

Does the CRYOVEST preserve the cognitive functions of workers at the time of rounds under strong heat?

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Resume

The heat effect on the behavior has been widely investigated in the sports world and laboratory, it reveals an accelerated development of tiredness and has a negative impact on the capacity to effectively regulate its activity.

Therefore, in the industry world, although it is subject to health and security stakes, it has not been yet really studied concerning the potential effect of a deterioration on cognitive control led by the heat.

6 workers of ArcelorMittal company (Dunkerque) have been assessed on 5 cognitive tasks which reflect their daily work, while doing their round in a high heat production zone (up to 50°C).

A cooling system like Cryovest has been tested by the workers during their round, in a randomized way during the 2 days of tests.

Measures of heart rhythm, hydric status, cutaneous temperature and psychological have been taken before, during and after the round.

In view of the size of the study sample, a statistical filter of the results analysis has not been considered. The results suggest a selective deterioration of the heat (without wearing the vest) on the evaluated cognitive function, and a partial (or complete) restoring of the cognitive performances while wearing the vest. A saving functioning seems to explain the beneficial effect of the Cryovest, characterized by a hydric conservation, a minimum cardiovascular constraint and a better thermal comfort.

To conclude, this study objectifies the beneficial use of the Cryovest on the daily cognitive control implemented by rounders in their working context.

Introduction

The nature of the thermal atmosphere in a physical or mental activity affects the result of this activity. Particularly hot environments (more than 28°C) act in a way of a reduction of the granted intensity to realize a task and come with a progressive disability of the individual to effectively regulate its behavior. In that context, many sectors potentially appear to be concerned by the noxious effect of a long lasting exposure to the heat.

If its adverse effects, their practical implications and mechanical base tend to be more and more studied in the sport place, the professional workers environment exposed to heat stays less investigated by scientist search. However, this environment is characterized by health stakes and human security, productivity and material sustainability which makes each psychophysiological alteration linked to heat, prejudicial.

With the body temperature rising, the mechanism reflex of thermoregulation deteriorates the stable state of the physiological system. The blood flow redistributed to the skin to cool the body is added to the blood flow needed in the irrigation of the functioning organ, which increases the cardiovascular constraint. The sweat flow increases too in order to dissipate, by the evaporation, the body heat.

In ArcelorMittal, the rounder workers are not spared by this particular context, so and by inherent stakes to the fight against noxious effects of the heat on behavior. More precisely, rounds in the

« oven area » consists in the detection and the execution of human and mechanized intervention which are necessary to the well-functioning of the ovens, during the extended route (1h30 to 3h) around 5 ovens in activity (ap 1200°C). The up and down of the stairs are in consequence, irregular, the tasks are repetitive and the need to be performant while functioning by economy are important. The environmental heat (between 25 and 70°C) produced by the oven worsen the difficulty of this work in accelerating the tiredness, and weakening the attention capacity of the rounders in having potential endangerment (fall, mistakes, oversight, etc).

This potential risk linked to the development of hyperthermia state is controllable if the worker stays in a capacity to preserve the efficiency of its cognitive control during the whole round. The cognitive control sends back to the capacity of the individual to voluntarily adapt and to effectively answer to a situation which presents an uncertainty ratio. Due to their operation location, memorization, manual accuracy or decision-making realized under strong heat, rounders are widely concerned by the potential cognitive fragility. In this environment, preserving the entire functionality of these regular mental operations done by the rounders, suggest the implementation of a way to fight against hyperthermia state.

In order to assess the specificity of the cognitive components affected by the heat, as well as experimented potential ways to thwart the effects, many studies have been led in laboratory. From these studies, it stands out the idea that the rising of the body temperature (or just the skin temperature) affects the implementation of the cognitive functions. Concretely, through cognitive tasks made by computer and electric measures of cerebral activity, hyperthermia state has been linked to an extension of the reaction time and a reduction of the cognitive activity. However, even if it is lower, judicious cooling system of the body would be able to establish its well functionality or limiting its decline. For example, the application of cold packs on the forehead and the head or drinking cold drinks has shown relevance in the cognitive assessment in heat environment. However, these two strategies seems to be little applicability during rounds in thermes that they limit the driving availability of the workers.

