<0.0005$, n=25) between average HR and HR_{min} were observed while working on the factory deck on the same trawlers.

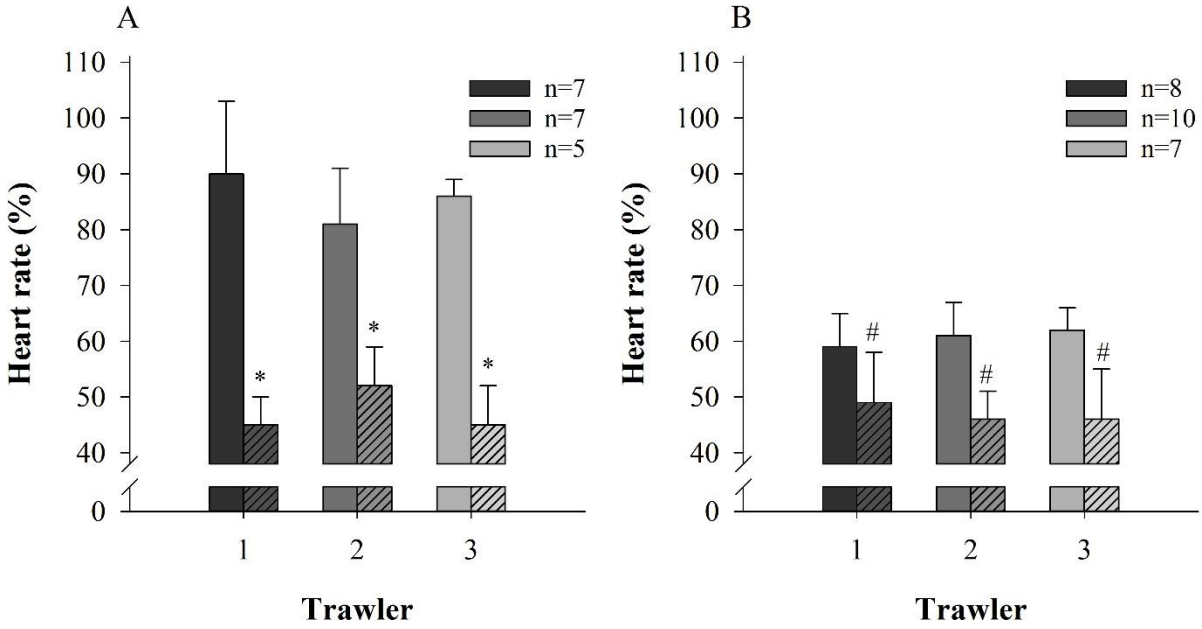

Figure 3-1. A) Maximum (HR_{max}, full colour) and minimum (HR_{min}, shaded) heart rate recorded during work on trawl deck of the three trawlers (1, 2 and 3). B) Average (full colour) and minimum (HR_{min}, shaded) heart rate recorded during work on factory deck of the three different trawlers (1, 2 and 3). Percentage of age estimated HR adjusted for upper body work. shows a significant difference between HR_{max} and HR_{min} on trawl deck ($p<0.05$). # shows a significant difference between average heart rate and HR_{min} on factory deck ($p<0.05$). Values are means ± SD.*

No differences between trawlers were registered for HR_{min} ($p=0.057$) and HR_{max} ($p=0.295$) on trawl deck. Neither were there any differences in HR ($p=0.550$) and HR_{min} ($p=0.763$) on the factory deck of the three trawlers. HR_{max} (156 ± 20, 136 ± 23, 146 ± 3 bpm) and HR_{min} (77 ± 8, 86 ± 12, 77 ± 11 bpm) were recorded during work on Trawler 1, 2 and 3 respectively, these corresponds to a percentages presented in fig. 3-1 A. Fig. 3-1 B shows the percentages of HR (100 ± 10, 100 ± 9, 104 ± 7 bpm) and HR_{min} (83 ± 15, 76 ± 7, 77 ± 14 bpm) during work on factory deck. The fishermen working on the trawl deck on trawler 1 increased their HR by 46 ± 13 % ($p<0.0005$). Fishermen on trawler 2 and 3 increased their HR by 29 ± 11% ($p<0.0005$) and 40 ± 7% ($p<0.0005$) respectively working on the trawl deck. HR were also measured on

factory deck of trawler 1, 2 and 3 with increases of 10 ± 6 % ($p = 0.002$), 15 ± 5 % ($p < 0.0005$) and 15 ± 7 % ($p < 0.0005$) respectively.

Oxygen consumption

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

3.1.3 Core and skin temperature

Trawl deck

Fishermen on the three trawlers entered the trawl deck with an average T_s of 31.9 ± 1.1°C and an average T_c of 37.1 ± 0.4°C. The average T_s of the three trawlers increased to a maximum of 32.1 ± 1.2°C before it decreased significantly to the lowest value of 29.8 ± 1.6°C ($p<0.0005$, n=15). Fig 3-2 A shows the start, maximum (max), minimum (min) and end T_s of fishermen on trawler 1, 2 and 3 in the sequence of observation. The average T_c on all three trawlers increased significantly ($p<0.0005$, n=15) from 37.1 ± 0.3°C to 37.8 ± 0.4°C during work on trawl deck. Fig. 3-2 B shows the start, min, max and end T_c of fishermen on trawler 1, 2 and 3 in the sequence of observation.

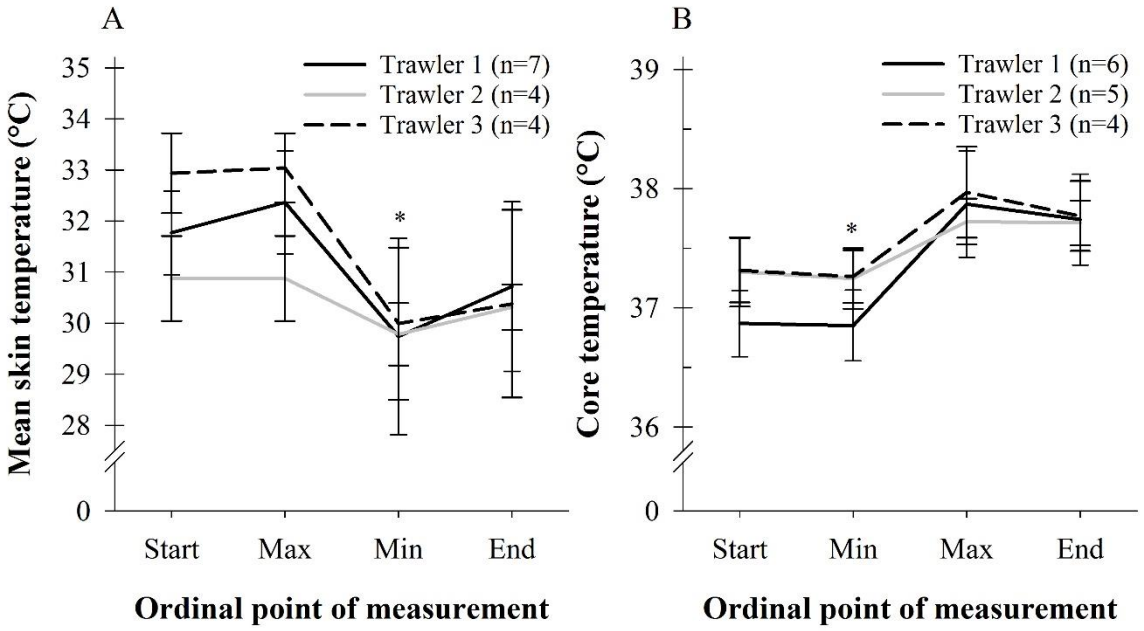

*Figure 3-2. A) Mean skin temperature (°C) during work on trawl deck of trawler 1, 2 and 3. B) Core temperature (°C) during work on trawl deck of trawler 1, 2 and 3. Notice the order of registered start, minimum (min), maximum (max) and end temperatures differ between graph A and B. * indicates a significant difference between lowest and highest mean skin and core temperature on trawl deck. Values are means ± SD.*

No significant changes in the T_s on trawl deck of all three trawlers from the start (31.9 ± 1.1°C) of the work period until the highest T_s (32.1 ± 1.2°C) were measured (p=0.475). While the fishermen were working on trawl deck, average T_s of all three trawlers decreased with 2.3 °C (95% CI, 1.2 to 3.5) to the lowest T_s measured (29.8 ± 1.6°C) ($p<0.0005$). No changes between start (37.1 ± 0.4°C) and minimum (37.1 ± 0.3°C) T_c were found between the three

trawlers (p=0.499). During work on trawl deck T_c increased with 0.8 °C (95% CI, 0.5 to 1.0, p<0.0005) to 37.8°C.

