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Abstract

Purpose: The purpose of this study was to examine the effects on sleep of two different environments that protect against chemical threats. **Methods**: Ten (7 male and 3 female) regular Canadian Forces personnel were divided into two groups and performed various command post (CP) duties for 24 hours while in a chemical threat scenario environment wearing Individual Protective Ensemble (IPE MOPP 4) or in a Collective Protective Facility (COLPRO) wearing IPE MOPP 0. During their trials, their sleep was monitored and recorded using actigraph technology. **Results**: Soldiers had significantly less sleep in the IPE MOPP 4 ensemble (mean ± sd, 3.2 ± 1.6 hours), compared to the COLRO environment, (5.0 ± 1.3 hours). The sleep quality was also significantly poorer as they had more awakenings during their sleep periods in the IPE MOPP4 ensemble (3.0 ± 1.9) compared to COLPRO (1.1 ± 1.1). **Conclusions**: It was concluded that 24 hours in IPE MOPP 4 produced sleep deprivation in soldiers that lead to severe decrement in cognitive and physical performance.

Résumé

Objet : Cette étude avait pour objet d'étudier les effets sur le sommeil de deux cadres différents qui assurent une protection contre les menaces chimiques. **Méthodes :** Dix militaires (7 hommes et 3 femmes) des Forces canadiennes (Force régulière) ont été divisés en deux groupes et affectés à diverses fonctions rattachées à un poste de commandement (PC) pendant une période de 24 heures dans un contexte de simulation de menace chimique alors qu'ils portaient une combinaison de protection contre les produits chimiques (EPI POSM 4) ou se trouvaient dans des installations de protection collective (COLPRO) et portaient une combinaison EPI POSM 0. Pendant les essais, on procédait à la surveillance et l'enregistrement de leur sommeil au moyen d'un actigraphe. **Résultats :** Les durée du sommeil était significativement inférieure dans la combinaison EPI POSM 4 (moyenne ± écart-type, 3,2 ± 1,6 heures) que dans les installations COLRO, (5,0 ± 1,3 heures). La qualité du sommeil était aussi significativement inférieure car on notait beaucoup plus de réveils durant les périodes de sommeil dans la combinaison EPI POSM4 (3,0 ± 1,9) que dans les installations COLPRO (1,1 ± 1,1). **Conclusions :** On a conclu que le port de la combinaison EPI POSM4 pendant une période de 24 heures produisait un manque de sommeil chez les soldats qui entraînait une baisse importante des capacités cognitives et physiques.

Executive summary

As warfare evolves, it is apparent that an increasingly asymmetrical nuclear, biological, chemical (NBC) threat exists. Under such a threat a Canadian Forces (CF) soldier must perform his/her duties or mission while encapsulated in a chemical protective suit; better known as nuclear, biological and chemical clothing (IPE MOPP 4). There are occasions, however, where the wearing of the suit is prohibitive i.e., in medical, matinence and command control communication and information [C^3I] roles. For such roles, there are facilities that have been developed to allow a soldier unrestricted performance in wearing the chemical suits. Such a facility is called a collective protection facility (COLPRO). The Directorate of NBC Defence (DNBCD) has tasked DRDC Toronto to explore the impact of the use of such a facility on current CF operations. Thus a field study was set up to do a direct comparison of COLPRO versus IPE MOPP 4 environments on command post duties. By conducting this comparison, information was generated that enabled DNBCD to better understand what value, if any, COLPRO would have for the CF in the future.

This report examined the effects of working in the two different environments that protect against chemical threats on the quantity and quality of sleep. Ten (7 male and 3 female) regular CF personnel were divided into two groups and performed various command post (CP) duties for 24 hours while in a chemical threat scenario environment wearing IPE MOPP 4 or in a COLPRO. During their trials, their sleep was monitored and recorded using actigraph technology. The results from the report showed that soldiers had significantly less sleep and that there were awake more often during the night in the IPE MOPP 4 ensemble. It was concluded that the sleep deprivation of the soldiers in IPE MOPP 4 was one of the reasons for the severe decrement in cognitive and physical performance.

