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Field Report

Work strain and thermophysiological responses in Norwegian fish farming — a field study

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Abstract: Fish farming is considered as a physical demanding occupation, including work operations with high workloads and awkward work positions for prolonged periods of time. Combined with potential challenging environmental conditions, these factors may negatively affect work performance, comfort and health. This study aimed to explore work strain and thermophysiological responses in Norwegian fish farming. Fourteen workers (age 35 ± 15 yrs) from four fish farms participated in the field studies, and measurements of heart rate (HR), core- and skin temperatures were registered continuously during a work shift. Questions about subjective thermal sensation and comfort were answered. This study has shown that workers at fish farms are periodically exposed to high or low levels of work strain, where the high workloads are manifested as increased core temperature and HR when working. The results are expected to give a better understanding of work strain and environmental challenges during fish farm operations.

Key words: Fish farming, Aquaculture, Work strain, Thermophysiological responses, Field measurements

Introduction

The fish farming industry has grown to be one of the most important industries in Norway through the production and export of Atlantic Salmon worldwide[1, 2]. This industry is an exposed and physical workplace, highly influenced by operational and environmental factors. Working conditions in fish farming include exposure to potentially hazardous situations, strenuous physical activity, low ambient temperatures[3], noise and, in periods, long work shifts[4]. Such conditions may affect work performance, comfort and health. Fish farms are often located in areas exposed to impact from wind, waves and currents, and work on movable surfaces may increase work strain. Impairment of physical and mental performance are also likely to occur more frequently at low ambient temperatures than in thermo-neutral environments[5–8]. Fish farmers are physical active for large parts of their working day, and frequently encounters heavy lifting, prolonged standing, awkward postures and repetitive work. A high occupational physical activity (OPA) increases the risk for both cardiovascular events and musculoskeletal disorders[9]. A recent study on self-reported health among 447 employees in Norwegian fish farming, showed that pain in the neck/shoulders/arms as well as back pain were common[4]. The results also showed that 33.6% had health complaints that they believed were related to their work situation[4]. OPA have traditionally been assessed by

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questionnaires or other subjective evaluations, but there is an increasing focus on the added value of including objective measurements to quantify OPA. A practical assessment of OPA and the individual physical workload can be done by continuously heart rate (HR) recordings[10, 11].

Different guidelines for work-intensity and duration of work have been suggested, and it appears that a workload taxing 30–40% of the individual's maximal oxygen uptake is a reasonable average upper limit for physical work performed regularly over an 8-h working day[12]. This workload equals 50–60% of maximal heart rate (HR_{max})[13]. It is also suggested that no more than 40% of maximal muscle strength should be applied in repetitious muscular work[12].

Although physical strain exerted by the work have previously been studied in a wide range of occupational groups, only a few have examined this topic among occupational fish farmers. To our knowledge, no studies have investigated work strain in combination with thermal responses among fish farmers at their workplace. The aim of this research was therefore to study work-induced physical strain and thermophysiological responses during a field study among Norwegian fish farmers.

Subjects and Methods

Participants

Fourteen fish farmers (thirteen males and one female) from four fish farms located at the coast in the middle part of Norway volunteered to participate in the study. They were all professional fish farmers who performed their regular work during the study. Typically, 3–4 employees work at each fish farm at any time. Therefore, four different farms were visited to include an adequate number of participants in the study. The characteristics of the participants were: age, 35 ± 15 yrs (range 16–64 yrs); height, 180 ± 5 cm (range 171–187 cm); weight, 88 ± 12 kg (range 71–105 kg); HR_{max}, 189 ± 9 beats·min^{-1} (range 170–200 beats·min^{-1}); BMI, 27 ± 3 kg·m^{-2} (range 23–32 kg·m^{-2}). Work experiences varied between apprentices to the very experienced fish farmers.

The participants were informed about the aim of the study, the test protocol and their rights to terminate their participation at any time of the study before they provided written consent. The representatives from the company approved participation before the start, and the study was approved by the Norwegian Centre for Research Data.

Protocol

Each fish farmer participated in the physiological measurements during one of their work shifts. During each shift, work tasks included daily routine work (at lower work intensities) such as manoeuvring boats, fixing the canvas to the cage, preparing salmon samples and counting salmon louse. The heavier work operations included delousing and crowding the fish for delivery for slaughter (moderate and high work intensities, respectively).