Factory deck

The T_s on factory deck for all three trawlers differed significantly between the lowest (29.5 ± 1.5°C) and average (30.9 ± 1.2°C) temperature (p<0.0005). Fig. 3-3 A shows T_s from trawler 1, 2 and 3. T_c on factory deck for the three trawlers showed a small but significant increase from 37.1 ± 0.3°C to 37.4 ± 0.2°C (p<0.0005). Fig 3-3 B shows T_c from trawler 1, 2 and 3. Both average (37.3 ± 0.1°C and 37.6 ± 0.3°C, p=0.031) and minimum (36.9 ± 0.1°C and 37.3 ± 0.3°C, p= 0.038) T_c significantly differed between trawler 2 and trawler 3 during work on factory deck. T_c measured on trawler 1 did not differ significantly from either trawler 2 or 3 (p=0.134 and p=0.075).

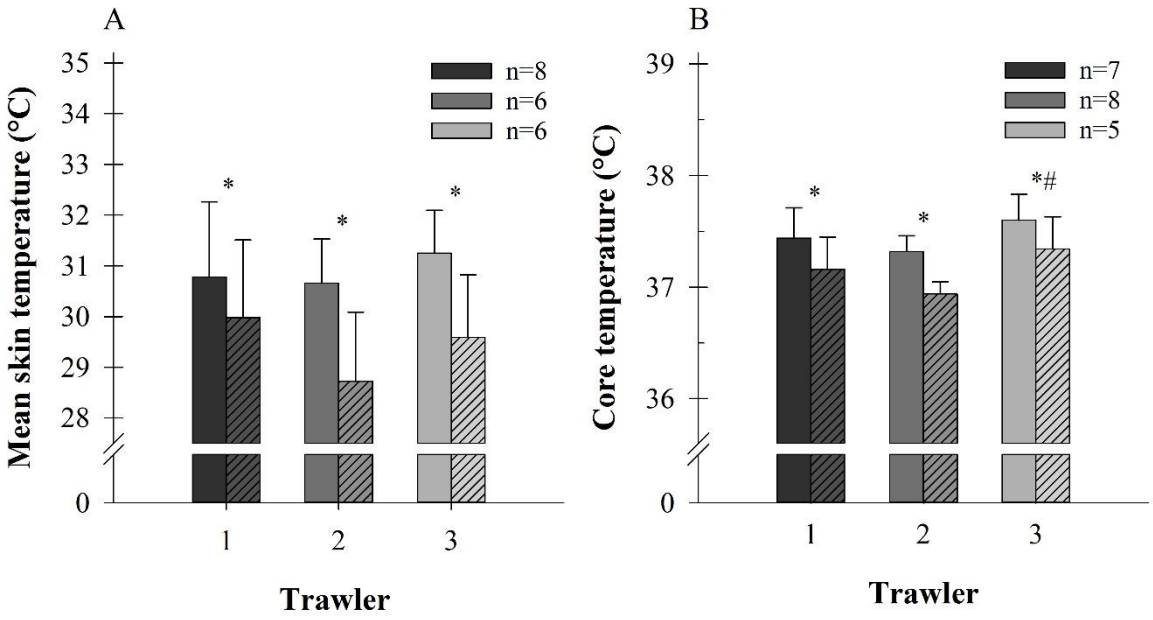

*Figure 3-3. A) Average (full colour) and lowest (shaded) mean skin temperature of fishermen during work on factory deck on trawler 1, 2 and 3. B) Average (full colour) and lowest (shaded) core temperature of fishermen during work on factory deck on trawler 1, 2 and 3. * Indicates a significant difference between minimum and average T_s and T_c (p<0.05). # indicates a significant difference in T_c between trawler 2 and 3. Values in means ± SD.*

Fishermen working on the factory deck on trawler 1, 2 and 3 increased their T_s with 0.8 ± 0.6°C (p=0.006) from 30.0 ± 1.6°C, 1.9 ± 0.7°C (p=0.001) from 28.7 ± 1.5°C and 1.7 ± 1.3°C (p=0.023) from 29.6 ± 1.3°C respectively. T_c of fishermen on trawler 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° respectively.

3.1.4 Subjective evaluation of thermal sensation and comfort

The fishermen voted their perceived thermal sensation (PTS) and comfort after the end of the shift by answering a questionnaire (A.1). There were no differences in mean scores between the three trawlers, except thermal sensation of the neck. The post hoc test showed a significant difference between the mean scores on thermal sensation of the neck of trawler 2 and trawler 3 ($p=0.019$). Fishermen reported themselves to be slightly warm on the trunk of the body, but this was not significantly warmer compared to rest of the body which was voted neutral ($p=0.186$). Furthermore the fishermen were rarely cold, but answered they were hot, very hot or extremely hot during work on trawl deck and when pulling blocks of fish from the freezers on the factory deck. Moderate to heavy sweating, wetness on the chest and back are reported during the work shift, but the fishermen did not find their working clothes too warm and they were thermally comfortable.

3.2 Laboratory study

3.2.1 Gross sweat loss

GSL was significantly higher in high (85% RH) humidity (796 ± 414 g·h^{-1}) compared to low (19% RH) humidity (489 ± 140 g·h^{-1}) conditions (p=0.010). Large variations in gross sweat loss (GSL) were observed between individuals and between environments (within subjects). There was no significant correlation between GSL and VO_{2max} (mL·min^{-1}·kg^{-1}), weight (kg) or body fat (%). GSL correlated positively with individual work intensities, expressed as weighted absolute mean metabolic rate, for both high (r=0.78, p=0.002) and low (r=0.87, p=0.001) humidity environments (Fig. 3-4). No significant correlation between GSL and T_s was present for either 19% RH or 85% RH (r_s=-0.285, p=0.425 and r_s=0.261, p=0.533).

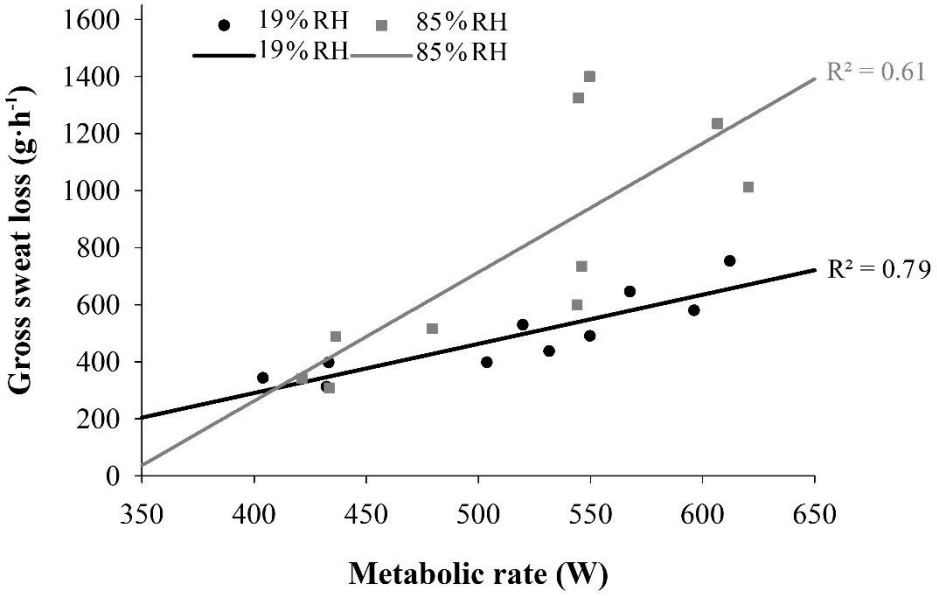

Figure 3-4. Absolute mean gross sweat loss (g·h^{-1}) and weighted absolute mean metabolic rate (W) for test subjects in high (85% RH) and low humid (19% RH) environments. Positive correlations between GSL and metabolic rate in both high (r=0.78, p=0.002) and low humidity (r=0.87, p=0.001). n=10.