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Sommaire

Si l'on observe l'évolution des pratiques de guerre, il semble que l'on soit de plus en plus confronté à une menace nucléaire, biologique et chimique (NBC) asymétrique. Dans pareil contexte, tout militaire des Forces canadiennes (FC) doit porter une combinaison de protection contre les produits chimiques, également appelée combinaison NBC (EPI POSM 4), pour accomplir ses fonctions ou remplir sa mission. Il y a des cas, cependant, où le port de la combinaison nuit aux opérations, comme les interventions médicales, la communication et l'information liées au commandement et au contrôle et l'entretien. Il existe, pour ce genre de rôles, des installations spécialement conçues de manière à permettre au militaire d'accomplir ses fonctions sans les restrictions imposées par les combinaisons de protection contre les produits chimiques. Il s'agit d'installations de protection collective (COLPRO). La Direction de la défense nucléaire, biologique et chimique (DDNBC) a chargé RDDC-Toronto d'étudier les répercussions de l'emploi de ce genre d'installations dans le cadre des opérations actuelles des FC. C'est ainsi qu'a été entreprise une étude sur le terrain visant à comparer directement les effets de l'environnement COLPRO et ceux du port de l'EPI POSM 4 sur les fonctions associées à un poste de commandement. L'information ainsi obtenue a permis à la DDNBC de mieux comprendre l'intérêt que pourrait présenter l'installation de protection collective (COLPRO) pour les FC à l'avenir.

Ce rapport a porté sur les effets physiologiques et psychologiques sur le sommeil du travail accompli dans deux cadres différents qui assurent une protection contre les menaces chimiques. Dix militaires (7 hommes et 3 femmes) des Forces canadiennes (Force régulière) ont été divisés en deux groupes et affectés à diverses fonctions rattachées à un poste de commandement (PC) pendant une période de 24 heures dans un contexte de simulation de menace chimique alors qu'ils portaient une combinaison de protection contre les produits chimiques (EPI POSM 4) ou se trouvaient dans des installations de protection collective (COLPRO). Pendant les essais, on procédait à la surveillance et l'enregistrement de leur sommeil au moyen d'un actigraphe. Les résultats du rapport indiquent que la durée du sommeil des soldats était considérablement inférieure et qu'ils se réveillaient plus souvent pendant la nuit lorsqu'ils portaient la combinaison EPI POSM 4. On a conclu que le manque de sommeil des soldats portant la combinaison EPI POSM 4 était l'une des raisons qui expliquaient la baisse des capacités cognitives et physiques.

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Acknowledgements

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Introduction

The Directorate of NBC Defence (DNBCD) has tasked DRDC Toronto to explore the impact of Collective Protection Facility (COLPRO) use on current CF operations. The lack of a COLPRO capability is a long-time acknowledged Canadian Forces deficiency. COLPRO is a portable pressurized facility that could be used for a group of soldiers in a field situation where command post type duties would be performed (8, 9, 16, 35). It consists of an enclosure within which personnel can operate without the requirement to wear the Individual Protective Ensemble (IPE) at the highest level - Mission Oriented Protective Posture 4 (MOPP 4) described below. COLPRO is reported to have two main functions: to provide protection beyond IPE endurance limitations; and to protect specific facilities or functions such as medical, maintenance, and command control communication and information [C^3I] roles, that would be operationally ineffective in a nuclear, biological, chemical (NBC) threat environment.

A field study was conducted to do a direct comparison of COLPRO versus IPE MOPP 4 environments on command post (CP) duties. By carrying out this comparison, information was generated that will enable DNBCD to better understand what value, if any, COLPRO will have for the CF in the future. These trials were conducted between 22-26 August 04, at Canadian Forces Base (CFB) Petawawa. in Ontario. During the trials, the outside environmental temperature ranged between 12°C to 23 ° C.

