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Assessment of physical, environmental, and cardiac strain in 43 operators (wearing protective equipment) conducting clean-up of heavy oil products

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ABSTRACT

Background. *The aim of the study was to organise an assessment of the physical strains and environmental exposure to hydrocarbon derivatives in persons involved in shoreline clean-up of heavy oil products, in order to investigate the dangers of oil spill clean-up.*

Material and methods. *Forty-three healthy volunteers wearing protective equipment cleaning up an artificial shoreline underwent cardiac strain measurements, as well as a study of thermal stress (approximate WBGT index, water loss, measurement of internal body temperature before and after physical activity). A subjective assessment of perceived exertion was correlated to articular strain indicators recorded for the weight of loads lifted, movement frequency, and the range of movement. Environmental exposure was determined by using portable hydrocarbon detectors.*

Results. *For adult subjects in good physical condition, in neutral temperatures, oil spill clean-up is considered non-arduous. However, in sedentary, stressed subjects exposed to difficult climatic conditions, clean-up can be considered hard to extremely hard. In terms of environmental exposure, slight traces of toluene appeared once out of a total of 18 analysed samples.*

Conclusions. *The sample studied was subject to physical articular strains and presented variable cardiac strain; environmental exposure was, on the other hand, slight when involving cleaning up heavy petroleum products. The subjects liable to carry out this activity are more tolerant to the efforts required when they are healthy, fit, young adults, in the non-arduous thermal conditions recorded in this study.*

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Key words: oil, toxicology, strains, heart, physiology

INTRODUCTION

The sea is a commonly used method of transport for chemicals. This heavy maritime traffic is the source of particularly serious concern for coastal states in terms of ensuring the safe circulation of oil tankers. Unfortunately, in spite of efforts to ensure safety and strict regulations for transporters, incidents resulting in major oil spills have occurred over the past years (shipwrecking of the *Prestige*, *Erika*...).

Although today we may be beginning to have a better understanding of the ecological, economic, aesthetic, and tourist-related impacts of a polluted coastline, the impacts of cleaning up oiled biotopes on responders' health (both volunteers

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and professionals) have been the subject of little or no studies despite the fears felt by the general public. An assessment of the physical strains and environmental exposure to hydrocarbon derivatives in persons involved in oil spill clean-up was therefore carried out.

In order to do so, a sample of healthy volunteers was selected from trainees taking part in oil spill response training courses at the facilities of the Centre of Documentation, Research, and Experimentation on Accidental Water Pollution (Cedre) in Brest (France) from May to September 2007.

This descriptive study also helps to determine whether the personal protective equipment used by the operators during these training courses is efficient enough to prevent the health risks inherent to the dangers of oil products.

Finally, the objective of this work is to have a global assessment of hazards which can exist when people are involved in cleaning-up of heavy oil products after oil spills. By recording cardiac strain and exposure to hydrocarbons the aim of this work is also to produce objective data to characterize these risks.

MATERIAL AND METHODS

This descriptive study involves the biometric, metrological and physiological analysis of a selected population sample of healthy adults. It assesses, on the one hand, the overall level of strain of shoreline clean-up following an oil spill through heart rate monitoring and the calculation of water loss, thermal and articular strains, as well as the inhalable fraction of hydrocarbons liable to intoxicate those cleaning up heavy petroleum derivatives.

This last parameter is important to quantify because although we are well acquainted with the acute neurological effects of inhalation of light hydrocarbons and the carcinogenic risk of chronic exposure, the question remains whether heavy or light hydrocarbons contained in heavy petroleum could reach the airways after clean-up activities.

POPULATION AND STUDY LOCATION

The study was carried out on an artificial beach and water basin at the Centre of Documentation, Research, and Experimentation on Accidental Water Pollution (Cedre) in Brest (France), which runs courses for trainees from different companies and bodies liable to be involved in cleaning oiled beaches. The participants take part in a theory course with practical clean-up exercises on an artificial beach and water basin polluted with oil.

The data was collected during four 5-day training courses between April and September 2007, with 2 afternoons of practical clean-up exercises on Cedre's artificial beach for each course, during which the measurements were taken.