3.2.2 Regional sweating

Individual regional sweat rates (RSR) during initial rest ranged between 1 to 17 $g \cdot m^{-2} \cdot h^{-1}$ and did not differ between trials ($p>0.05$). During the last five minutes of running RSR on the back was 1124 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 701 to 1802) in 85% RH and 886 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 534 to 1469) in 19% RH. Corresponding RSR on the arm were 498 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 397 to 623) in 85% RH and 341 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 251 to 465) in 19% RH. RSR decreased during recovery in both high and low humidity, and on both back and arm. Sample 8 during recovery measured 395 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 227 to 686) in 85% RH and 165 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 113 to 240) in 19% RH on the back. On the arm sample 8 measured 225 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 171 to 296) in 85% RH and 16 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, 6 to 48) in 19% RH.

Figure 3-5 shows that RSR were significantly higher at all time points without Bonferroni correction, on both back ($p<0.05$) and arm ($p<0.05$) during upright inactive recovery in 85% RH. With a Bonferroni correction applied RSR on the back were significantly higher during recovery in 85% RH for sample 4 ($p=0.001$), 5 ($p=0.001$), 7 ($p=0.007$) and 8 ($p=0.003$). RSR on the arm were significant on all sample intervals with a Bonferroni correction ($p<0.01$).

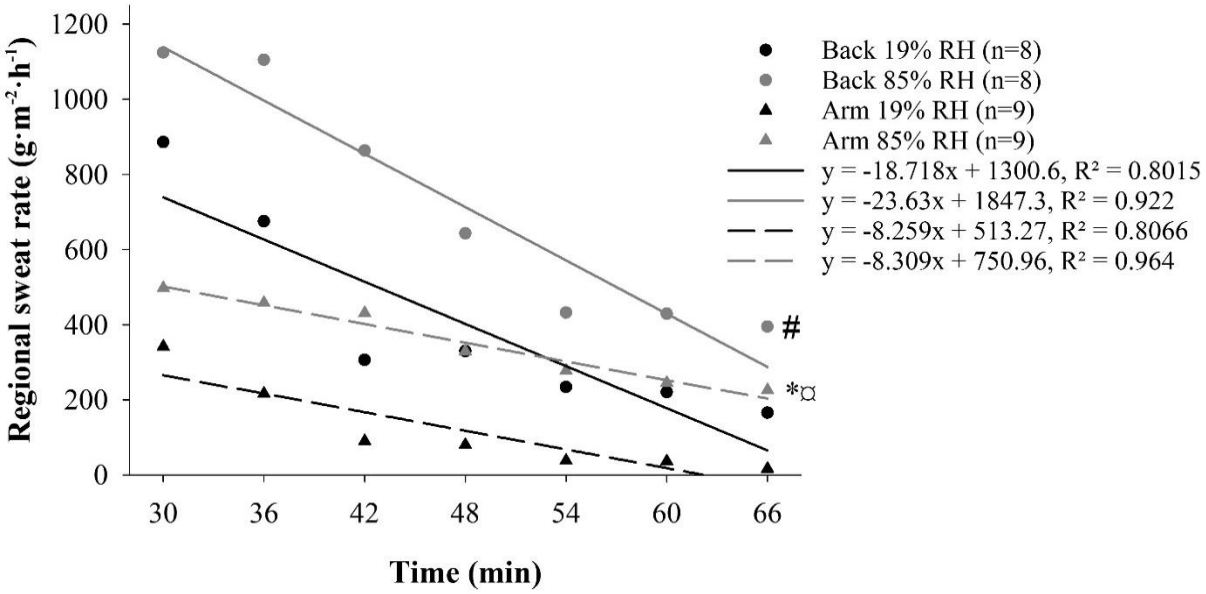

*Figure 3-5. Regional sweat rate (RSR) during the last five minutes of running and the upright recovery period. # indicates a significantly higher RSR on the back in 85% RH compared to 19% RH during all sample intervals. * indicates a significantly higher RSR on the arm in 85% RH compared to 19% RH during all sample intervals. ¤ indicates a significant difference in the slopes of the regression lines of the arm, between the interval 30 to 42 minutes. RSR is in geometric means.*

RSR on the back declined with a rate of 23.63 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, ± 9.81) per minute in 85% RH and 18.72 (95% CI, ± 10.58) $g \cdot m^{-2} \cdot h^{-1}$ per minute in 19% RH. The difference in rate of decline was not significant (p=0.53). Neither were there any differences between the slopes of any sequence of sweat samples on the back. RSR on the arm declined with a rate of 8.31 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, ± 2.94) per minute in 85% RH and 8.26 $g \cdot m^{-2} \cdot h^{-1}$ (95% CI, ± 2.82) per minute in 19% RH. The difference in rate of decline was not significant (p=0.967). A significantly faster decline in RSR were found between sweat samples 2 to 4 in 19% RH compared to 85% RH (p=0.033).

RSR on the back showed a weak correlation (r_s=0.351, p=0.014) with local skin temperature during inactive recovery in 19% RH and a moderate correlation (r_s=0.56, p<0.0005) in 85% RH. There was a weak positive correlation (r_s=0.35, p=0.001) between RSR on the arm and local skin temperature during inactive recovery in 19% RH. RSR on the arm in 85% RH showed a strong positive correlation (r_s=0.612, p<0.0005) with local skin temperature during inactive recovery. There was no significant correlations between RSR and local skin temperature during running.

Table 3-2 and Table 3-3 shows mean, median and geometric mean values with corresponding SD, 95% CI, upper confidence limit and lower confidence limit for all sweat samples on the back (Table 3-2) and on the arm (Table 3-3). Significant levels for the geometric means with and without Bonferroni correction, corresponding to figure 3-5 are shown in the last column of table 3-2 and 3-3.

*Table 3-2. Mean, median and geometric mean values for regional sweat rate (RSR) on the (mid-centre) back, with corresponding SD and CI values. * indicates a significantly higher RSR in a high humidity environment ($p<0.05$). # indicates a significantly higher RSR in a high humidity environment, with Bonferroni correction ($p<0.007$). Letters a, b, c, d, e, f, g indicates significant difference from samples 2, 3, 4, 5, 6, 7 and 8 respectively (n=8).*

	Sample	Mean ($g \cdot m^{-2} \cdot h^{-1}$)	±SD	Median ($g \cdot m^{-2} \cdot h^{-1}$)	±95% CI	Geometric mean ($g \cdot m^{-2} \cdot h^{-1}$)	Upper confidence interval	Lower confidence interval	Significance level
Low humidity (19% RH)	1	8	14	0	9	3	9	1	
	2	1100	756	867	524	886	1469	534	defg*
	3	856	744	668	516	675	1093	417	defg*#
	4	351	219	279	152	306	442	212	*#
	5	362	204	302	141	329	443	245	abfg*
	6	253	117	220	81	234	311	176	ab*
	7	252	163	188	113	220	316	153	abd*#
	8	189	115	157	80	165	240	113	abd*#
High Humidity (85% RH)	1	12	13	8	9	6	17	2	
	2	1387	1016	1008	704	1124	1802	701	fg
	3	1379	1123	1020	778	1105	1765	691	cfg
	4	1093	954	917	661	863	1390	536	bfg
	5	939	1128	594	782	643	1138	363	
	6	724	737	373	511	432	845	221	
	7	622	737	363	511	429	758	243	abc
	8	565	671	338	465	395	686	227	abc

*Table 3-3. Mean, median and geometric mean values for regional sweat rate (RSR) on the posterior side of the underarm, with corresponding SD and CI values. * indicates a significantly higher RSR in a high humidity environment ($p<0.05$). # indicates a significantly higher RSR in a high humidity environment, with Bonferroni correction ($p<0.007$). Letters a, b, c, d, e, f, g indicates significant difference from samples 2, 3, 4, 5, 6, 7 and 8 respectively. (n=9).*