The present paper reports on the effect of these two different chemical protective systems on sleep and is part of a larger study (7) that looked at the physiological and psychological response to these two environments on CP duties. There is very little information about the effects of MOPP 4 on sleep. The information available is sparse and has been obtained in the laboratory (5, 28) and on very few subjects (5). Both studies, however, concluded that the amount of sleep and sleep quality were reduced. There is no information about the effects of sleeping in MOPP 4 on sleep in a sustained field operation.

Purpose

The aim of this study was to compare the effects of the COLPRO and IPE MOPP 4 on the quantity and quality sleep during CP activities during a field simulated chemical threat scenario.

Method

Subjects.

Ten CF personnel (3 females and 7 males) aged 32 ± 8 (mean ± SD) yrs, weight 77.2 ± 11.6 kg and height 179 ± 10 cm from the 2nd General Support Battalion CFB Petawawa, gave their

written informed consent for their participation in the study. The experimental protocol was approved by the DRDC Human Research Ethics Committee. The 10 soldiers were divided into two groups of 5. Each group performed 24 hours in COLPRO and 24 hours in IPE MOPP 4 environment with a 24-hour rest period in between conditions. During the rest period, they went back to their regular activities and were not required to be in the area of the experiment, nor in the IPE MOPP 4 ensemble. During their time in the two conditions they performed the CP duties described below.

Procedures.

CPOperations: The performance assessment environment was the operation of a Service Support CP for a major Land Force Exercise. The tasks performed during this activity include monitoring and logging radio communications; producing and promulgating both written and verbal orders; and physical liaison with units external to the CP. The timing of the majority of the tasks performed was determined by the external units who promulgated the orders to the CP. In addition, the experimental staff inserted activities to ensure that each condition was evaluated consistently; for example, each of the test conditions were required to produce at least one written transport request.

COLPRO Environment: The specific COLPRO facility was the Trelleborg COLPRO system, which has air filtration and air conditioning units. The tent material is a poly vinyl chloride coated synthetic fabric that is both flame and infra red resistant. The ground area for a single tent is 38 m^2 (length 2.25 m x width 5.20 m). The volume inside is 58 m^3 and the height under the ribs is 2.6 m. The COLPRO tents were set up with an operations centre, an ablution area, a rest/sleeping area and a storage area. Before entering the shelter, subjects were required to pass through a decontamination line. When not in the COLPRO shelter, subjects were required to wear their full IPE at a MOPP 4 level, as described below. Once they entered the COLPRO shelter they operated in normal combat clothing (MOPP 0). Temperature within the COLPRO was maintained between 21 – 22°C and the relative humidity between 40 - 60%. The COLPRO condition was part of a larger filed trial, and, as such, there were more individuals making use of this facility. Consequently, the noise level and the coming and going of troops within this environment were greater than in the MOPP4 IPE condition.

IPE Environment: The in-service chemical suit is a one-piece coverall with an attached hood and a combination Velcro and a two-way zip fastener front closure. The coveralls have three pockets, two breast pockets designed for carriage of ammunition magazines and one large pocket on the right thigh for maps. Internal suspenders provide for an adjustment fit at the crotch. The wrist and ankles are closed with Velcro and an elastic stirrup is placed under the arch of the combat boot to hold the trouser leg down. The chemical warfare (CW) over-boot is worn over the stirrup. The material of the outer shell is a woven nylon/cotton-twist cloth, dyed olive green and treated with water and a chemical repellent. The inner material is polyurethane foam, bonded to nylon tricot. The foam is impregnated with activated charcoal to absorb any CW agent vapour that penetrates the outer material. Nylon and rubber gloves are put on the hands and to complete the ensemble, a rubber mask with a respirator is worn over the face. This whole ensemble is worn over combat clothing, which in turn is layered over a T-shirt, underwear and socks and is defined as IPE MOPP 4. Once the soldier is fully clothed at this level and in the tent where wind velocity is essential zero, the thermal insulation of the clothing system is 2.35 clo. The physical layout of the CP for the IPE MOPP