The cryovest constitutes a potential alternative. In fact, this ergonomic cooling vest, light and long lasting (1 to 2h depending on the use) has already been validated in the sport environment while using before or/after the effort. Contrary to former cooling systems, the vest allows a full gestural amplitude.

Furthermore, compared to other commercialized vests (ex: ArticHeat), the efficiency of the cryovest lays on an optimization of a compromise between its weight and the cooled surface (1800 cm²). In maximizing the cooling zone, it lowers thermal stress, favors an economy functionality and improves the performance compared to situation without the vest. Even so, if the comfort feelings brought by the Cryovest has systematized its use on athletes, the validation of its efficiency on workers subject to high heat has not been considered.

The goal of this study was to test the impact of the Cryovest on cognitive functions on rounders working in real working environment. For that, a series of cognitive tasks realized 3 times in 2 different situations (with and without the vest) has permits to objectify the effect of the cryovest on cognitive operations mainly done during the round. Psychophysiological measures established before, and after the round have been realized in order to rationalize the potential effects of the heat and of the vest on the cognitive performances.

2 Method

2.1. Participants

6 rounders of the « oven area » from the company ArcelorMittal have participated to the study which occurred in December on a 2 day test. Every single one, after having been informed of the modality and goals of the study, has given its agreement to join the protocol. To the extent that the tools used were not invasive, that the testes was not suggesting any infringement of an extreme unusual state

of the body, and that the context of intervention was the same as daily made by the worker, no inclusion criteria of the study has been made to the participants.

2.2. Experimental protocol

The First day, each participant was first made sensitive to cognitive tasks on the series of tests (see below), and stopped the learning once the performances to the different tasks were stabilized. A break of 45min was then done in order to permit the subject to rest, hydrate himself and prepare its equipment.

The protocol is imaged in figure 1. Before doing the round, the worker answered few questions assessing his level of tiredness, of stress and his motivation to realize the protocol from Likert scale (7 points). The range of test, similar to the tasks done in learning, was then done in order to get a base performance level, and announced like that to the subject. The before tests were realized in a silent control cabin.

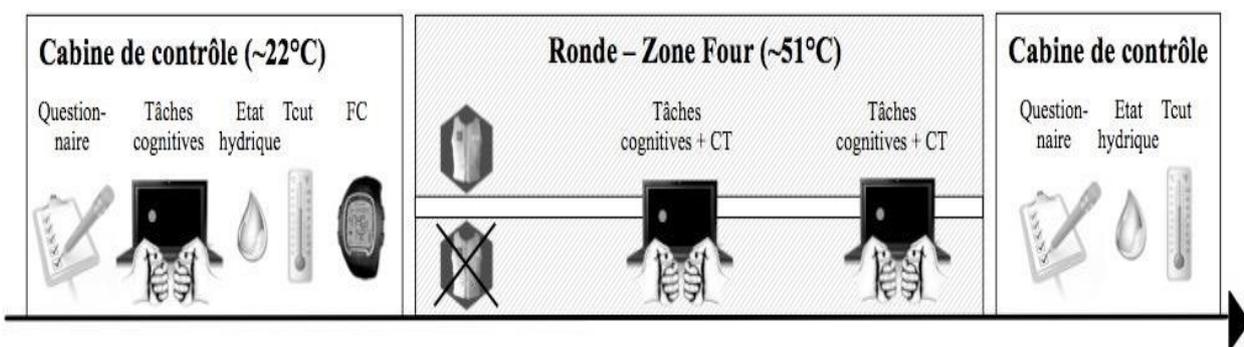


Fig 1. Schematic representation of the experimental protocol which consists in doing 5 cognitive tasks before, during and at the end of the round done in the oven area. The round was done in 2 different conditions on a 2 day test: with and without wearing the vest. Perceptive and physiological measures were made just before and after the round.

Cutaneous temperature measures were then obtained from a thermal camera situated 2 meters from the subject. An estimation of his hydric state were then realized from the gravity density of the urine. Then, the subject was weighed naked and dried. Finally, he was equipped by a heart rate monitor in order to measure his heart rhythm during the whole round.

In order to be close to the real working conditions, 2 subjects were doing their round (same hours from one day to another). One of them was wearing the Cryovest whereas the other one did his round with the usual working conditions. The wear of the vest was randomized and counterbalanced on the 2 days of test.