	Sample	Mean ($g \cdot m^{-2} \cdot h^{-1}$)	±SD	Median ($g \cdot m^{-2} \cdot h^{-1}$)	±95% CI	Geometric mean ($g \cdot m^{-2} \cdot h^{-1}$)	Upper confidence interval	Lower Confidence interval	Significance level
Low humidity (19% RH)	1	12	18	0	12	4	12	1	
	2	376	176	333	115	342	465	251	cdefg*#
	3	247	163	219	107	216	300	155	c**#
	4	103	57	82	37	90	130	63	ab**#
	5	89	42	89	27	80	113	56	a*#
	6	62	38	68	25	38	102	14	a*#
	7	52	26	61	17	36	89	15	a*#
	8	33	29	26	19	16	48	6	a*#
High humidity (85% RH)	1	13	15	12	10	5	15	2	
	2	524	181	507	118	498	623	397	defg
	3	484	177	426	116	459	573	367	efg
	4	476	248	352	162	431	579	321	fg
	5	357	151	361	98	329	436	248	af
	6	293	108	269	70	278	346	223	ab
	7	264	108	238	70	245	321	188	abcd
	8	244	105	217	69	225	296	171	abc

3.2.3 Heart rate and oxygen consumption

Heart rate

From an average resting value of 76 ± 6 bpm in both conditions, HR increased to 175 ± 11 bpm and 164 ± 10 bpm while running in 85 % RH and 19 % RH respectively. The HR at the end of the 20 minute run in high humidity was significantly higher than in the low humidity environment (p=0.001). During inactive recovery there was a significant difference in HR between high and low humidity (p=0.038) (Fig 3-6). HR was significantly higher in 85 % RH during the first twenty-four minutes in inactive recovery, whereas there were found no significant difference in HR during the last twelve minutes between high and low humidity.

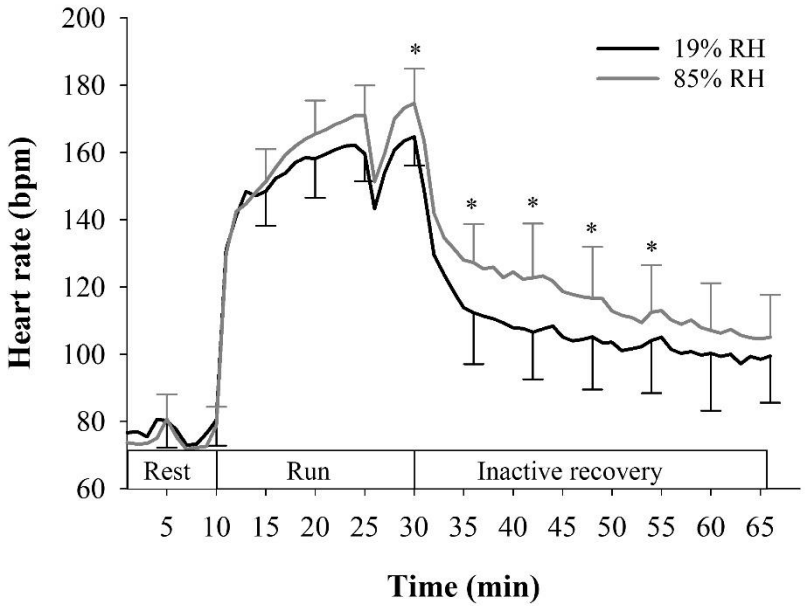

*Figure 3-6. Heart rate (HR) during initial rest, running at 70% VO_{2max} and upright inactive recovery. * indicates significant difference in HR between high and low humidity of sweat samples 2, 3, 4, 5 and 6 ($p<0.05$). Values are mean ± SD, n=9.*

Oxygen consumption

During the run period, the exercise intensity was 67 ± 3% VO_{2max} during the first five minutes and 69 ± 4% VO_{2max} the last five minutes in 19% RH. In 85% RH the corresponding VO_{2max} values were 67 ± 4% and 70 ± 4%. There were no significant differences in oxygen consumption between or within environments.

3.2.4 Skin temperature

Significant differences in T_s over time between high and low humidity conditions ($p<0.0005$) were registered. From an average resting value of 31.2 ± 0.6°C in both ambient conditions, T_s reached 35.4 ± 0.4°C during exercise at 68% VO_{2max} in 85% RH and 34.9 ± 0.6°C in 19% RH. T_s were significantly higher in 85% RH compared to 19% RH ($p<0.05$), except for the last point of measurement ($p=0.135$) (Fig. 3-7). The highest T_s (35.3 ± 0.5°C) was recorded after four minutes of inactive recovery in 19% RH. In 85% RH the highest T_s (35.9 ± 0.5°C) was recorded after five minutes of inactive recovery. T_s cools with the rates of 0.057°C and 0.052°C per minute during upright inactive recovery in high and low humidity respectively. The difference in the rate of cooling were not significant ($p=0.184$).

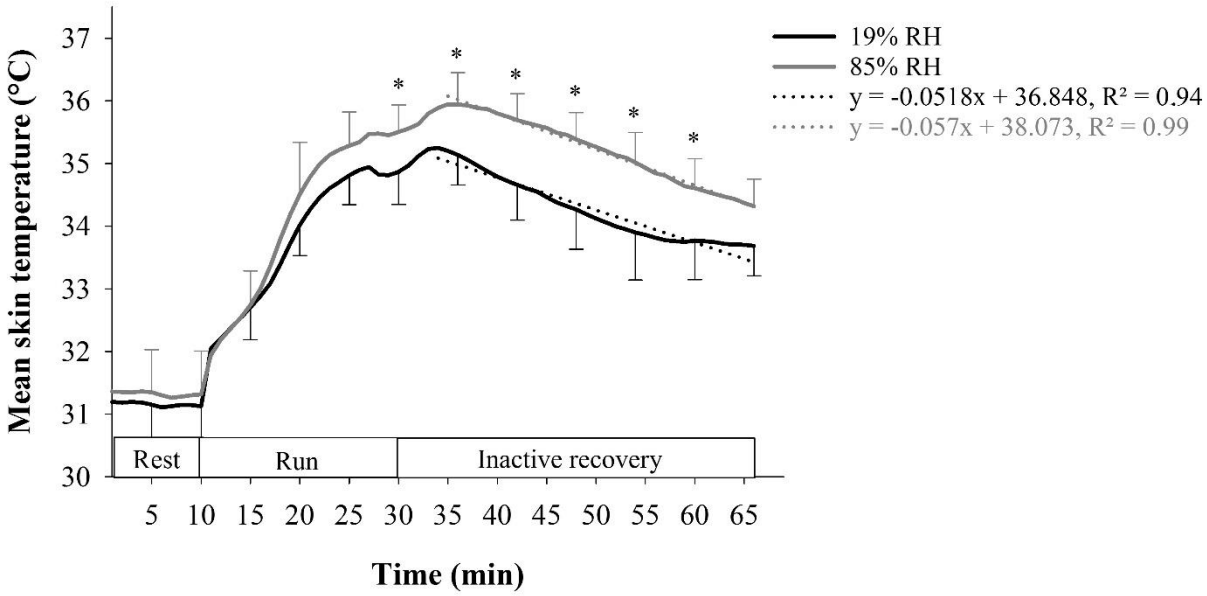

*Figure 3-7. Mean skin temperature (T_s) during initial rest, running at 70% VO_{2max} and upright inactive recovery. Linear regression lines (dotted) fitted from the point of highest T_s of the inactive recovery for both ambient conditions. * indicates significant difference in T_s between high and low humidity ($p<0.05$). Values are mean ± SD, n=10.*

3.2.5 Core temperature

Significant differences in T_c over time between high and low humidity conditions ($p<0.0005$) were registered. From an average resting value of 37.0 ± 0.3°C in both ambient conditions, T_c reached 37.7 ± 0.4°C during exercise at 68% VO_{2max} in both 19% RH and 85% RH. T_c were significantly higher in high humidity ($p<0.05$), except for the last five minutes of running and the first five minutes of recovery ($p=0.795$ and $p=0.085$) (Fig. 3-8). The highest recorded T_c of 38.1 ± 0.3°C in 85% RH and 37.8 ± 0.3°C in 19% RH were reached at three and seven minutes after exercise. After T_c reached the highest values, T_c decreased with the rates of 0.011°C and 0.013°C per minute in high and low humidity conditions respectively. The difference in cooling rate was not significant ($p=0.490$).