In total, 80 people were enrolled for these courses and were to be divided into groups of 20 for each exercise. We informed them all about the study and explained that a medical examination would be done to exclude those with a history of cardio-vascular disease and those on treatment (which might impact on heart monitoring). 28 people refused to participate. 9 were excluded because of a medical history or medication use.

Nevertheless all the adult volunteers with a clean medical history and without any on-going medical treatment whose physical examination was normal were included in the study by an occupational physician. In total, 43 subjects were able to take part in the study.

Furthermore, during the physical examination, the subjects were questioned on their exercise habits (where they existed) and on the average daily duration of exercise.

ORGANISATION OF THE PRACTICAL CLEAN-UP SESSIONS

During the practical sessions which took place on Cedre's artificial beach and water basin, each subject was equipped with protective equipment (weighing 6 kg) including (Figure 1):
- 2 protective suits (a Tyvek® suit and a waterproof);
- 1 helmet, goggles, FFP1 mask;
- 1 pair of gloves;
- 1 pair of boots;
- 2 earplugs.

The practical part of these oil spill response training courses on shoreline clean-up was divided into two sessions:
- a session on the water basin;
- a session on the artificial beach.

Our study focused exclusively on the second session, which involved three activities:
- cleaning stones (Figure 2);
- cleaning riprap (Figure 3);
- removing buried pollutant (Figure 4).

The clean-up techniques vary for each activity, the three main techniques being:

Figure 1. Protective equipment

Figure 2. Cleaning stones

Figure 3. Cleaning riprap

Figure 4. Removing buried pollutant

— flushing, clean-up using an impact hose;
— high pressure washing with seawater at a temperature of between 80°C and 100°C after application of a cleaning product without surfactants;
— the “cement mixer”, a technique which consists of cleaning oil derivatives on small oiled stones and pebbles.

The products spilt were the following: lamp oil, composed of hydrodesulphurised kerosene, (CAS n° 64742-81-0), and heavy fuel oil, a liquid product produced from various refinery fractions which may contain a high proportion of hydrocarbons (CAS n° 68476-33-5).

DATA COLLECTED

Heart rate monitoring, analysis of thermal and articular stress, water loss measurement, and research into the inhalable hydrocarbon fraction in the trainees enabled the assessment of the overall level of strain of clean-up of these heavy oil products.

PARAMETERS STUDIED

Heart rate monitoring. The heart rate at rest, during exercise, and the recovery heart rate were measured during the different practical sessions of the courses using individual heart rate monitors. Scales of physical strain listing the heart rates obtained (Frimat grid) [1] were used to characterise the activity from non-strenuous (lowest ranking) to extremely hard (highest ranking).

Each of the candidates was equipped with a Polar® S610i heart rate monitor, which included:
— an adjustable chest strap equipped with a heart beat detector made up of grooved electrodes which were moistened before use;
— a wrist receiver to which the heart rate was transmitted. The heart rate was recorded every five (05) seconds.

All the heart rate monitors used coded transmission between the transmitter and the receiver.

All our volunteers were fitted with heart rate monitors before putting on their protective equipment. We began by recording their heart rate at rest. The subjects sat for 10 minutes without speaking, after a period of 60 minutes without smoking, not immediately after a snack and at least an hour after the last meal. Subsequently, during the practical session, the heart rate was recorded continuously and the following points were measured:
— the average heart rate recorded during the working period (AVG);
— the peak heart rate recorded during the working period (HR_{peak});
— the acceleration of the heart rate (^HR), which is equal to the difference between the peak heart rate and the average heart rate (HR_{peak} – AVG);
— the net cardiac cost (NCC), which represents the difference between the average heart rate and the resting, or reference, heart rate (AVG – RHR);
— the relative cardiac cost (RCC), which expresses the NCC as a percentage of the reserve heart rate, the reserve heart rate being defined as the differential of the theoretical maximum heart rate and the resting heart rate (NCC/TMHR-RHR);
— the theoretical maximum heart rate (TMHR), defined by the formula **TMHR = 220 – age (years)** according to

Astrand [2–4], either by an effort test or an approximation formula.

The Frimat method that was selected [5] opts to assess the level of strain of the work according to a set of indices resulting from the analysis of the continuous heart rate monitoring. Thus, according to the heart rates recorded, we obtained ratings which could then be added together to determine an overall strain score. The higher the cardiac strain, the higher the score, the minimum score being 5 and the maximum 30.