The progress of the round was organized so that it stays similar in terms of time and route from one day to another. Indeed, in order to avoid any induced body temperature differences, and tiredness, a defined route were made with the rounders and repeated on the 2 days. The time of the route (ap 1h15min) was initially calculated from the needed time for each subject to realize the series of cognitive tasks during the round (ap 12min) and with the average estimated time for each rounder to realize his usual round (ap 2h).

During the round and at the end of each round, a series of cognitive tasks was done on a table and a chair situated in the middle of a duckboard regularly done by the rounders. Because of their high temperature and in order to to be close to the summer working conditions, the paths of the ovens number 1 and 5 were target to host the realization of the cognitive tasks (average thermal environment $51,5 \pm 7$ °C, $7,9 \pm 1,4$ % of relative humidity). During the assessment of one subject on the series of test, the other one kept going his round, and was then called to realize the series of

tests. Beside the cognitive tasks, and during the round, rounders were asked to strictly do the same operation as usual. None of the subject hydrate themselves during the round.

2.3. Cooling by the CryoVest®

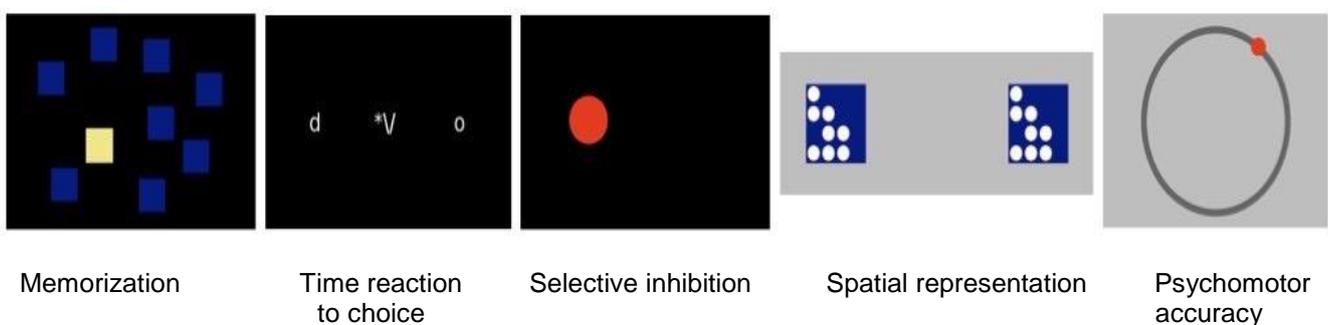
Before doing the round, a subject was equipped by the Cryovest from the effective organized conditions of the workplace. Each of the 8 cold bags of the vest was then placed at least 4 hours in the freezer available for the workers and then inserted in the 8 pockets of the vest immediately before the beginning of the round. According to the subject, the cryovest was placed under or above the t-shirt and then removed once the round was done to take measures of the cutaneous temperature. Each Cryovest was individually used. The size was adapted to the morphology of the subject and the 4 fastening elastic on two sides of the vest were personally adjusted for an optimal tightening.



Fig 2. Representation of the externe and deep parts of the Cryovest. The vest is composed of 8 pockets (4 on the front, 4 on the back) which permits to put the cold bags.

2.4. Cognitive task

Each of the cognitive tasks realized was chosen to copy the use of the cognitive functions implanted during the round. The realization of a tasks lasts 2 to 3 minutes. The cognitive tasks were done in sequence by computer, and randomized one compared to another for each assessment (before, during, and at the end of the round) in order to control a potential order effect.



**Fig. 3. Screen shots of the different cognitive tasks of the series of test (ap12 min)
Notes. Each task included a number of adequate trials in order to be representative of the efficiency of the cognitive control without exceeding a realization time of 3 minutes.**

Memorization task

Insofar as the rounders are regularly subject to operation which require operationalization of defined procedures, or they have to be able to remind specific details in order to report information, a memory task have been asked to do for them. The process of the task suppose, from a defined disposition of squares of the screen, to replicate the order of enlightenment of the squares once the enlightenment series was done. For each level, 2 trials are proposed to the subject in order to go to the next level. The participant answer with the computer mouse.