Prior to starting their work shift, the fish farmers were equipped with sensors for measurements of work intensity and thermal stress. During the tests regular work clothing with a lifejacket was used. The outer garment was provided by the employer while the underwear and middle clothing was personal. The most common used clothing was t-shirt, sweater, sweatpants, outer jacket and trousers. The sweater was used as intermediate clothing when appropriate, and the clothing was adjusted by some of the fish farmers during work by taking off and putting on their outer jacket. Thermal insulation of the different clothing ensembles was not measured, but we estimate the clothing insulation to be approximately 2–2.5 Clo[14]. When possible, in relation to the work operations, the subjects answered a questionnaire about thermal sensation and comfort during work operations.

Measurements and instruments

To measure work intensity, the fish farmers were equipped with a heart-rate recorder (Equivital EQ02 Life-Monitor, Hidalgo, Cambridge, UK or Polar RS800, Polar Electro, Oy Kempele, Finland) and HR was continuously measured during a work shift.

Thermal stress during work was quantified by measurements of core temperature (T_c) using a gastrointestinal temperature pill (Vital Sense Jonah capsule ± 0.1°C, Mini Mitter Inc, Bend, OR, USA). It was not possible to deliver the pills the evening before the test started, and the pills were therefore handed over and swallowed when the fish farmers arrived in the morning at their workplace. Lunch and coffee were consumed when the pill still was in the stomach, and from some of the fish farmers a temperature peak could be observed for a short period. However, these data were not used in the study.

Skin temperatures were measured by attaching thermistors (YSI, Yellow Springs, OH, USA, ± 0.15°C) at four locations (chest, upper arm, front thigh and front leg) of the body, and were measured continuously every minute during the workday (Datalogger ACR Smart Reader Plus 8, logging interval 1 minute). Skin temperatures were measured on seven fish farmers at two locations (n=3 and n=4) at ambient temperatures of 6–7°C and 14–15°C.

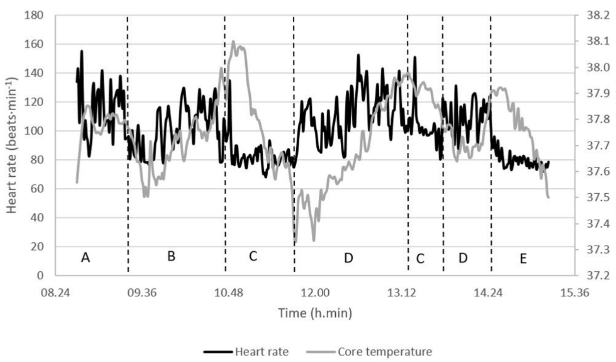

Fig. 1. Continuous recording of heart rate and core temperature for one fish farmer during a six-hour working period. A = rope work and crane handling. B = working with fish/delousing. C = rest. D = rope work. E = crane handling.

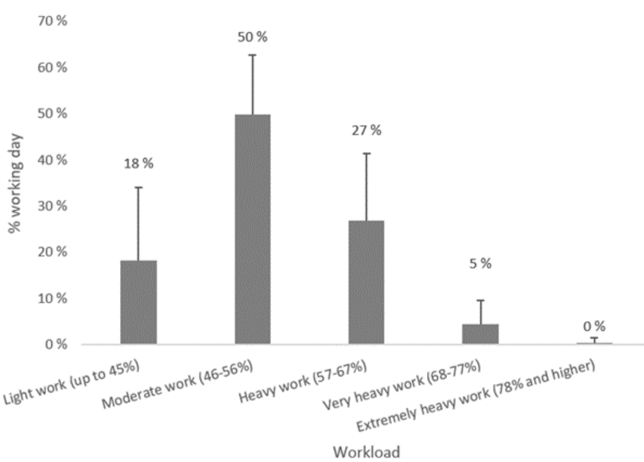

Fig. 2. Work intensity in per cent of a working day excluding lunch break (mean and SD, *n*=14).