4 condition consists of multiple sections of modular tents similar to the COLPRO tents but without air conditioning and no pressurization to keep the chemical threat out. The tent opened to the outside environment. The inside of the tent was divided into working, eating, ablution and sleeping areas similar to those within the COLPRO. The sleeping area was divided off from the working area via a canvass wall as in the COLPRO conditions. The CP was to be manned continually for 24 hours with work/rest/sleep schedules being established by the officer in charge. Time allotted for sleep was 6-8 hours in both the IPE MOPP 4 and COLPRO conditions and was scheduled to occur sometime between 2100 to 0800 hours. Subjects performed the same duties in the IPE MOPP 4 environment as in the COLPRO environment. They performed all of the NBC drills associated with sleeping, working, resting, defecation, urination and eating. Subjects were required to wear IPE at a MOPP 4 level during test conditions for 24 hours, even during sleep. Temperature within the tent from 2100 hours on the night of the 22 August until 2000 hours on the night of the 23 August ranged from a low of 12° C to a high of 23°C, with mean temperature being 18°C. Relative humidity ranged from 40 – 80 %, with a mean of 60%. Temperature within the tent from 2100 hours on the night of the 25 August until 2000 hours on the night of the 26 August ranged from a low of 20°C to a high of 26°C, with a mean being 23°C. Relative humidity ranged from 70 – 85%, with a mean of 80%.

Sleep measures: Prior to performing the CP duties the subjects reported to the physiological monitoring preparation area where a motion logger actigraph (model AMA-32, Precision Control Design Inc., Fort Walton Beach, FL, USA) was strapped around the individual's non-dominant wrist. The actigraph monitors and records all hand movement and this is correlated with activity patterns. These activity patterns can be further subdivided if the timing of a specific event, such as sleep, is known. During sleep, disturbances in the patterns can be measured and evaluated from the actigraph as either awakenings or tossing and turning (23, 29, 34). The type of information was down loaded from the actigraph to a computer system and produced graphically for analysis as shown in Figure 1. Knowing when sleep was to occur permits the measurement of sleep time visually with a ruler. The awakenings during scheduled sleep can be seen as major disturbances and can be counted. The subject wore the actigraph throughout the two conditions. One actigraph was used for two subjects and thus was continually on during the 96-hour period of the study. To support the actigraph data, scientific staff recorded the timings of the various events and activities through out the trials. Trials commenced at 2000 hours Sunday 22 August 2004 and end at 2000 hours Thursday 26 August 2004.

Statistics.

The amount of sleep and the number of awakenings during the sleep period time for each subject was analyzed with a one-way repeated analysis design (ANOVA) (10) to determine the difference between conditions (MOPP4 VS COLPRO). Statistical significance was accepted at the $p \leq 0.05$ level.