Task of time reaction to choice

A second task of time reaction to choices were made in order to measure the ability of the subject to quickly decide without doing any mistake from precise information. This operation concretely sends back to a whole decision making process that rounders have to take from few signs from the field communicated by the post. The cognitive task consists in detecting a quick flashed letter on the screen, then, in selecting this letter from a choice of 2 letters displayed on the screen. The number of right answer constituted the variable of interest in this task. The participants answered to 80 trials via 2 Wii control stick.

Selective inhibition task

An important dimension of the mission of the rounders constitutes the repeat of usual tasks, which can lead to certain monotony (usual round route, systematized information taking, accoutumance to a place, etc). So a regulation comportemental test has been considered in order to verify the ability of the participants to voluntary and correctly adjust their drivability despite the prevalence of spontaneous behavior, and despite the heat. Simon's tasks was a speed and accuracy test where the subject has to answer with the right hand or the left one to a color of a stimulus (blue or red) regardless his localization (left or right of the screen). Depending on the situation given by the trial, it was sometimes necessary to regulate his spontaneous behavior (induced by localization of the stimulus) to bring the right answer. 80 trials have to be realized to complete the task. The participants answered via nunchucks sticks.

Spatial representation task

A fourth task to fill in echoes the necessity of visual identification of the rounders during the whole route (irregularity, materials failures, checkin of the conformities, etc). In order to test the ability of the rounders to quickly determine the compatibility and incompatibility of stimulus, a visual comparative task has been submitted to them. The goal was to answer via keyboard to convergente dimension of 2 images displayed on the screen for 30 trials, then to the non-convergent dimension for 30 other trials, in a time period of 1,5seconde per trial.

Psychomotor accuracy task

Finally, beyond the inherent cognitive character of any intervention, the functionality of the motor control of the rounders was evaluated in order to consider if their manual and meticulous intervention could potentially be affected by their particular working conditions. With this aim, a psychomotor task was done, with instructions to follow via computer mouse the predictable move of a lighted point. 3 repeats of this task (15sec per repeat) were realized, with interest variable which was the time of contact with the lighted target, in addition with the average distance of gap to this target.

2.5. Thermal comfort

After realizing 2 of the 5 tasks, and for each assessment time, a scale was presented to the subject in order to evaluate his thermal comfort. This notion was defined to the participants as the feelings more or less pleasant of the heat environment on the comfortable character of the situation and measures from a scale with 11 points.

2.6. Data analysis

Regarding the number of participants to this study, the significant character of the data has not been considered in statistic level. However, from the moment the important gap results were reported from the different conditions, an interpretation was undertaken in order to prescribe the practical

applications. Furthermore, the results which were obtained from the cognitive evaluations realized in the middle of the round have been averaged in the presentation of the results. Each result on the cognitive performances, as well as the one echoing the thermal comfort, are related to the following manner: before vs round. For their part, psychological measures of cutaneous temperature, body and physiological mass are presented as followed: before vs after. Finally, Simon's task were modeled from the theoretical activation model - deleted, distribution analysis has been considered for the performance analysis of the cognitive task, beside general average time and accuracy measures of the answer.