Several factors can affect the heart rate [6–8]. We were therefore careful only to collect the results relative to the tasks undertaken, to their duration, and to the environmental parameters involved. The other factors were minimised by selecting healthy volunteers, in terms of their cardiovascular system.

At the end of the course, the candidates were made to rest for 7 minutes to obtain their recovery heart rate.

The recorded heart rates were processed using an IT interface and ProPulses Ergo® software, used to display heart rate graphs. The automated tests and calculations of the different cardiac strains recorded were processed using the same software and compared to the Frimat grid. The different measurements were compared to the reference values.

Assessment of body weight loss. Each healthy volunteer was weighed without protective clothing before the practical phase, in order to obtain the reference weight or initial weight W_i. Each subject was then allocated a water supply, which was monitored.

According to the rule that 1 litre of water is equal to 1 kilogramme, we calculated the weight W_L which corresponded to the water intake. The subjects were not allowed to urinate during the periods of measurement. Subjects urinated prior to Body mass measurement preceding measurement periods.

At the end of the course, the subjects were weighed again; this weight was labelled W_f.

We deducted W_f from (W_i + W_L) to obtain ▲W, a fairly good indicator of the variation in weight according to the individual's water intake.

According to the International Organization for Standardization standard ISO 7933: 2005, French AFNOR standard X35-204, (required sweat rate): "3% dehydration is accepted as the maximum allowable limit in industry for a 4 to 8 hour exposure period".

Assessment of the variation in core temperature. In this study, tympanic temperature measurements were taken as the closest value to the core temperature. The temperature was measured using a First Temp Genius® infrared tympanic thermometer (sensitivity of 0.1°C) at the beginning before the subjects put on their protective gear and at the end of the exercise once they had removed their gear.

The increase in tympanic temperature beyond which we considered that the subject presented too high a thermal strain was +1°C [9].

Atmospheric measurements. The thermal atmosphere was analysed using an approximate Wet Bulb Globe Temperature (WBGT) index (standards X35-201 and ISO 7730: 1994) providing the dry bulb temperature, wet bulb temperature, radiation temperature, and air speed during the practical training sessions.

In this way, we sought to identify any possible environmental constraints which may have been liable to interfere with the heart rate during exercise and the recovery heart rate [10].

A Fulher® Testo 445 thermo-hygro-anemometer was used.

For the radiation temperature, a Kimo® TK 100 black globe sensor was used.

Individual dosimetry. Amongst the group of healthy volunteers, 18 subjects were picked at random and equipped with an activated carbon cartridge placed at the neck of the waterproof connected to a flow meter pump (200 ml/s).

Individual dosimetry was then conducted in order to assess the inhalable fraction of hydrocarbon vapours and therefore the environmental exposure to oil derivatives during the practical session.

The analysis of these dosimetry results, obtained by the laboratory LERES (*Laboratoire d'étude et de recherche en environnement et santé de Rennes*), enabled us to assess the trainees' exposure to hydrocarbons resulting from the oil spilt during the practical sessions and to adapt the individual protective equipment accordingly.

The chemical derivatives found were eluted with a solvent (pentane) then analysed by gas phase chromatography coupled with FID and mass spectrometric detection. They were then categorised into heavy or light products according to their composition and the length of the hydrocarbon chains found.

Assessment of articular strain. In order to obtain objective criteria of articular strain during clean-up we focused on 3 biomechanical factors:

Extreme posture

Extreme posture is defined as using over half the range of motion (ROM) of a joint regularly during the workday.

As a risk factor, posture must always be evaluated in relation to duration or frequency or both. The more a posture deviates from the resting position, the more important it is to take into account the duration of the movement and recovery time. One reason is that maintaining such a posture increases the strain on the affected muscles.

Movement repetition

Not only the extent of movement, but also its frequency, must be taken into account. Movements are usually defined as highly repetitive if they are performed more than 2 to

4 times a minute or in cycles of less than 30 seconds, depending on the upper-extremity region involved.

Even when the repetition does not exceed these guidelines, duration may play a role when the movements are performed during most of the day, i.e. for more than four hours per workday.