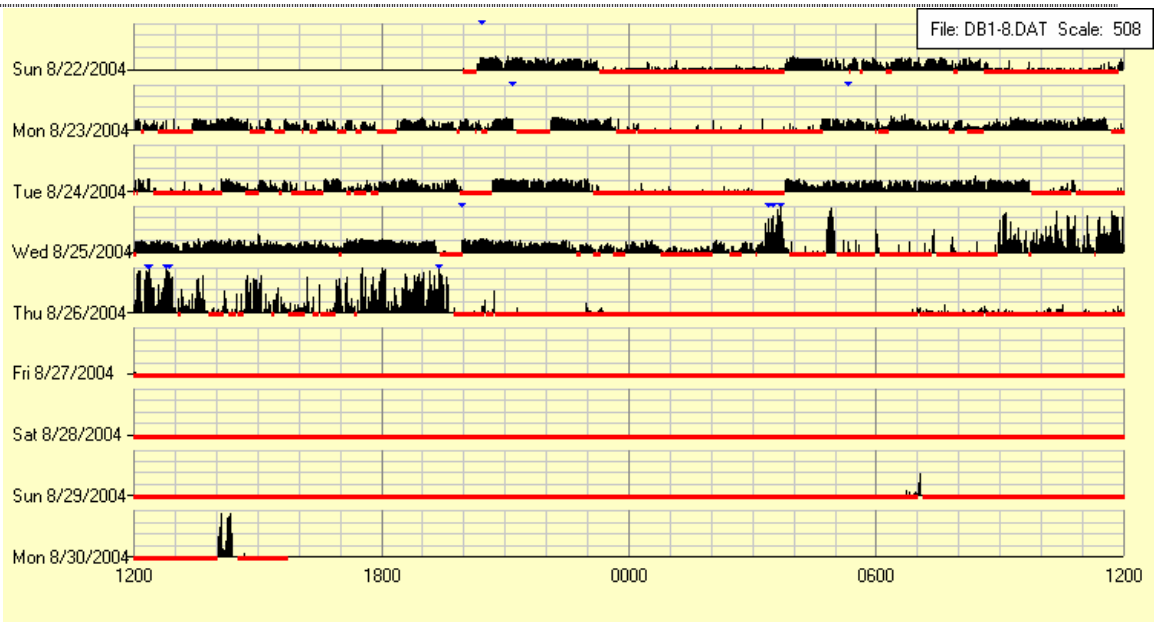

Figure 1. Actigraph data on subjects 1 and 8 while they were in the Individual Protective Ensemble (IPE MOPP 4) condition and the Collective Protection Facility (COLPRO) condition. Subject 1 was in IPE MOPP4 on the night of the 22nd through the day of the 23rd and in COLPRO from the night of the 24th through the day of the 25th. Subject 8 was in COLPRO on the night of the 23rd through the day of the 23rd and in IPE MOPP 4 from the night of the 25th through the day of the 26th

Results

Sleep.

The amount of sleep while in the IPE MOPP 4 ensemble, 3.2 ± 1.6 hours, was significantly less than the amount of sleep obtained in the COLRO environment, 5.0 ± 1.3 hours (p= 0.011; Figure 2). The sleep quality was also significantly poorer in the IPE MOPP 4 ensemble as they had more awakenings during their sleep period, 3.0 ± 1.9 awakenings, compared to the COLPRO environment, 1 ± 1.1 awakenings (p=0.032; Figure 3).

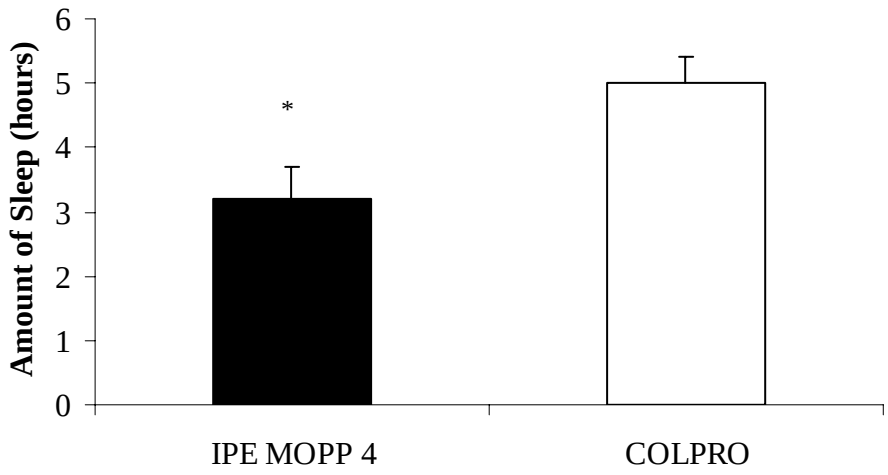

Figure 2. Amount of Sleep (mean ± sem) obtained in IPE MOPP 4 condition compared to the COLPRO condition. *IPE MOPP 4 significantly different from COLPRO.