3 Results

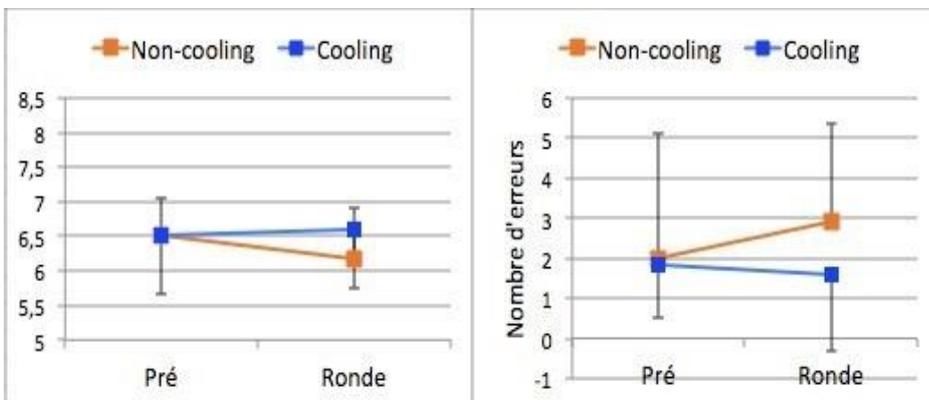
3.1. Psychological measures

The motivation rate of the subject appears comparable before the 2 conditions, was respectively of $4,7 \pm 1$ with a non-cooling situation and of $4 \pm 1,3$ in a cooling situation. The tiredness rate of the subject has moved in a similar way from one situation to another, from an average of $4,1 \pm 0,3$ to $4,7 \pm 0,8$. The stress feeling seems to differ depending on the condition. Whereas it stays stable in a cooling situation (2,3), it increases to 2,5 to 3 in non-cooling situation.

3.2. Cognitive performances

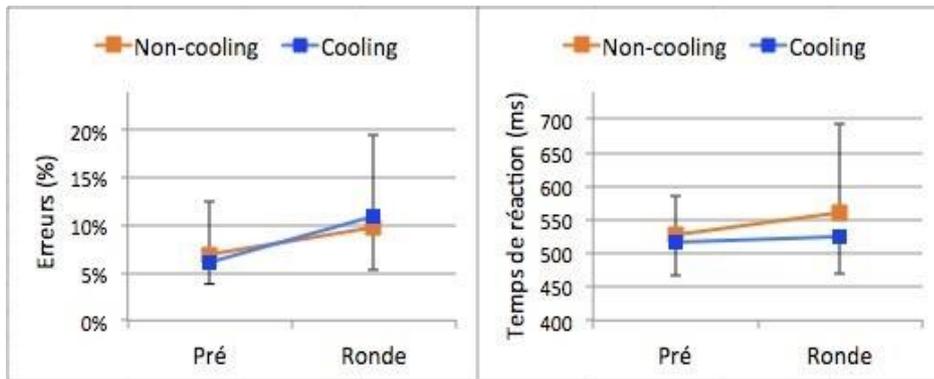
Memorization task

The maximum performance rate has stayed stable in a cooling situation whereas it decreased $0,4 \pm 0,6$ between before and the round in a non-cooling situation. Furthermore, the number of mistake done by the participant before getting to level 6 of the task increased in a non-cooling situation of $0,9 \pm 2,9$ between before and the round, whereas it stays stable in a cooling situation ($-0,2 \pm 1,8$).



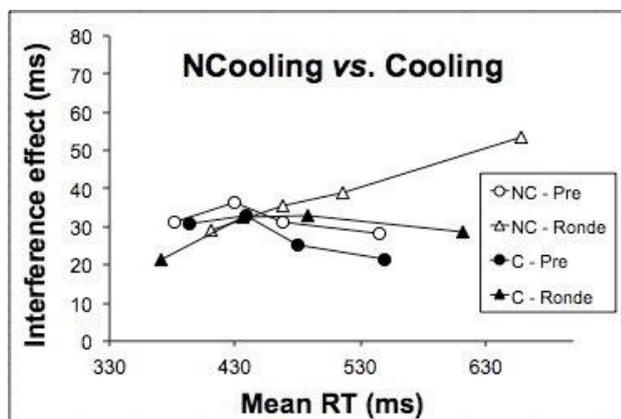
Task of time reaction to choice

No significant difference have been noticed on the analysis of the accuracy percentage. The quality of the answer given by the subject moved in the 2 conditions, increasing in average of $4,8 \pm 5,5$ % of mistakes between before and the round. However, reaction time stays stable between before and the round in a cooling situation ($+9 \pm 34$ ms) but increased in a non-cooling situation ($+35 \pm 91$ ms). Together, these results suggest that in a non-cooling situation, more time was needed for the subject to bring the same quality of answer as in a cooling situation.