Muscle force

One way to assess the degree of muscle strain is to measure the use of muscle force in relation to duration-recovery time for static actions. The greater the muscle force, the longer the required recovery time.

Maintaining the same posture for too long is a risk factor. To collect these data we observed the activities, took pictures, made films and weighed the equipment they manipulated.

Scale of perceived exertion. At the end of the course, we invited each subject to complete a subjective self-assessment. The aim was to determine how arduous the subjects felt the tasks to be. The average of the scores obtained for each activity for all the trainees was taken to define a subjective overall exertion rating for the different pollution response phases.

The scale used was Borg's rating of perceived exertion [11]. The results of this scale were correlated with the heart rate readings.

Other information on the subjects liable to affect their perception of the arduousness of the work was also taken into account such as whether or not they took regular exercise.

Finally, this subjective analysis of the exertion as perceived by the trainees was correlated to the articular strain indicators identified using films and photographs of the practical sessions.

RESULTS

SAMPLE CHARACTERISTICS

The sample was made up of 43 subjects, of which 40 were men and 3 were women.

The average age of this sample was 39 years (ranging from 25 to 58 years old). The average weight was 80 kg (56–120 kg). The average theoretical maximum heart rate of this sample was 181 beats per minute (162–195 beats per minute).

THE MEASUREMENTS

Heart rate monitoring. Of the 43 subjects equipped with heart rate monitors, 11 recordings could not be entirely used for the whole of the practical session due to accidental interruptions (possible interruption to recording due to accidental mechanical pressing of the stop button, memory full, spray of water or sand or some other interference). Nevertheless, of these 11 recordings, some were able to cover a whole activity, such as the buried pollutant removal exercise or the stones or riprap clean-up exercises. The results from the correlation with the Frimat scale are presented below.

Every clean-up activity sequence of the monitoring which was interpretable allowed us to calculate:

- the average heart rate recorded during the working period (AVG);
- the peak heart rate recorded during the working period (HR_{peak});
- the acceleration of the heart rate (^HR), which is equal to the difference between the peak heart rate and the average heart rate (HR_{peak} – AVG);
- the net cardiac cost (NCC) which represents the difference between the average heart rate and the resting, or reference, heart rate (AVG – RHR);
- the relative cardiac cost (RCC), which expresses the NCC as a percentage of the reserve heart rate, the reserve heart rate being defined as the differential of the theoretical maximum heart rate and the resting heart rate (NCC/TMHR-RHR) as shown in the example below.

Afterwards we calculated the difficulty of each sequence and for the whole clean-up.

The results from the correlation with the Frimat scale are presented below.

For the stone clean-up activity (33 recordings):

More than half of the participants found this activity difficult (Figure 5).

For the riprap clean-up activity (33 recordings):

It was the activity where most people found the task extremely hard (Figure 6).

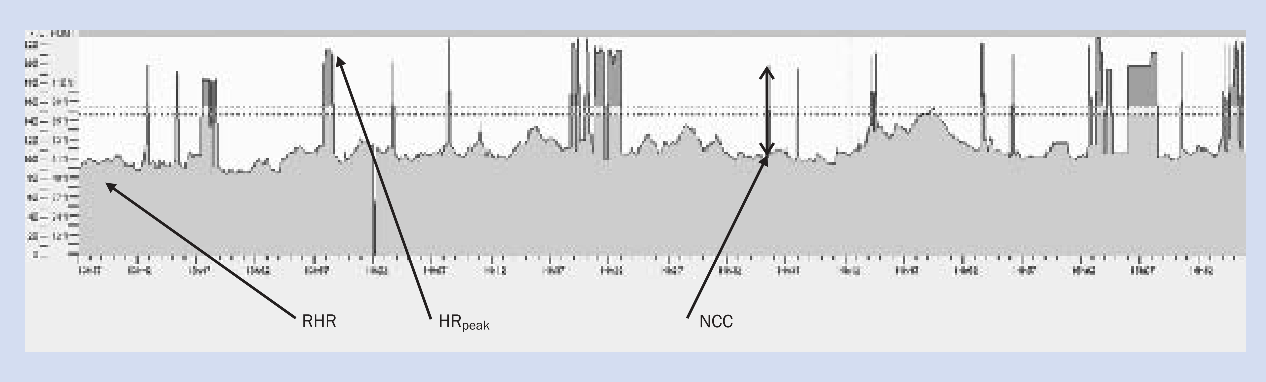
For the buried pollutant removal activity (33 recordings):

This activity was tolerable from the cardiac aspect for most people but most stressful for the back (Figure 7).