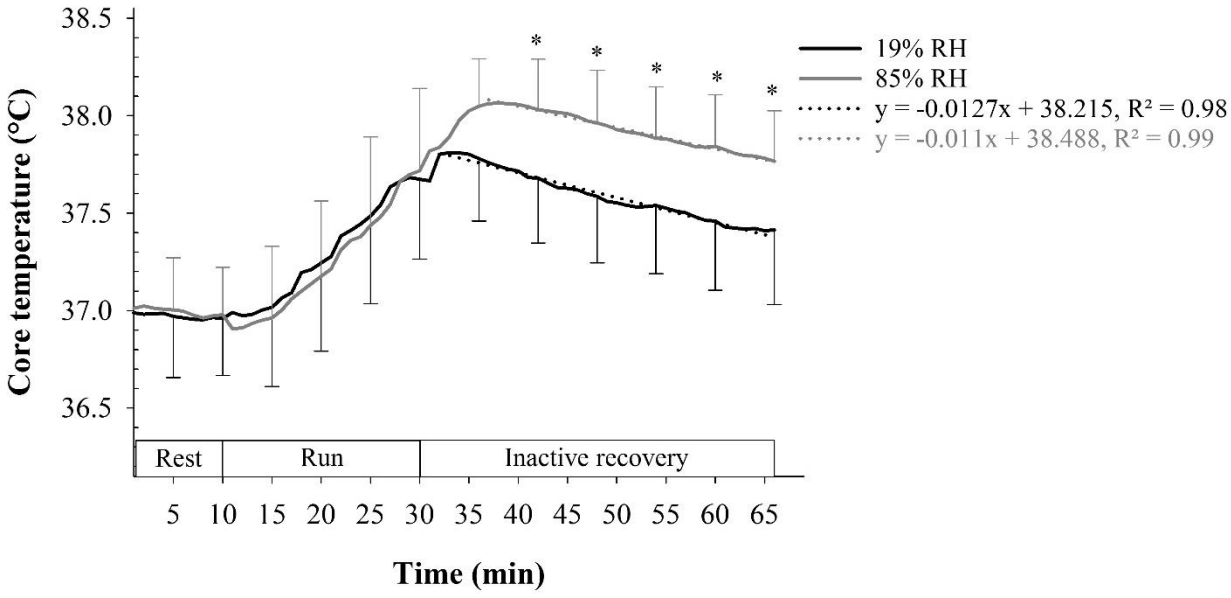

*Figure 3-8. Core temperature (Tc) during initial rest, running at 68% VO_{2max} and upright inactive recovery. Linear regression lines (dotted) fitted from the highest point of T_c on the inactive recovery data for both ambient conditions. * indicates significant difference in T_c between high and low humidity of sweat samples 4, 5, 6, 7 and 8 ($p<0.05$). Values are mean ± SD, n=10.*

3.2.6 Subjective evaluation

Perceived thermal sensation (PTS) was significantly higher during initial rest (p=0.046) and after 20 minutes of running (p=0.007) (Fig. 3-9). The test subjects felt significantly warmer after both 5 and 20 minutes of running compared to initial rest scores in both 19% and 85% RH (p<0.05). Seven of ten test subjects voted a higher degree of skin wetness after 20 minutes of running in high humidity conditions. All test subjects felt that their skin were more wet during recovery in 85% RH. The higher score in skin wetness was significant for both run and recovery in 85% RH (p=0.014 and p=0.014) compared to 19% RH (p=0.004 and p=0.011). Ratings of perceived exertion (RPE) was voted 15 in 85% RH and 14 in 19% RH after 20 minutes of running (p<0.0005). There were no significant differences in RPE between 19% RH and 85% RH during initial rest and inactive recovery.

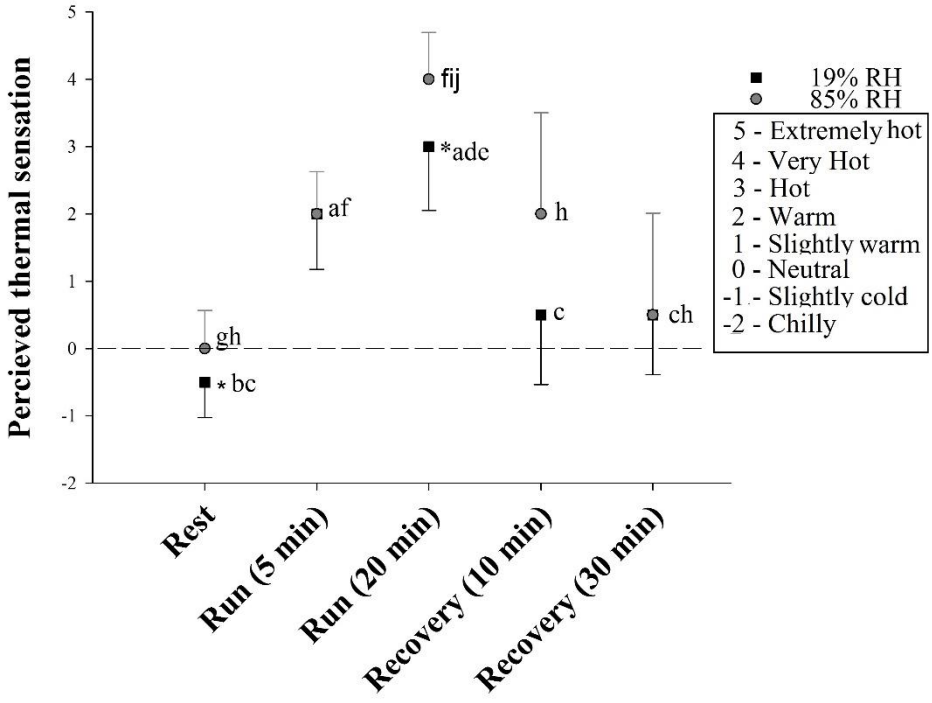

*Figure 3-9. Perceived thermal sensation (PTS) of the body during rest, after 5 and 20 minutes of running, and 10 and 30 minutes of inactive recovery. * indicates a significant lower score of PTS in 19% RH (p<0.05). a, b, c, d, e indicates significant differences between rest, run (5 min), run (20 min), recovery (10 min) and recovery (30 min) in 19 % RH respectively (p<0.05). f, g, h, i, j indicates significant differences between rest, run (5 min), run (20 min), recovery (10 min) and recovery (30 min) in 85 % RH respectively (p<0.05). Values are medians ± 95% CI, n=10.*

4 Discussion

4.1 Field study

To increase our knowledge about real-life work strain and work-related environmental challenges of fishermen during work on Norwegian deep-sea trawlers, we recorded physiological parameters of fishermen during work in a field study. Findings form our field study of fishermen during work on deep-sea trawlers, supported our hypotheses that fishermen worked short periods with heavy work strain on trawl deck and long periods with light work strain on factory deck in cold ambient conditions.

4.1.1 Work intensity and heart rate

We predicted that there would be a difference in work intensity between work on trawl deck and factory deck. Our results showed that the fishermen spent a few minutes above 86% of maximal heart rate (HR_{max}) and a long period on trawl deck above 67% of HR_{max}. A study Åstrand et al. (1973)of Norwegian coastal fishermen by discovered VO_{2max} peaks up to 80 % of VO_{2max} during fishing, which is in accordance with our findings in heart rates of fishermen working on trawl deck of deep-sea trawlers. In accordance with previous findings from Norwegian costal fishing (Rodahl et al. 1974) work on trawl deck can be characterized as an intermittent work activity as shown by the relatively equal distribution of time within the work intensity intervals easy, fairly light, somewhat hard and hard. A relatively equal distribution of time within the different intervals indicate a work situation with changing intensities classified as intermittent work.

We also predicted that fishermen worked long periods at light work intensities on factory deck. We found that the fishermen spent more than 60% of his worktime on factory deck between 52 and 66 % HR_{max}. In contrast to the intermittent character of work on trawl deck, work on factory deck shows a highly monotonous repetitive character, also observed by Törner et al. (1988a). The ambient temperatures inside the factory deck were measured to 8.6 and 14.5°C in trawler 2 and 3 respectively and can be described as cold and cool work environments (BS EN 7915: 1998; ISO 15743: 2008). Repetitive work at low intensity in cold (5°C) environments have a negative effect on muscle function and fatigue (Oksa et al. 2002), that may lead to overuse injuries and in the long run musculoskeletal disorders (Chiang et al. 1990). Several studies have been performed on the occurrence of work-related

musculoskeletal disorders from cold indoor work (Pienimäki 2002; Piedrahita 2008), especially among workers in the fish processing industry (Chiang et al. 1993; Ohlsson et al. 1994; Ólafsdóttir and Rafnsson 2000; Bang et al. 2005). Our findings of prolonged low intensity high repetitive work in a cold environment can indicate a higher risk of developing musculoskeletal symptoms among fishermen, which is in accordance with previous studies (Törner et al. 1988a; Lipscomb et al. 2004) and new findings among Norwegian fishermen on deep-sea fishing vessels (Sandsund et al. In press).