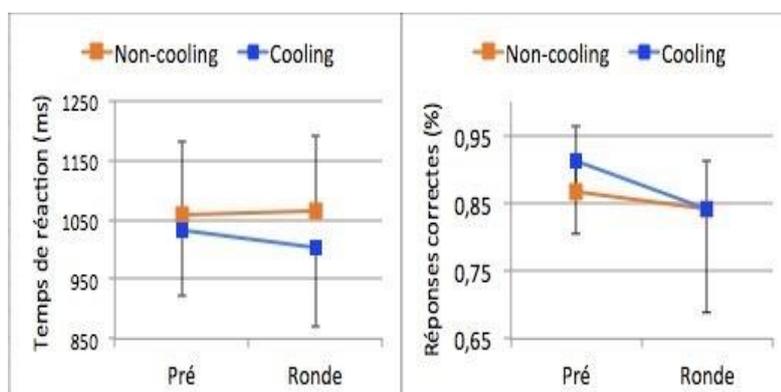
Selective inhibition task

In a similar way to the reaction to choices, the percentage of mistakes moved in a parallel way between the 2 conditions, increasing in average of $3,5 \pm 5 \%$ between before and the round. Whereas the reaction time in cooling situation seems to stay between before and round ($+8 \pm 46$ ms), and increased in non-cooling situation ($+48 \pm 51$ ms).



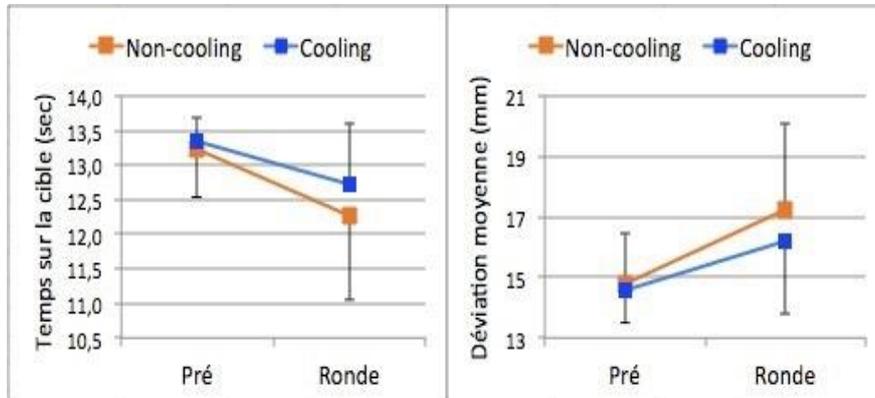
Spatial representation task

In non-cooling situation, answer's speed and the percentage of right answer stayed stable between before and round (from 1058 ± 100 ms to 1066 ± 92 ms, and from $87 \pm 11\%$ to $84 \pm 9\%$, respectively). In cooling situation, between before and round, reaction time (from 1034 ± 99 ms to 1003 ± 97 ms) and the percentage of right answer from $91 \pm 8 \%$ to $84 \pm 13\%$) seems to decreased. Facing each other, these answers suggest the potential setting up of a compromise by the subject between quick answer and accuracy associated: in answering faster during the round, more mistakes were made. This pattern of answer was obvious as for the dimension similarity and divergence of the task. Consequently, cooling situation does not seem to affect the performance linked to this task.



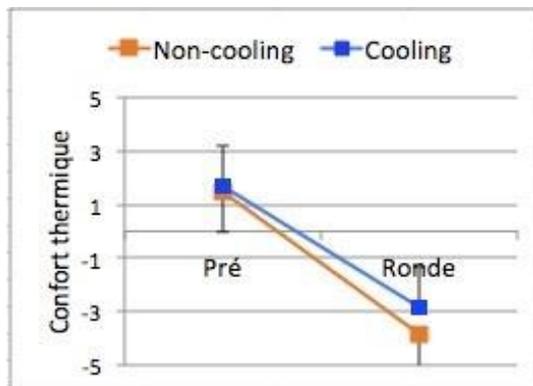
Accurate psychomotor task

In the 2 test conditions, interest variables were impacted by heat. In non cooling situation, time contact with the target was reduced, from before to round, from $1 \pm 0,9$ dry, whereas the gap at the target increased of $25,5 \pm 19,8$ mm. This degradation of the psychomotor answer was minimized by wearing the vest : whereas time contact with target decreased of $0,6 \pm 0,9$ dry, the gap increased of $16,2 \pm 22,3$ mm.



3.3. Thermal comfort

Decrease of the thermal discomfort linked to thermal stress was worsen in non cooling situation between before and round ($-5,3 \pm 2,4$) compared to the vest situation ($-4,5 \pm 2,5$).