Finally, the distribution of levels of strain for the whole of the practical session was variable for one subject to another (Figure 8).

Within our sample, we also note that the 3 women who took part in the study all presented an overall level of strain greater than 24 (very hard on the Frimat scale). Furthermore, a tendency seems to emerge: the more athletic the subjects were, the lower the cardiac strain. The most athletic subject (15 hours of exercise per week), aged 45, presented the lowest level of physical strain (less than 10) (Table 1).

If we study the age and level of physical strain variables in men, the Kruskal-Wallis test investigating the relationship between increasing age and increasing cardiac strain points to a correlation bordering on significant (s = 0.0706). We can therefore presume that the level of strain tends to increase with age, even if our sample is not large enough to demonstrate this significantly. However, age is not an isolated factor in this case, as a good level of fitness helps (despite increasing age) to tolerate the efforts required by the clean-up activities more effectively.



P. Frimat grid representing levels of physical strain

Score	1 point	2 points	4 points	5 points	6 points
AVG HR	90 to 94	95 to 99	100 to 104	105 to 109	110 and +
Delta HR	20 to 24	25 to 29	30 to 34	35 to 39	40 and +
Peak HR	110 to 119	120 to 129	130 to 139	140 to 149	150 and +
NCC	10	15	20	25	30
RCC	10%	15 %	20%	25%	30%

If the score is: 25 — extremely hard; 24 — very hard; 22 — hard; 20 — arduous; 18 — endurable; 14 — light; 12 — very light; ≤ 10 — non-strenuous, constrainless, easy

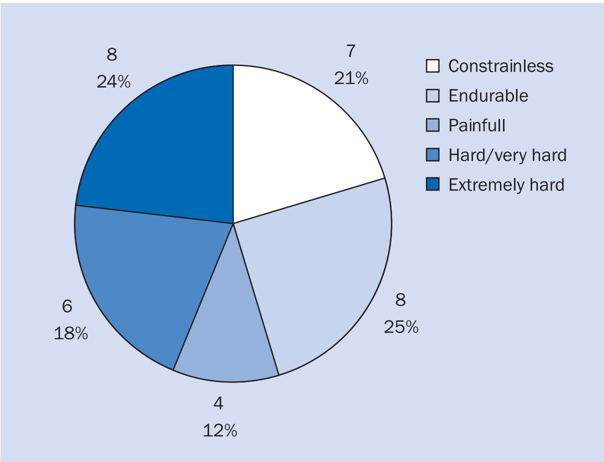


Figure 5. Heart rate scoring for stone clean-up activity

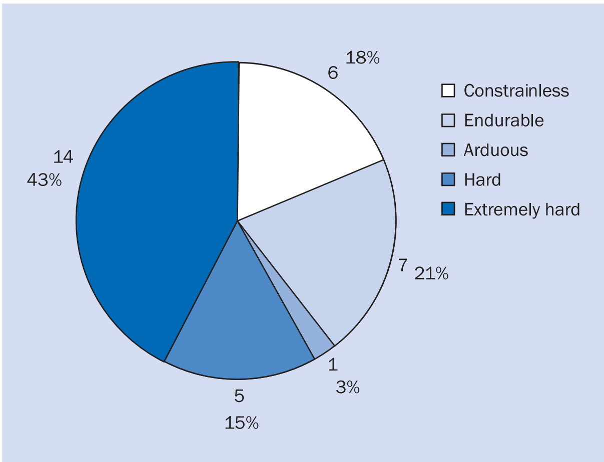


Figure 6. Heart rate scoring for the riprap activity

Assessment of body weight loss. The variation in body weight during the practical sessions ranged from +0.85 kg to –1.9 kg.

Four subjects from the sample studied exceeded the maximum acceptable value of 3% weight loss (in relation to the weight of the individual before activity).