We predicted that heart rate would peak above 86% HR_{max} during work on trawl deck and remain stable between 52 and 66% HR_{max} during work on factory deck. Our study confirms our predictions and shows that fishermen work at high intensities. Heart rate reached peaks above 86% of HR_{max} during work on trawl deck and averaged at 60% of HR_{max} on factory deck. World Health Organization (WHO) classifies heart rates below 100 beats per minute (bpm) as light, between 100 to 125 bpm as moderate and above 125 as heavy cardiac strain (Andersen et al. 1978). During work on factory deck, fishermen on trawler 1, 2 and 3 had average heart rates of 100, 100 and 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. (1978). Maximal heart rate during work on trawl deck was 156, 136 and 146 bpm on trawler 1, 2 and 3 respectively. Average cardiac strain experienced by the fishermen on trawl deck can be classified as moderate, but we measured a high occurrence of heavy cardiac strain shown as time spent at somewhat hard and hard work intensities.

The WHO classification of cardiac strain by Andersen et al. (1978) does not consider the relevance of the workers age or physical fitness. A heart rate 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 variation of age makes HR presented as bpm a poor measure to describe work intensity or cardiac strain of fishermen aboard the investigated trawlers. Rodahl et al. (1974) and Rodahl and Vokac (1977) present cardiac strain and work load as heart rate reserves with corresponding oxygen uptake equivalents. Heart rate reserves is a method to estimate exercise intensity, but it does not correlate well to VO_{2max} (Lounana et al. 2007). We present our data as percentage of age estimated HR_{max}, as this has an established linear relationship with VO_{2max} (Hawley and Noakes 1992; Arts and Kuipers 1994). Operating fishing equipment and fish processing machines relies heavily upon upper body work (Törner et al. 1988a; Fulmer and Buchholz

2002), we therefore chose to adjust the age estimates of HR_{max} for upper body work. The adjustment by 13 bpm (McArdle et al. 1977; Gergley et al. 1984; Franklin 1989) were applied to heart rate during work on both factory and trawl deck. Åstrand et al. (1973) and Rodahl et al. (1979) showed that fishermen in coastal fishing and on Norwegian trawlers had an average energy expenditure during all activities corresponding to about 39% of VO_{2max}, which is in accordance 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} (Andersen et al. 1978). A study of open-pit miners in Finland and Sweden by Oksa et al. (2014) 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}. Both our findings and those of Oksa et al. (2014) did not exceed the recommendations set by WHO related to metabolic strain.

4.1.2 Core and skin temperature

We predicted that high work strain on trawl deck would lead to an increased core and mean skin temperature. We measured a decrease in mean skin temperature and an increase in core temperature during work on trawl deck, which is in accordance with previous studies on high intensity work in cold environments (Galloway and Maughan 1997; Sparks et al. 2005; Sandsund et al. 2012).

The fishermen reported to be warm and sweaty after working on the trawl deck, which is a possible contradictory to the decreased mean skin temperature measured. Sparks et al. (2005) measured mean skin temperature to about 29°C at an ambient temperature of 10°C, which are supported by findings from Sandsund et al. (2012) and is in accordance with the lowest measured mean skin temperature during work on trawl deck in our study. Skin temperature will decrease in cold environments in response to vasoconstrictions, which reduces skin blood flow. In our study the ambient temperatures were 7 and 10°C on trawler 2 and 3 respectively, but there were no differences between the lowest mean skin temperature measured on the three trawlers.

In accordance with previous findings (Sparks et al. 2005; Sandsund et al. 2012) we observed an increase in core temperature during work in a cold (10°C) environment. Our results show an average increase of 0.8°C in core temperature on all three trawlers during work on trawl deck. This increase is in accordance with core temperature measured during duathlon in 10°C

(Sparks et al. 2005). The lower core temperature in our study is likely a result of the intermittent nature of work on trawl deck compared to more continuous exercise protocols usually performed in laboratory studies (Wiggen et al. 2012; Sandsund et al. 2012). Fishermen reported themselves to be warm and sweaty during work on trawl deck in spite of a reduced mean skin temperature. This can be explained by an increased core temperature leading to an enhanced central drive towards sweating as shown by Kondo et al. (1998).

We also predicted that low work strain on factory deck would lead to a low mean skin temperature and unchanged core temperature. Average core temperature of all three trawlers was 37.4°C and the lowest was 37.1°C. These corresponds to the pre-exercise temperatures in 23°C found by Sandsund et al. (2012). The core temperature measured in our study during work on factory deck is within the interthreshold zone of thermoregulation (Mekjavic and Eiken 2006) 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 average mean skin temperature of fishermen on trawler 1, 2 and 3 was 30.9°C in ambient temperatures of 9 and 15°C on trawler 2 and 3 during work on factory deck respectively. These finding is in accordance with previous studies on exercise in similar ambient temperatures (Sparks et al. 2005; Sandsund et al. 2012). Neither the average or lowest mean skin temperature of the three trawlers indicate an uncomfortable thermal environment according to the relationship between mean skin temperature and thermal comfort and sensation (Gagge et al. 1967; Gagge et al. 1969). This also corresponds well with the subjective evaluations of thermal comfort and perceived thermal sensation answered by the fishermen.

4.2 Laboratory study

Based on the observations and measurements from the field study we performed a laboratory study on ten young males, studying the relationship between high (85%) and low (19%) relative humidity and sweat rate during inactive recovery after work with high intensity in a warm (30°C) environment. Findings from the laboratory study simulating periods of high work intensities followed by inactive recovery in environments with high or low humidity supported our hypotheses that high humidity would lead to a higher thermal load and affect thermal comfort and perception of effort negatively compared to low humidity.

4.2.1 Gross sweat loss

We predicted that gross sweat loss (GSL) would be higher when exposed to high humidity compared to a low humidity environment, and show a positive correlation with metabolic rate.

Our findings were in accordance with earlier studies (Niwa and Nakayama 1978; Shapiro et al. 1982; Maughan et al. 2012)and show that GSL increased in a high humidity environment compared to a low humidity environment. GSL in the present study was calculated from the test subject's weight change, from before the start of the initial rest to the end of the recovery period. The combination of high intensity running and inactive recovery explains our data's lower GSL compared to earlier studies were one work intensity during the test sessions were used.

Our findings show a strong significant correlation between GSL and metabolic rate for both environmental conditions, which is in accordance with the results of Smith and Havenith (2010). Exercise intensity does not affect the relationship between GSL and metabolic rate (Smith and Havenith 2010). Several studies have also shown correlations between GSL and VO_{2max} (Havenith and Middendorp 1990; Havenith 2001; Smith and Havenith 2010), which was not apparent in the present study.

Our results show a significant difference between the GSL regressions lines of high and low humidity environments. This indicates a change in the relation between sweat and work rate between low and high humidity conditions. To account for the differences in heat production between running and upright recovery, we adjusted metabolic rate to the total heat production to obtain an estimate of absolute metabolic rate during the test session. We did not measure the weight change between running and inactive recovery in this study. It was therefore not

possible to calculate separate GSL values for running and inactive recovery, which might have highlighted the change in sweat rate from running to recovery.

4.2.2 Technical absorbents vs. capsule techniques

Regional sweat rate was measured with technical absorbents pads (Havenith et al. 2008a; Smith and Havenith 2010). This technique covers a larger area in comparison to the more classical approach of ventilated capsules (Cotter et al. 1995; Kondo et al. 1998; Machado-Moreira et al. 2008). Morris et al. (2013) have recently compared the two methods and concluded that technical absorbents pads is a reliable alternative to ventilated capsules. Ventilated capsules have the advantage of continuous measurements, whereas technical absorbents pads require a period between applications to ensure no impact on local sweating. Available sweat measurement techniques will affect the amount of sweat produced. Havenith et al. (2008a) qualitatively compared the different methods of sweat measurement. Technical absorbents may cause increased skin wetness leading to hidromeiosis (Inoue et al. 1999) and increase local skin temperature as a result of no evaporation (Havenith et al. 2008a). To avoid hidromeiose, technical absorbents with high absorption capacity was used in the present study. Increased local skin temperature under the technical absorbent was avoided by short sample periods (5 minutes).