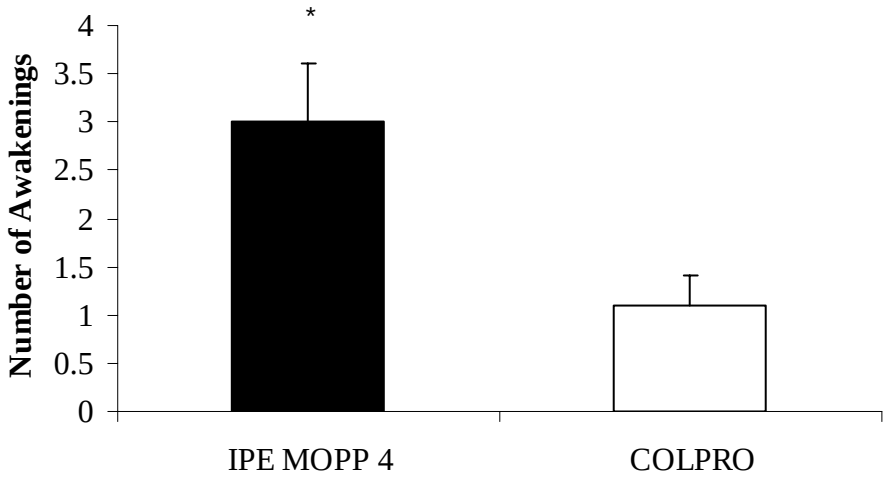

Figure 3. Number of awakening (mean ± sem) during sleep period in soldiers in the Individual Protective Ensemble (IPE MOPP 4) condition compared to the Collective Protection Facility (COLPRO) condition. *IPE MOPP 4 significantly different from COLPRO.

Discussion

The purpose of this report was to examine the effect on sleep of performing CP duties in two different systems that protect against chemical threats in a sustained operations scenario. One environment had the soldier encapsulated in a protective suite, IPE MOPP 4, while the other environment had the soldier protected in an air-conditioned, temperature controlled tent, COLPRO. The controlled environment of the COLPRO facility, enable the soldiers to have a better quality of sleep and to sleep longer than the IPE MOPP 4 condition.

Of the few reports in the literature (5, 18, 28), all agree that the amount of sleep and the sleep quality is reduced when NBC ensembles or respirators are worn. In the study of Rogers et al. (28), six aircrew personnel after one night of sleep during which control sleep recordings were obtained, then wore the NBC aircrew equipment ensemble on two different nights that were separated by 5-6 days. These subjects retired at 2300 hours to individual bedrooms, which were sound attenuated with a controlled temperature set at 18°C and 55% relative humidity. The time allotted for sleep was 8 hours. On the control night, the subjects slept for 7.6 hours, while on the two nights in NBC ensembles sleep time was significantly reduced to 6. 5 hours on the first night and 6.9 hours on the second night. Also the duration of the awakenings was significantly longer in the NBC ensemble for the first night (59.2 minutes) and second night (38.6 minutes) compared to the control condition (10.6 minutes). From these results, Rogers

et al. (28) concluded that sleeping in protective clothing may initially produce some sleep loss but individuals were able to partially adapt to the equipment over time.

Nemetz et al. (22) tend to support the finding of Rogers et al. (28) as they reported that training in MOPP 4 is critical to optimize tolerance time. Training would acclimatize the soldiers both physically and mentally to this environment and thus reduce the time to perform normal duties. Lieberman et al. (18) do not agree with the adaptation concept. They had 9 soldiers sleep with and without the respirator mask of the NBC ensemble on four different nights and showed no evidence of adaptation. Further, Lieberman et al. (18) reported significant adverse effects of the mask on sleep and daytime function.