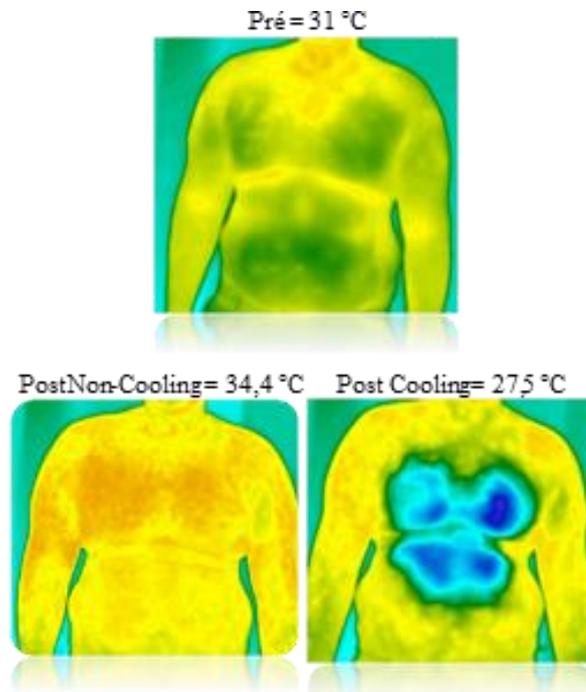


3.4. Hydric state measures of the subject

No difference between the 2 conditions has been noticed concerning the evolution of the measures of gravity density of urine of the subject of before and round ($+0,004 \pm 0,005$). Conversely, the weighing realized after revealed, compared to before, a loss of body mass of $1,1 \pm 0,3$ kg in non cooling situation against $0,8 \pm 0,2$ kg in cooling situation.

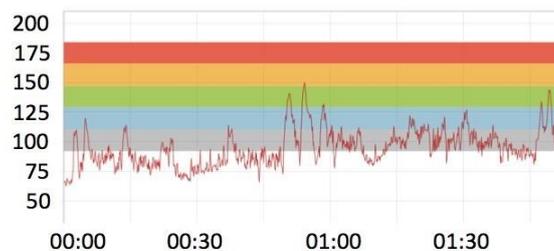
3.5. Cutaneous temperature measures

Before, the subjects did not present any difference of cutaneous temperature between the 2 conditions ($0,2 \pm 0,2$ °C). Whereas the skin temperature (chest and back) was higher after in non-cooling situation ($+2,7 \pm 1,3$ °C), it was reduced after the cooling situation ($-3,1 \pm 1,7$ °C).



3.6. Heart rhythm

Compared to a non-cooling situation, heart rhythm has decreased of 6 ± 18 beats per minute during the cooling situation. An example of the heart rate is displayed below.



4 Discussion

This study had for goal to determine if the wear of the Cryovest permitted to fight against the noxious effects of the heat on cognitive functioning of rounders in their working conditions. For that, 2 days of test were realized in the oven area of ArcelorMittal. The results suggest that, when the heat induced a decline of specific cognitive performances during the round, the wear of the Cryovest partly or completely protects the rounders from this negative effect. A psychological and physiological functioning linked to the vest seems to be the main factor of such cognitive deprivation.

4.1. The effects of heat on rounders's work

All the mental operations evaluated during the round has shown a global but nonsystematic deterioration of cerebral activity under the effect of the heat. Indeed, while the relative performances to difficult and psychomotor tasks shown a slowdown of the answer's speed and an inability under time constraint, to answer as precisely as in a neutral thermal ambiance, the operations of spatial representation did not seem to suffer from heat effect. This constat can result from the fact that the rounders, through their daily work activity, are used to realize comparative object in confronting their models in memory to field observations. In automating these types of operations on visual reference scheme, it is then possible that they developed a singular skill to quickly decide and effectively of the compatibility of simple images like in task of spatial representation. However, this performance was the only one no to be altered by thermal stress and the major part of the assessed functions in non-cooling situation discriminated a performance decline.

This specificity of the cerebral impact of the heat is not isolated. Even if the cognitive task chosen for the study were estimated to be send back to the daily activities of the rounders, it has been brought, that for a same thermal stress, we noticed differences of cognitive performances depending on the nature of the task to realize and the experience of the subject. In this context, it appears that the thermal constraint generated by the ovens leads to a noticeable inability for the subject to control as efficiently their behavior as in neutral environment. This result objectifies for this population the increase of the incurred risks during the round and certifies the necessity to bring a help to the thermoregulation of the subject in order to act in a way for a bigger safety at work.