Assessment of the variation in tympanic temperature. In the first series, only one measurement was taken to obtain the temperature T, a commonly used technique [12], but one which appears not to be fully representative. We therefore decided subsequently to take measurements in both eardrums of each subject. In the last three series, the temperature T is therefore the average of the temperature of the left ear and that of the right ear.

No significant alterations in the trainees' tympanic temperature were found during the sessions. Only one trainee showed an increase in tympanic temperature of +1°C.

Thermal atmosphere. The WBGT index was obtained from the thermal, hygrometric, anemometric, and radia-

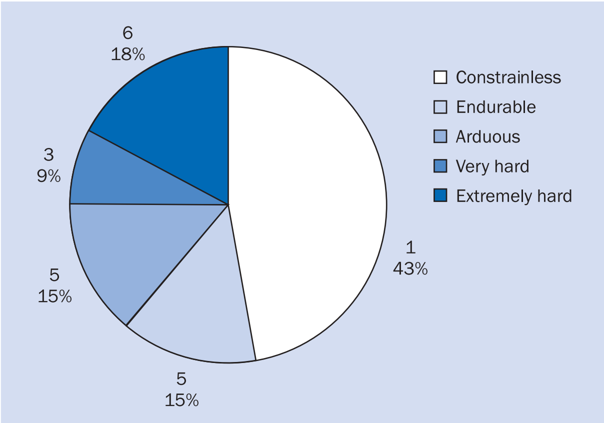


Figure 7. Heart rate scoring for buried pollutant removal activity

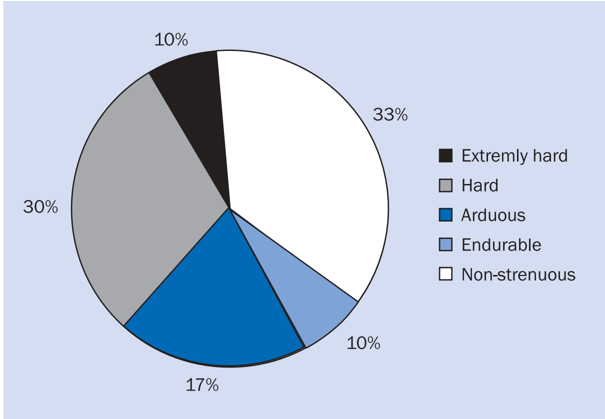


Figure 8. Overall level of strain for the entire practical session

Table 1. First seven subjects scoring for the whole session in regard to their physical activity

Subjects N = 8	Age	Type of physical activity and hours of practice by week	Scoring	Level of difficulty
Subject 1	46	Cycling, walking (10 h)	6	Easy
2	29	Football (9 h)	6	Easy
3	39	Jogging (3 h)	11	Very light
4	34	Judo (2 h)	13	Light
5	44	Judo (2 h)	14	Light
6	36	None	25	Extremely hard
7	56	None	28	Extremely hard

tion parameters (0.7 x wet bulb temperature + 0.3 radiation temperature + 0.1 air temperature) in the outdoor environment [9, 13]. In general, this index is used for working conditions in confined spaces; however, in practice, the WBGT index acts as a heat stress indicator for high-risk situations.

The wet bulb temperature is obtained by calculating the thermal comfort zones according to the American Society of Heating and Ventilating Engineers' standards, following the measurement of the dry bulb temperature and the hygrometry percentage.

If the WBGT result is over 25°C, the situation should be investigated further. In our study, only one of the calculated WBGTs was slightly higher than 25°C.

The values obtained are given in the Table 2.

Individual dosimetry. Individual dosimetry was conducted by picking subjects at random from the 43 adults included in the study, giving 18 samples in total. The detection threshold was 0.1 μg.

Only a barely detectable toluene fraction was found in one sample, out of the 18 samples analysed.

Scale of perceived exertion and articular strain. According to Borg's perceived exertion rating (1970), we found average values according to the activity for each of the four sessions studied (Figure 9). When holding the hose was needed the subjects found it stressful. This task was painful because of the posture required.

DISCUSSION

The methodology of the study is based on the need to have objective data in relation to the clean-up activity of heavy oil products. In this case it is difficult to be sure that this was the only activity which impacted on heart rate. In fact many subjects could be stressed by the knowledge of the measurement and the fact that they were observed throughout their activity.