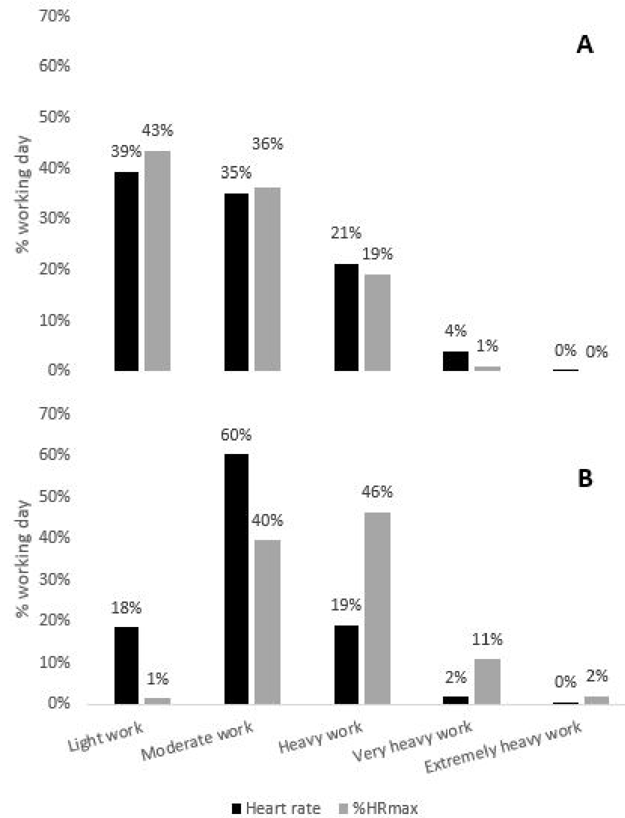

Fig. 3. Work intensity in per cent of a working day for (A) a 16-year- and (B) a 64-year-old subject (five-hour work period). %Hrmax: Percentage of maximum heart rate.

During and after the shift, participants were asked to evaluate their perceived thermal sensation and thermal comfort by answering questions modified from Nielsen and Endrusick[15]. Questions are scaled from –5 to 5, where –5 is extremely cold, 0 is neutral and 5 is extremely hot.

A multi-channel hand-held thermometer (Testo 435, Testo, Lenzkirch, Germany, accuracy ± 0.3°C, ± 2%RH) was used to measure ambient temperature (T_a, °C), relative humidity (RH, %) and wind speed (m/s) at the worksite.

Data analyses

To account for the great variation of the participants' age, the HR was adjusted for age according to this formula:

Maximal HR estimated: 211 – 0.64 × age[16].

For each subject, work intensities over a working day without lunch breaks were calculated as a percentage of time spent within the intervals of $\%HR_{max}$ corresponding to light work (<45%), moderate work (46–56%), heavy work (57–67%), very heavy work (68–77%) and extremely heavy work (>77%) modified from[12, 17]. Mean work intensity for all participants ($\%HR_{max}$) is presented as mean ± standard deviation (SD). Individual data for HR and core temperature are presented over time for selected individuals.

Changes in T_c are presented as the highest and lowest T_c during a working day. Differences between maximum and minimum values for T_c were analysed using Student's *t-test* for paired samples. Statistical significance was accepted at $p<0.05$.

Results

Ambient conditions

The field measurements took place in March and November 2017 and May and November 2018. The T_a, RH and wind speed varied between 0 and 1°C, 36–51%, 0.5–4 m/s (March 2017); 6–7°C, 67–75%, 0.5–5 m/s (November

2017); 13–15°C, 70–77%, 0.5–3 m/s (May 2018) and 11–13°C, 80–90%, 3–6 m/s (November 2018), respectively.

Heart rate, core- and skin temperature

The core temperature for the fish farmers (n=9) fluctuated during a working day. The minimum T_c was 37.1 ± 0.2°C and the maximum T_c was 38.1 ± 0.2°C. Skin temperatures (n=7) ranged from 18°C (front thigh) to 35°C (chest). At ambient temperatures of 6–7°C and 14–15°C, the lowest skin temperatures were measured on the front thigh and upper arm.

Fig. 1 shows an example of HR and T_c measurements for a fish farmer during a six-hour working period performing different work tasks, such as maintenance work, rope and crane handling, work operations hauling the net, crowding the fish for delivery and delousing operations. From a core temperature of approximately 37.5°C at the beginning of the workday, the core temperature increased to a maximum value of 38.1°C after approximately 2.5 hours of work. In this period, the fish farmer was working with fish/delousing operations that required higher effort. The mean HR over the entire working period was 105 bpm, which is classified as moderate workload[12]. With an estimated maximal HR of 187 bpm, this means a mean work intensity of 56% of his HR_{max}. The highest HR measured was 155 bpm, which means a work intensity of approximately 83% of HR_{max} for a short period during this work operation. This is classified as very heavy work[12].