4.2. Cryovest® protects from noxious cognitive effects of the heat

For each cognitive task where the performance has been worsen by the heat, the wear of the Cryovest has a positive impact. More precisely, whereas this impact materialized by a minor diminution of the cognitive performances in heat for certain functions (behavioral regulation and motor control), the vest permits a feedback to original performances for others (memory, reaction time to choice). The part or complete beneficial effect of the Cryovest on the recovery of the cognitif functionality could be due to the difficulty of the task, and more precisely to the time pressure which is inherent. In other terms, the less a quick answer is required, the more the effect of the vest was important.

Regarding this beneficial effect on cognitive performance, the cooling vest Cryovest integrates the whole fight against tiredness linked to heat strategy behavior. If chilled hydration systems, or cold bags manually put on the head and the neck turned out to be relevant in high thermal environment, they seem to be very few functional in the actual working place of the study. Indeed, each rounder has to be able to intervene with his whole motor availability and fully clear. The product proposed in this study, in order to help the subjects to thermoregulate, fully fill the role without constituting a discomfort for the rounders's work.

The cognitive functions of the rounders in heat situation intervened in the middle (after 45min) and at the end (after 100 min) of the round, which permits them to fully benefit from the cold transfer of the cold bags to the vest and the vest to the skin as of the first evaluation. Cutaneous temperature measures revealed, after 1h50 of round, a still effective cold ($-3,1 \pm 1,7$ °C in average). In a convergent way, the sustainability of the action of the Croyvest has also lead to less loss of sweat during the round, revealed by weighing at the end of the round. This result can be explained by the absence of the necessity of the organism to cool covered zone and already refreshed by the vest (chest and back). The subject sweating less, a preservation of his hydric state was then favored by the vest. The observation which suggested that the data of gravity density of urine do not support this result, can be considered that the participants hydrate themselves in a consequential way before the beginning of the round. This preservation of the thermoregulation mechanism can also explain

the trend of a decrease of the heart rhythm via a less cutaneous vasodilatation, reflecting the cardiovascular spare during the round. However, this result must be weighed, regarding potential gap of route during the round from one day test to another, despite the will to have controlled this effect.

Similar to the sport environment, thermal comfort induces by the vest has been noticed during the study. An even less leeway of unpleasant feeling linked to heat (thermal comfort) was reported during and at the end of the round while the vest was worn. This affect was accompanied, at the end of the round, by a less stress feeling. It is then possible that in complement of physiological effects linked to the vest on dissipation of the heat and preservation of a stable state of the organism, a less oppression feeling could be the origin to a reduction of cognitive performances on heat.

In this context, the use of the Cryovest for rounders in their usual working environment has to be encouraged. Indeed, if the initial feeling of workers constituted a spontaneous measure in favor of a cooling system installation, the results of this study objectifies the cognitive impact of the heat, like the profitable one of the vest. To this effect, the addition of space of the Cryovest and of freezing the cold bags to actual spaces of preparation for the beginning of the round can definitely be considered.

An obvious limit of the study resides in the number of subjects. Despite that, the results obtained in physiological, perceptual, cognitive terms reflect the current results observed in the nature. This convergence validates the datas obtained in this field study, in the same time that the study advocates the use of ergonomic cooling system for this work population. Indeed, we do not have to forget that if this study has been done in December, more stressful conditions have to be considered during months of high heat.

Conclusion

To conclude, this study has investigated the cognitive effects of the induced heat by the oven in activity on cognitive functions of workers in their work environment, and the impact on his mental performances of a cooling system like Cryovest technology. The results revealed that after 2h of round, generated by the vest always effective, has preserved hydric and cardiovascular status of the subjects, and was accompanied by an improved feeling of thermal comfort and stress. These effects have been induced to a less deterioration of cognitive capacity of the subjects in hot conditions, if not, a return to normal situation of certain performances of cognitive tasks. While the Cryovest seems to be a practical way to counteract the noxious cognitive effects of the heat, the development of further strategy (cooling neck and tights, hydric strategy, etc) seems to encourage, for the rounders like other workers daily exposed to high heat.

Thanks

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