We wanted to have many samples of hydrocarbon detection but it was not possible to have more devices at each session. Moreover these devices are very fragile and needed to be used with extreme care. It was not very easy to keep them functioning well during the clean-up activity.

The male-dominated nature of this sample can be explained by the composition of the oil industry workforce. The

Table 2.

Date	25/04/07	26/04/07	23/05/07	24/05/07	12/09/07	13/09/07	19/09/07	20/09/07
WBGT	15.70°C	15.33°C	18.16°C	19.4°C	22°C	25.2°C	20°C	21°C

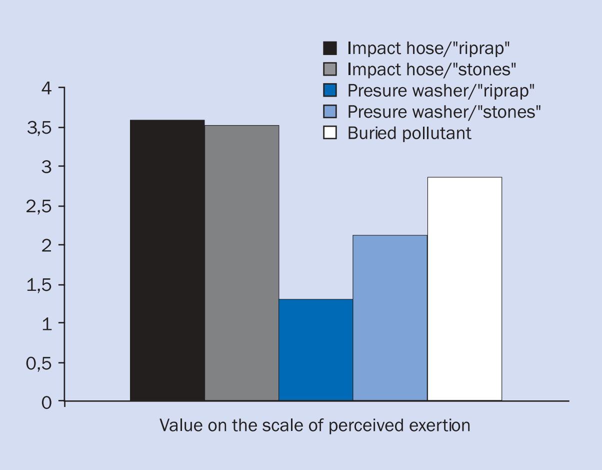


Figure 9. Value on the scale of perceived exertion

sample may therefore not necessarily reflect a whole population that may be liable to be involved in an oil spill clean-up. In fact, this population is largely made up of volunteers and is often very heterogeneous (older adults, children, subjects with a history of cardiovascular problems, etc.). The results of this study should therefore be considered in accordance with a certain knowledge of occupational physiology and of the normal working conditions of these individuals. The extrapolation of these results to a large, heterogeneous population should therefore be taken with caution.

Nevertheless, the results can act as a basis for advice and recommendations on the protective equipment to use on this type of worksite, especially as so many heart rate readings (even if some data was missing) have rarely been analysed for the same tasks [14–16].

Despite the acquisition of all the data relative to these cardiac parameters, we cannot eliminate the possibility of interference in the interpretation of these results. Furthermore, it is possible that the monitors may have been polluted by external elements (sand, seawater, dust, knocks). Nevertheless, we were able to obtain a large number of measurements over the four training courses studied, confirming the data, found in the literature, showing that a clean-up activity in which protective equipment is worn induces cardiac strain, which must be taken into account when considering the medical capacity to lift this type of equipment [17–20].

By way of comparison, the removal of buried pollutant exercise appears to be less strenuous than the stone clean-up exercise and especially than the riprap clean-up.

The physical strain of the buried pollutant removal exercise determined by the heart rate monitoring should be weighed up against the biomechanical strains on the spine, the shoulders, and the wrists that it involves. Furthermore, the trainees spend less time on this activity than on the others (less than 10 minutes). All the trainers also underline the fact that this activity requires a particular technique. The repeated plunging of an impact hose into the sand requires the operator to have a controlled hold of the hose and to bend backwards to an angle of 10 to 45°.

The order in which the activities are carried out also influences the cardiac strain. Thus the trainees who began the practical session with an activity which was not overly strenuous showed a lower overall cardiac cost for the practical session, compared to those who began with a very strenuous activity. This suggests that a warm-up is necessary to help the trainees to endure the efforts more easily and indicates muscular exhaustion, which hinders the continuation of the practical session in terms of cardiac strain when the trainees begin with the hardest activity.

The cardiac strain induced by the riprap clean-up activity is greater when this exercise is carried out first.

Cardiac strain also varies according to other personal criteria such as physical fitness. The more athletic the subject, the greater the range in cardiac cost and the lower the peak heart rate during exercise [21]. In our study, the most athletic subjects were generally those whose cardiac strain was nil or endurable for the 3 activities.

In terms of thermal stress, the environmental conditions were favourable during the practical sessions, and the periods of activity were short. However, in real-life situations, this is not always the case. Clean-up activities can last for whole days and sometimes for several months [22]. Furthermore, the different clean-up techniques can sometimes be difficult to implement in demanding weather conditions (considerable heat, high humidity levels) and on difficult access sites (cliffs, sloping beaches, beaches with rip currents...).