The distribution of work intensity throughout the selected periods of the day for the 14 fish farmers can be seen in Fig. 2. The average period included in the workload intensity analysis was 4 hours and 55 minutes, with a standard deviation of 1 hour and 7 minutes. The average absolute HR during the workday was 101 ± 5 bpm, which represents 54 ± 4%HR_{max}. The maximum and minimum values for HR were 145 ± 14 bpm and 69 ± 12 bpm, respectively. The corresponding values for %HR_{max} were 78 ± 8% for the maximum and 37 ± 6% for the minimum.

Two case studies were selected to illustrate the effect of age when presenting work intensity as absolute (bpm) or relative (%HR_{max}) HR. Fig. 3 presents work intensity distribution during one workday for the youngest (16 yrs) and the oldest (64 yrs) subjects participating in the study.

Subjective evaluation of thermal sensation and comfort

In May, the ambient temperature was 13–15°C, and the fish farmers voted their body, hands and feet as warm. They were sweating, but they still felt comfortable. During the visit to another fish farm in March, at an ambient temperature of approximately 0°C, the thermal state of their body was voted neutral and they still felt comfortable. Subjective feedback from the fish farmers was that periods with low temperatures and wind during winter months caused problems with cold hands and feet.

Discussion

This study has shown that workers on fish farms are periodically exposed to high or low levels of work strain, where the high workloads are manifested as increased T_c and HR. The field measurements took place during spring and autumn, with no exposure to any extreme weather or sub-zero temperatures. This study therefore focuses on work strain and thermoregulatory responses during different work operations at ambient temperatures between 0 and 15°C.

Workload and core temperature

Depending on the work tasks performed (hauling the net and fish crowding vs. maintenance work) great fluctuations in HR and T_c were found during a working day. An individual's age and physical fitness will also determine the degree of effort for each work task. In our study, the individual variations caused large differences in both HR between the specific work tasks performed, and between subjects performing the same work tasks. The differences may be explained by several factors, such as the individual's maximal aerobic power, size of the engaged muscle mass, working position, whether the work is intermittent at a high rate or continuous at a lower intensity and environmental conditions[12].

Prolonged physical work can be classified as to the severity of workload and to cardiovascular response[12, 17, 18]. High physical demands are considered a risk factor for both several musculoskeletal disorders[19] and cardiovascular events[9]. According to the classification, HR below 90 bpm can be classified as light, between 90 and 110 bpm is classified as moderate and above 110 as heavy, very heavy and extremely heavy work. In one of the fish farmers (age 24 yrs) a mean HR of 101 bpm (51%HR_{max}) was registered during daily maintenance work which is classified as moderate workload[12]. However, the highest HR measured for a short period in the same subject was 147 bpm, which means a work intensity of approximately 75% of HR_{max} during this work operation and is classified as very heavy work. During the same period, the T_c increased from 37.4°C to 38.3°C. HR_{max} is predicted, to a large extent, by age alone and is independent of sex and habitual physical activity status.

The findings by Tanaka *et al.*[20] suggested that the equation (HR_{max} is 208 – 0.7 × age) used in their study underestimates HR_{max} in older adults and would have the effect of underestimating the true level of physical stress.

Various attempts have been made to establish maximal permissible limits for daily energy output for people working at the same task year round[21]. In the literature, limit values for acceptable levels of strain at work have been described between 33 and 50% of maximal oxygen uptake for an 8-h shift[12, 22]. However, establishing such norms may be quite meaningless, given the large individual differences in physical work capacity or fitness, and because the classification of cardiac strain does not consider the relevance of the age or physical fitness of workers[10, 23]. This means that an HR of 100 bpm does not imply the same work intensity or cardiac strain for a 20- and a 50-year old person. Because the values also refer to average individuals 20–30 years of age, they can be used only as general guidelines in view of the vast individual variations in ability to perform physical work.