The present field study confirms that the total amount of sleep will be reduced, while in an IPE MOPP 4 ensemble compared to the COLPRO conditions. As well, the quality of sleep as expressed by the number of awakenings was greater in IPE MOPP 4 compared to the COLPRO condition. The severity of the sleep loss in IPE MOPP 4 in the field situation was much greater than in the laboratory study (28) and adaptation to the environment is less likely. Soldiers in IPE MOPP 4 in the field did not adhere to the scheduled sleep cycle because of the difficulty of sleeping in the gear. The mask and canister were cited, during the focus group discussion, as the main factor that prevented normal sleeping position. Therefore, the soldiers often cut short their scheduled sleep time, got up and went back on duty, even if they were not needed for work. It would be interesting to determine which stage of sleep was disturbed as it is known that disruption of the various stages can produce different magnitudes of delayed cognitive responses (12, 32, 33).

It has been reported that just wearing IPE MOPP 4 produces a deficit in cognitive performance (16, 25, 26, 36). It is also well documented that sleep loss impairs cognitive performance (2). It seems highly probable that wearing the IPE MOPP 4 ensemble over a 24-hour period will compound the two effects thus increasing the rate at which performance decrement in cognitive function will occur. This has been shown to a certain extent in the study of Haslam (11) that looked at the combined effect of sleep loss and NBC clothing on military performance of a clerical nature. Haslam (11) reported significantly greater performance decrements when MOPP 4 was worn in a sleep deprived state. In other reports on sleep, Belenky et al. (2) state that cognitive performance will be degraded with less than 7 hours of sleep in each 24-hour period. If 4 to 7 hours of sleep are obtained within every 24-hour period, cognitive performance will stabilize at a lower level. With less than 4 hours of sleep in every 24 hours, cognitive performance will degrade continuously and rapidly over days with no stabilization (2). Chronic restriction of sleep to less than 4.5 hours is not possible – this is the lower limit of sleep duration for most individuals and failure to obtain at least 4-5 hours of sleep each night results in the rapid deterioration in mood, motivation and performance on even the simplest of task (3). Physical performance is more resistant to sleep deprivation (24, 30, 31); nonetheless, those physical tasks that involve self-pacing and motivational efforts to continue are affected by sleep deprivation (19, 26). Military guides have been developed to assist commanders in the management of cognitive fatigue during periods of sleep deprivation (27) but these guides have not considered in detail, the impact of wearing NBC clothing on the sleep of soldiers and its subsequent effect on performance. Even in the most recent review on the effects of chemical protective clothing on military performance (16), little attention is given to the effect of NBC protective ensembles on sleep.

One point of interest to note is that there has been no investigation looking at the effects of working/sleeping in MOPP 4 on circadian rhythm. An aberration in circadian rhythm can lead to increased irritability, loss of vigor, poor sleep and mental confusion (1, 6, 13, 15). Circadian rhythm can accurately be mapped by core temperature variation (14). In our previous report on the effects of COLRPO and IPE MOPP 4 environments on physiological variables, core temperature was followed for most of the 24-hour period (7). Figure 4 shows the pattern of core temperature response of one individual in these two environments. The circadian rhythm is obviously evident in both curves. Further, there does not appear to be a leftward or rightward shift in core temperature between the two curves, which would suggest