In the present study technical absorbent pads were cut by hand from a premeasured outline drawn on the technical absorbent material. Corresponding with limitations described by Morris et al. (2013) there is a possibility of some error in the estimate of the sweat pad surface area used to calculate RSR. An alternative method of technical absorbent pad surface area estimation (Havenith et al. 2008a; Smith and Havenith 2010) is to use mass of the technical absorbent material. This estimation was not deemed accurate for the technical absorbent material used in the present study.

4.2.3 Regional sweating

We predicted that regional sweat rates in young males would be significantly different between low and high humidity conditions. Our findings support this for arm and back, and during both running and upright inactive recovery.

Our findings show significant differences with a Bonferroni correction in RSR on the posterior forearm between low and high humidity environment for all sweat samples. RSR on

the mid-central back was significantly higher between low and high relative humidity with a Bonferroni correction on four of six samples during inactive recovery. Significance levels with a Bonferroni correction are not graphically presented in the result because of its stringent nature (Perneger 1998), even with the risk of inflating type I errors. All our measurements during running and inactive recovery showed significant differences in RSR between high and low humidity conditions without a Bonferroni correction.

Our findings of high RSR on the central mid back and low RSR on the posterior forearm supports our second laboratory prediction and is in accordance with the well documented variation in distribution of sweating (Kuno 1956; Hertzman 1957; Cotter et al. 1995). Recent studies by Smith et al. (2007, hands and arms), Havenith et al. (2008a, upper body), Machadi-Morerira et al. (2008, upper body) and Smith and Havenith (2010, whole body) are also in accordance with the variation in sweat production within and between posterior forearm and mid-central back in the present study. These findings show that there is no uniform sweat rate for the whole body, in fact sweat rates are largely dependent on location of measurement. This knowledge is highly important in development of protective and high performance clothing to ensure optimal evaporation and reduce heat stress.

We also predicted that RSR would diminish faster during upright inactive recovery in a low humidity compared to a high humidity environment. Comparisons of the linear regression slopes between humidity conditions did not result in a significant difference in the rate of declining sweat responses. RSR in low humidity conditions showed a significantly steeper slope from the last five minutes of running to the end of the first 10 minutes of inactive recovery, which was the only exception. Havenith et al. (2008a) found a significant reduction in RSR 10 minutes after exercise stopped, which corresponds with our findings of RSR in a low humidity environment. Our results of sweat rate in high humidity exhibits a significant fall in RSR after 10 minutes into the recovery period indicating a prolonged sweat response in high humidity compared to a low humidity environment.

The effect of post exercise mode (active, inactive and passive) of recovery are well documented in previous studies (Carter III et al. 2002; Wilson 2004; Journeay et al. 2005; Jay et al. 2008). In our study upright inactive recovery were chosen as mode of recovery to simulate work situations were sitting would not be possible. Sweat rate during upright recovery might be modified by baroreceptors (Carter III et al. 2002; Wilson 2004) but the

effect was not considered important in the testing of our hypotheses. All of the above studies on post-exercise recovery were conducted in low to moderate relative humidity and at 24-25°C, which corresponds well to the low humidity environment in the present study. To our knowledge, no studies have been performed on post-exercise sweat rate in high humidity environments. Candas et al. (1983) described the effect of hot humid environments on sweating in resting men, and showed that sweat rate increased for one hour before starting decline due to the effect of skin wettedness (hidromeiose). With profound sweating skin becomes hydrated and swells, which induces a decline in sweating (Nadel and Stolwijk 1973; Gonzalez et al. 1974; Candas et al. 1979; Candas et al. 1983). RSR in our study did not appear to be affected by hidromeiosis, which can be attributed to the high absorption capacity of the technical absorbents pads used to measure sweat. If hidromeiosis had an effect on RSR one would expect a decline in sweat rate during the first five minutes of recovery in high humidity regardless of increasing core and mean skin temperature. Instead our results indicate a delayed onset of the decline in sweat rate in a high humidity compared to a low humidity environment. This corresponds well the continued increase in core temperature measured during the first seven minutes of inactive recovery.

Several studies show that exercise intensity and ambient temperature affects both regional and total sweat rate during exercise (Havenith and Middendorp 1990; Galloway and Maughan 1997; Kondo et al. 1998; Cheuvront et al. 2002; Sparks et al. 2005; Smith and Havenith 2010). In the present study exercise intensity and ambient temperature were kept constant, so the significant differences in RSR and GSL must result from a change influenced by the humidity of the environment. The classical work by Nadel et al. (1971) emphasises the importance of local skin temperature on sweat rate. The relationship between RSR and local skin temperature during exercise as proposed by Nadel et al (1971) were not evident in the works by Bothorel et al. (1991), Cotter et al. (1995) and Smith and Havenith (2010). Our findings show weak to strong correlations between RSR and local skin temperature during inactive recovery for both high and low humidity conditions. In the present study, local skin temperature statistically accounts for 37 (arm) and 31 (back) percentage of variation in RSR in high humidity and 12 (arm) and 12 (back) percentage in low humidity conditions. The higher percentage of variation in RSR explained by local skin temperature in our study might indicate the importance of exercise intensity as the drive of the sweat response (Kondo et al. 1998). This is supported by the lack of correlation between RSR and local skin temperature

during running in our findings and is in accordance with earlier studies by Bothorel et al. (1991), Cotter et al. (1995) and Smith and Havenith (2010).

4.2.4 Heart rate

Our study found a significant difference in peak heart rate between the high and low humidity environments. These findings are not in accordance with the studies by Maughan et al. (2012) and Backx et al. (2000). We observed a significant increase in heart rate at the end of the run and during the first 24 minutes of recovery. Several studies show that heart rate increases with increasing temperatures during exercise in hot environments (Claremont et al. 1975; Nadel et al. 1979; Nielsen et al. 1993; Galloway and Maughan 1997). In our study ambient temperature were kept at 30°C in both high and low humidity. However, there was still a significantly higher peak heart rate measured in high humidity conditions. A high heart rate in hot environments are explained by a redistribution of blood to the periphery of the body. This lowers the central blood volume which in turn reduces stroke volume and leads to an increased heart rate (Rowell et al. 1966; Montain et al. 1996; González-Alonso et al. 2000). The significantly higher heart rate during inactive recovery in high humidity can be explained by the significant elevation in core temperature in the same condition (Rowell 1974; Bergh and Ekblom 1979; Kenney 2008). However, the significantly higher heart rate during running in high humidity can not be explained by an elevation in core temperature, as there were no significant differences in core temperature between high and low humidity conditions during running. Our findings of an increased heart during running is in accordance with the works by Rowell (1974) and González-Alonso et al. (2008) and related to the increased mean skin temperature due to reduced evaporative efficiency in high humidity. An increased mean skin temperature promotes a redistribution of blood to the skin and leads to a reduction in stroke volume and increased heart rate.

4.2.5 Mean skin temperature

One of our predictions was that mean skin temperature would be higher during exercise in high humidity compared to a low humidity conditions. Our results show a 0.5°C increase in mean skin temperature in high compared to low humidity at the end of the exercise period, which is in accordance with previous findings (Gonzalez et al. 1974; Maughan et al. 2012). Skin temperature will increase in hot environments due to vasodilatation, which increases the skin blood flow resulting in an increased amount of warm blood in the periphery (Rowell 1974; González-Alonso et al. 2008). This is an important mechanism to maintain a skin

temperature higher than the surrounding air and thus maintain the evaporative gradient between skin and air (Alber-Wallerström and Holmér 1985; Webb 1995; Havenith et al. 2013).