It should be noted that the cardiac strain recorded varied greatly from one individual to another, but with a tendency towards the riprap clean-up exercise being the most strenuous in favourable thermal conditions (approximate external WBGT index not exceeding 26°C).

This low thermal stress is corroborated by the water loss results. Although we noted that the majority of the sample lost weight, only one subject exceeded the 3% limit. This subject claimed to be "stressed" by the study and their physical capacities diminished throughout the day.

Assessing core temperature is a source of controversy in the literature [9, 12]. In this study, the method chosen was tympanic temperature, on the one hand as it seemed the easiest to implement given the conditions of the study, and on the other hand because it determines the core temperature. Although there was no significant increase in tympanic temperature (which confirms the presence of low thermal stress), we were surprised by certain results as some variations were negative, i.e. the temperature after activity was lower than the initial temperature. So far, we have not found an explanation for these negative variations, other than the possibility of the rain and outdoor thermal conditions cooling the tympanic membrane. We therefore concluded that tympanic measurement was not a reliable method of obtaining an indication of variation in the core temperature of the subjects.

In terms of the subjective evaluation of the exertion levels, some subjects from the sample who were not native French speakers had some difficulty in understanding the terminology of this survey (conducted in French). We also noted that the exertion levels provided, based on this subjective scale, were often lower than those provided by the heart rate analysis using the Frimat method.

The scores varied considerably from one series to another. However, the articular stress appeared to be the greatest hindrance for many subjects as the activities that involved holding the impact hose at shoulder height resulted in the highest perceived exertion indices. In this respect, many subjects complained of mechanical pains in the lower back and shoulders at the end of the day.

Finally, as concerns the inhalable hydrocarbon fractions obtained by individual dosimetry, the results from the first training course could not be relied on as LERES laboratory informed us of the saturation of many detectors.

The hydrocarbon detectors had been polluted with sand and seawater. It should be noted that these sensors are designed more for sampling in a dry or low humidity atmosphere. Nevertheless, the almost undetectable presence of toluene (< 0.1 µg) was reported on one sample while many grains of sand were found on the other samples.

Thereafter, we therefore chose to sample only during the pressure washing exercise (vaporisation and temperature between 80 and 100°C). Each sample was then transported to the laboratory the same day. The 9 following samples were all negative.

However, projected grains of sand (liable to be inhaled) were also detected by the sensors. Furthermore, in this situation of pollution by an artificial oil spill, the products spilt were represented by heavy fuel oil and lamp oil (low volatility). However, in reality, the oil derivatives which pollute the coast are sometimes different: lighter and more harmful [23–25]. These products could therefore result in exposure different to that of heavy products in a neutral thermal atmosphere. Generally speaking, however, prolonged contact with the skin should be avoided [26]. Responders should therefore wear gloves, protective suits, waterproof boots, and goggles for these exercises. It should be noted that protective clothing (weighing 6 kg in our study) will inevitably increase the cardiac strain of the clean-up activity. The results of the dosimetry tests indicate that respiratory protection should also be deployed, by using FFP1 masks, mainly to prevent the inhalation of grains of sand liable to be contaminated with the heavy oil derivates used for these training sessions.

CONCLUSIONS

When carrying out shoreline clean-up following an oil spill, it appears that the population, in this case made up of oil industry professionals, when wearing suitable protective equipment (protective suit, boots, waterproof gloves, goggles, FFP1 mask) is subject to physical articular stress and to non-negligible cardiac strain. The environmental exposure is, however, low when cleaning up heavy oil products. In fact we did not detect the presence of free hydrocarbon products in the air while cleaning heavy oil products.

The subjects liable to carry out this activity are more tolerant to the efforts required when they are healthy, fit, young adults, in the non-arduous thermal conditions recorded during the practical sessions studied. For other subjects, further investigation would help to determine the impact of the physical stress and the cardiac strain on those suffering from chronic problems reducing their cardio-respiratory and articular capacities.

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To all the members of LERES (Laboratoire d'étude et de recherche en environnement et santé de Rennes).

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