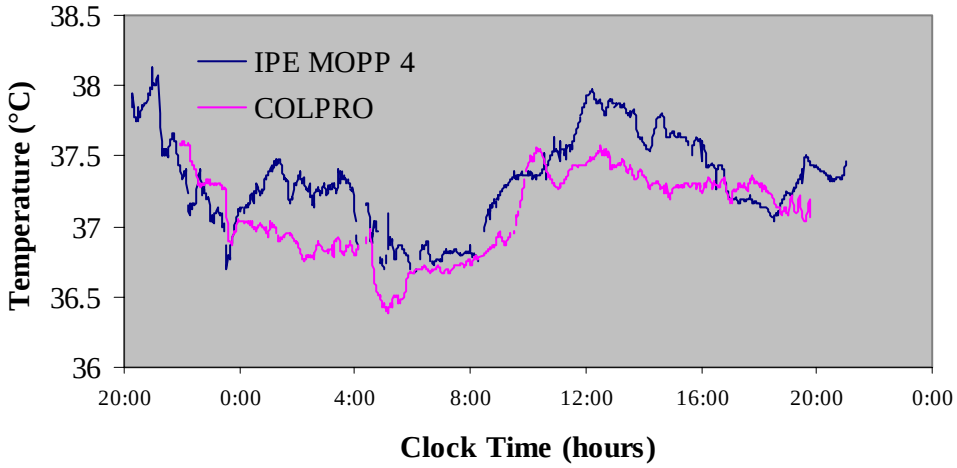

Figure 4. Core temperature of subject 6 while in the Individual Protective Ensemble (IPE MOPP 4) condition compared to the Collective Protection Facility (COLPRO) condition.

a deviation in natural circadian rhythm. There was only an elevated temperature response in the IPE MOPP 4 ensemble. This would suggest that working and sleeping in IPE MOPP 4 for 24 hours does not appear to affect circadian rhythm over this short period. However, it can't be said that extending the time in IPE MOPP 4 would produce a similar non-affect on circadian rhythm. This whole area of sleep deprivation, circadian response and the wearing of the IPE at the MOPP 4 level require further research.

It must be remembered that if the COLPRO is considered to be the control environment, it is not a normal environment because the individuals worked inside the facility for the 24-hour period and were not exposed to normal daylight. This fact in itself could also affect circadian response as it is known that light is a major player in controlling circadian rhythm (4, 17, 20, 21, 37). If the time of operation in this type of a facility were extended, then performance could be eventually degraded. In addition, the increased noise and constant coming and going of troops that occur within this facility would also impact the amount of sleep the troops

obtain. In this environment, sleep was still reduced compared to the laboratory study of Rogers et al. (28).

In conclusion, it can be said that the IPE MOPP 4 ensemble was more stressful on the sleep response compared to the COLPRO environment. In fact, it puts the individual in a sleep-deprived state after only 24 hours of working/sleeping in this ensemble. Not only will the physical limitations of the suit affect a soldier's performance, the sleep deprivation, which occurs after sleeping in the suit will likely exacerbate and even accelerate the degradation of the soldier's cognitive and physical performance.

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(U) As warfare evolves it is apparent that an increasingly asymmetrical nuclear, biological, chemical (NBC) threat exists. Under such a threat a Canadian Forces (CF) soldier must perform his duties or mission while encapsulated in a chemical protective suit; better known as nuclear, biological and chemical clothing (IPE MOPP 4). There are occasions, however, where the wearing of the suit is prohibitive i.e., medical, command control communication and information, and maintenance roles. For such roles there are facilities that have been developed to allow a soldier unrestricted performance that occurs in the chemical suits. Such a facility is called a collective protection facility (COLPRO). The Directorate of NBC Defence (DNBCD) has tasked DRDC – Toronto to explore the impact of the use of such a facility on current CF operations. Thus a field study was set up to do a direct comparison of COLPRO versus IPE MOPP 4 environments on command post duties. By conducting this comparison, information was generated that enabled DNBCD to better understand what value, if any, COLPRO would have for the CF in the future.

This report examined the effects of working in the two different environments that protect against chemical threats on sleep. Ten (7 male and 3 female) regular Canadian Forces personnel were divided into two groups and performed various command post (CP) duties for 24 hours while in a chemical threat scenario environment wearing individual protective ensemble (IPE MOPP 4) or in a collective protective facility (COLPRO) wearing IPE MOPP 0. During their trials, their sleep was monitored and recorded using actigraph technology. The results from the report showed that soldiers had significantly less sleep and that there were awake more often during the night in the MOPP 4 ensemble. It was concluded that if the soldiers continued their duties in MOPP 4 over 48 hours, sleep deprivation would be serious and would lead to an exponential decrement in cognitive and physical performance.

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(U) sustained operations; protective clothing; MOPP 4; NBC; COLPRO; collective protection; sleep

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