The peak load of the task may also be more important than the mean energy expenditure when it comes to strain imposed on the worker[23]. According to Rodahl *et al.*[23], in some cases, such as the older commercial fishermen, the only way a person can endure workloads close to the permissible physiological limits, day after day, year after year, is by working intermittently, with periods of high work intensity interspersed with frequent, brief, rest periods. In our study, several work tasks showed periods of higher work strain than these recommended limits. Depending on the number and length of rest periods, shorter or longer work periods require higher or lower acceptable limits[22], and a standardized work–rest schedule is recommended for activities that result in prolonged periods of dynamic work[12]. According to Preisser *et al.*[22], establishing limits for permissible physical workloads is of limited value because, at least in the western world with its advanced technology, excessively heavy work can easily be eliminated with technical aids depending on cost and priority. These authors claim that of far greater importance to the worker today is the way the work is being performed, the opportunity to influence the working situation and to govern one's rate of work. In addition, the perception of safety and general atmosphere of the working environment and the arrangement of work shifts are mentioned[22]. Poulianiti *et al.*[24] also suggest that current occupational guidelines and future research should provide updated energy cost estimates within a wide spectrum of occupational settings considering the sex, age and physiological characteristics of the workers as well as the individual characteristics of each workplace.

Core- and skin temperatures, ambient temperature and clothing

Physical work increases the heat production of the body, and the heat produced by the working muscles is carried to the body core, elevating deep-body temperature. Depending on the work intensity the T_c rises and may stabilize at different levels[25]. The core temperature for the fish farmers in our study increased significantly during periods of work, from a minimum of 37.1°C to a maximum of 38.1°C. This rise in core temperature is proportional to relative rather than absolute workload and provides the central stimulus for sweating and cutaneous vasodilation[26, 27]. It is well known that the T_c shows a clear circadian rhythm with a daily variation of 0.5–0.7°C[28], which could also have influenced the T_c in our study. However, the rise in T_c was observed during limited periods of time when the fish farmers performed heavy work, and we may therefore assume that the effect of circadian rhythms contributed for only a minor part of the total increase in T_c.

In spite of various challenges from the environment it is shown that human body core temperature is kept fairly constant[29] and that heat produced by the working muscles elevating the T_c is independent of ambient temperature over a wide range[26, 30]. On the other hand, skin temperatures are more influenced by the ambient temperature. The overall skin blood flow response is proportional to a combination of core and skin temperatures, with T_c being the more influential variable[31] whereas thermal comfort are influenced by several factors, such as metabolic rate, air temperature, mean radiant temperature, air speed, relative humidity and clothing insulation[32]. Our field tests took place during spring and autumn, and the participants were not exposed to any extreme weather or sub-zero temperatures (lowest temperature 0°C). In May, at an ambient temperature of 13–15°C, the temperature of the chest and front thigh varied between 29 and 35°C during the workday (n=4) which was also reflected in the subjective evaluations of thermal sensation and comfort where the fish farmers voted their body, hands and feet as warm. They were also sweating, but they still felt comfortable. During the visit to another fish farm in November, at an ambient temperature of 6–7°C, the chest temperature (26–33°C) and the temperature of the front thigh (18–30°C) (n=3) was lower than at the higher ambient temperatures in May. The fish farmers subjective thermal evaluation of their body was voted as neutral, and they felt comfortable. In our study the most common work clothing used was t-shirt, sweatpants, outer jacket and trousers. A shirt or a sweater were also used as an intermediate layer when needed, and since the fish farmers could adjust their amount of clothing during work, we may assume that this also affected their subjective feedback of thermal sensation and comfort. Even though we did not experience any challenging environmental conditions in this field study, feedback from the fish farmers was also that periods with low ambient temperatures and wind during winter months caused problems with cold hands and feet. In many countries, a substantial number of fish farmers are at risk of exposure to air and water temperatures that are near or below freezing, particularly during the winter months[4, 33]. In a study by Thorvaldsen *et al*.[4], 7.6% of the fish farmers answered that they felt cold often or very often at work. These potential exposures mean employees need to be appropriately trained and properly outfitted for the prevailing conditions[34]. Another result from the same study was that self-reported health complaints such as pain in the neck/shoulders/arms and back pain are most common in this occupational group. Fish farmers relate these complaints and strain injuries to their work, which partly is on moving work platforms (sea-based net cages) and includes exposures such as heavy lifting, working with the upper body twisted or bent. In cold work, a part of the musculoskeletal complaints, muscle strain and fatigue may be due to the combined effects of cold exposure and repetitive work[5, 35–37].

Conclusion

This study confirms that workers on fish farms are periodically exposed to high levels of work strain, manifested as increased core temperature and heart rate when working. The results have provided a better understanding of work strain and environmental challenges during fish farm operations.

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