We predicted that mean skin temperature would decline faster in low humidity compared to high humidity conditions. Our study showed no differences in the rate of cooling after the highest measured mean skin temperature in high and low humidity during recovery. Both mean skin temperatures cooled with a rate of approximately 0.05°C per minute of inactive recovery. Our results are contradictory to the earlier work by Shibasaki et al. (2004) where there were no significant reduction in mean skin temperature during inactive recovery. However the increase in mean skin temperature directly after exercise was in accordance with a study by Wilson et al. (2004). Heat transfer between the skin and surrounding environment can explain the lack of difference between the slopes of mean skin temperature. When considering heat dissipation in a hot environment there are two important factors. These are the sensible heat loss to the surrounding air through radiation, conduction and convection (Webb 1995) and the evaporative heat loss by sweating (Candas et al. 1979; Alber-Wallerström and Holmér 1985). The importance of evaporative heat loss is the most important when environmental temperature is higher than skin temperature (Torii 1995), because in these conditions the gradient of heat transfer from the environment to the body (Gagge et al. 1938). In our study the ambient conditions of 30°C and high relative humidity did not restrict sensible heat loss during inactive recovery, in fact our results show no significant differences in the combined sensible and evaporative heat loss between high and low relative humidity. The equal rates of cooling in both mean skin and core temperature, and equal decline in RSR between inactive recovery in high and low relative humidity supports this statement. In conclusion, there were no significant difference between high and low humidity on the total effect of heat loss.

4.2.6 Core temperature

We predicted that core temperature would remain unchanged between running in high and low humidity. We found no significant difference in core temperature between running at 68 ± 4% of VO_{2max} in high or low relative humidity. Core temperature increased from 37.0°C during initial rest to 37.7°C during running in both high and low relative humidity, this is in accordance with earlier findings (Gonzalez et al. 1974; Maughan et al. 2012). Maughan et al. (2012) tested exercise capacity in men during cycling at 70% VO_{2max} at 30°C in four different

humidity conditions, and found no significant difference between core temperature in low and high humidity after 20 minutes of exercise. The core temperature in our study corresponds very well to those measured by Maughan et al. (2012).

The main finding considering core temperature is in accordance with the last part of our prediction of core temperature. The core temperature continued to increase after the running period ended and reached a higher temperature in high humidity. The core temperature reached a peak of 38.1°C after seven minutes of inactive recovery in high humidity and a peak of 37.8°C after three minutes of inactive recovery in low humidity. This observation is also in accordance with earlier studies of cardiovascular responses of heating and recovery (Rowell et al. 1969; Detry et al. 1972; Niwa and Nakayama 1978). The prolonged increase in core temperature during post-exercise inactive recovery in high relative humidity indicates a higher thermal load compared to inactive recovery in low relative humidity.

4.2.7 Limitations of the study

Field study

All field measurements took place between late Mars and August 2014 on board Norwegian deep-sea trawlers. A total of 25 fishermen participated in the study, divided between three trawlers (Trawler 1, n = 10, Trawler 2, n = 7, Trawler 3, n = 8). Recordings of physiological parameters took place during the day shifts, between 08:00 and 20:00. To measure physiological parameters of fishermen during work, several challenges had to be addressed. Severely limited space, bad weather and the movements of the trawlers made the gathering of data difficult. There was also a consideration for the safety of all participants involved. We also tried to minimize our presence and not disturbing the fishermen during their work. We did not measure hand temperatures on the last two trawlers, because the thermistors would not stay in place while the fishermen worked. As this study was conducted during spring and summer, the fishermen who participated was not exposed to any extreme weather or temperatures below zero. Therefore, this study is limited to circulatory and thermoregulatory responses during work on deep-sea trawlers of an ambient temperature of about 10°C.

Laboratory study

Pre-tests were performed between the 9th and 13th of February 2015 and all main tests between 26th of February and 16th of Mars 2015. Ten pre-tests and 20 main tests were

performed. All individual tests were separated by two days to avoid heat acclimation. The relative short duration of the test period reduced the risk of training effects.

5 Conclusion

Fishermen endures short periods of heavy intermittent work strain shown by heart rate peaks above 86% HR_{max}, increased core temperature and reports of sweating and feeling warm on trawl deck. On factory deck fishermen endures long periods of light to moderate repetitive work strain shown by a stable work intensity between 52-66% of HR_{max}, unchanged core temperatures and comfortable mean skin temperatures. This characterizes the work strain and environmental challenges of fishermen on Norwegian deep-sea trawlers. A better understanding of work strain and environmental challenges during work on Norwegian deep-sea trawlers will help identify risk exposures during work in cold and heat, and may be used in future works to reduce symptoms of musculoskeletal disorders among fishermen.

Observations and measurements of high humidity in the work environments shown in the field study provided the background of the laboratory study. Thermal load measured by gross sweat loss, regional sweat rate, heart rate, core and skin temperatures was higher during post-exercise recovery in a high humidity (86%) compared to a low humidity (19%) environment at 30°C. This identifies relative humidity as an important thermoregulatory factor at high temperatures and its importance for thermal comfort and physiological responses during inactive recovery after high intensity activities. This study emphasizes the importance of including the effect of relative humidity in any assessment of work in hot environments and development of protective and high performance clothing to ensure optimal heat balance.

5.1 Future studies

It would be interesting to continue the laboratory study, and try to identify threshold values for both temperature and relative humidity on physiological responses observed in this study. This would help identify hazardous combinations of relative humidity, ambient temperature and exercise intensity. A second interesting study would be to investigate physiological responses of "extreme sweaters" under varying environmental strains. These individuals are usually considered as "outliers" in present studies, but it would be interesting to see if there is any difference in physiological responses between "extreme sweaters" and a control group. Lastly, a study comparing male and female sweat responses to different environmental conditions would be highly important as there is very limiting literature focusing on physiological responses of females to different environmental conditions.

6 References

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Appendix

A.1 Questionnaire for subjective evaluation of thermal sensation and comfort during work on trawlers

1. During the shift, how did you thermally feel your:
a)Body?, b)Feet?, c)Hands?, d)Head?, e)Neck?

-5 Extremely cold
-4 Very cold
-3 Cold
-2 Chilly
-1 Slightly chilly
0 Neutral
1 Slightly warm
2 Warm
3 Hot
4 Very Hot
5 Extremely hot

a)___ b)___ c)___ d)___ e)___

2. On a scale from 0 to -5 what's the coldest you have been during your shift?
Did not feel cold (0)/ ____

3. **Which work task/activity did you perform when you felt cold to extremely cold?**

4. On a scale from 0 to 5 what's the warmest you have been during your shift?
Did not feel warm (0)/ ____

5. Which work task/activity did you perform when you felt warm to extremely warm?

6. Did the following happened during your shift?

1. Heavy shivering from cold
2. Moderate shivering from cold
3. Slightly shivering from cold
4. Did not shiver or sweat
5. Slightly sweating
6. Moderate sweating
7. Heavy sweating

7. During your shift, when did you slightly too heavy shiver from cold?

8. During your shift, when did you slightly too heavy sweat from cold?

9. How did your skin feel during the shift?

1. More dry then normal
2. Normally dry
3. Lightly moist chest and back
4. Moist chest and back
5. Wet body
6. Wet body and clothes stick to the skin

10. How did your work clothing feel during the shift?

1. Cold
2. Slightly cold
3. Neutral
4. Slightly warm
5. Warm

11. How did you thermally feel during your shift?

1. Comfortable
2. A little uncomfortable
3. Uncomfortable
4. Very uncomfortable

12. Any comments on thermal conditions during the shift?

A.2 Questionnaire for evaluation of ratings of perceived exertion, perceived thermal sensation and comfort in the laboratory study

1. Ratings of perceived exertion

6
7 Very, very light
8
9 Very light
10
11 Fairly light
12
13 Somewhat hard
14
15 Hard
16
17 Very hard
18
19 Very, very hard
20

2. How do you thermally feel your body?

-5 Extremely cold
-4 Very cold
-3 Cold
-2 Chilly
-1 Slightly chilly
0 Neutral
1 Slightly warm
2 Warm
3 Hot
4 Very Hot
5 Extremely hot

3. Do you?

1. Shiver heavily from cold
2. Shiver moderately from cold
3. Shiver slightly from cold
4. Do not shiver or sweat
5. Sweat slightly
6. Sweat moderately
7. Sweat heavily

4. How do your skin feel?

1. More dry then normal
2. Normally dry
3. Lightly moist chest and back
4. Moist chest and back
5. Wet body
6. Wet body and clothes stick to the skin

5. How would you prefer the surrounding air temperature?

1. Colder
2. Cooler
3. Neutral
4. Warmer
5. Hotter

6. How do you thermally feel?

1. Comfortable
2. A little uncomfortable
3. Uncomfortable
4. Very uncomfortable