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Effect of various environmental stressors on target detection, identification, and marksmanship

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Abstract

The advent of high resolution interactive simulation has made it possible to bring greater realism into the laboratory where experimental rigour is more easily controlled than in a field setting. Using a small arms trainer (SAT), the detection, identification, and engagement of targets were tested under a variety of environmentally stressful conditions including heat and cold exposure, noise, fatiguing exercise, and sleep deprivation, with caffeine intervention applied in the latter two trials. Additional investigations on the efficacy of a monetary incentive on individual performance, and on differences between individual and team performances were also conducted during the noise study. Target presentations were randomized and varied from standing pop-ups to moving figures of both foe and friendly types appearing seldom or frequently. Performance was judged according to the number of targets detected, correct target identifications, and marksmanship. Surprisingly, none of the physiological strains caused any serious degradation in performance except fatigue, which adversely affected target detection but not when caffeine was ingested to alleviated the fatigue. Generally, once a target had been detected (with or without fatigue), its engagement, which required intense but short-term focus (i.e., 6 s or less), was competently managed under significant levels of physiological strain, as if the act of detecting a target obviated the strain. The monetary incentive during the noise study failed to improve performance, which validated the use of the SAT in so far as extracting a best effort is concerned. However, an interesting dichotomy emerged during the same study whereby target engagement time increased with time on task during the individual trials in a failed speed vs. accuracy trade-off, yet the opposite occurred during the team trial, which appeared to invoke competitiveness between the subjects. Implications of all the findings are discussed from a military perspective.

Résumé

L'avènement de la simulation interactive haute résolution a permis de faire entrer un plus grand réalisme dans les laboratoires, là où la rigueur expérimentale est plus facilement contrôlée que sur le terrain. À l'aide d'un entraîneur de tir aux armes légères, la détection, l'identification et l'engagement de cibles ont été éprouvés dans diverses conditions environnementales difficiles, dont l'exposition à la chaleur et au froid, le bruit, l'exercice épuisant et la privation de sommeil, avec absorption de caféine dans les deux derniers cas. Des études supplémentaires sur l'efficacité des mesures incitatives financières par rapport au rendement individuel et sur les différences entre le rendement individuel et le rendement de groupe ont également été effectuées pendant l'étude sur le bruit. La présentation de cibles était variée et répartie au hasard, allant des cibles bondissantes aux formes mobiles, de types ennemi et ami, apparaissant rarement ou fréquemment. Le rendement a été évalué selon le nombre de cibles détectées, la bonne identification des cibles et l'adresse au tir. Étonnamment, aucune des contraintes physiologiques n'a causé de sérieuse dégradation du rendement, à l'exception de la fatigue, qui a eu un effet défavorable sur la détection des cibles, sauf en cas d'absorption de caféine afin de surmonter la fatigue. De façon générale, une fois une cible détectée (avec ou sans fatigue), son engagement, qui exige une concentration intense mais de courte durée (six secondes ou moins), était géré avec compétence dans des conditions de contraintes physiologiques importantes, comme si le fait de détecter une cible permettait de parer aux contraintes. Les mesures incitatives financières mises en place pendant l'étude sur le bruit n'ont pas permis d'améliorer le rendement, ce qui a prouvé le bien-fondé de l'utilisation d'un entraîneur de tir à armes légères pour ce qui est de mobiliser l'effort maximum d'un soldat. Cependant, une dichotomie intéressante est ressortie pendant la même étude, alors que le temps d'engagement des cibles a augmenté avec le temps de la tâche lors des essais individuels, dans une vaine tentative d'échange de vitesse contre de la précision. Pourtant, le contraire s'est produit lors de l'essai en équipe, lequel a semblé réveiller la compétitivité entre les sujets. Les répercussions de toutes les conclusions sont exposées d'un point de vue militaire.

Executive summary

Effect of various environmental stressors on target detection, identification, and marksmanship:

Soldiers rarely operate in a stress-free environment and must be prepared to surmount a variety of challenges beyond facing an adversary. These include external stressors such as climatic extremes and internal stressors such as fatigue from physical exertion and sleep deprivation. It is self-evident that proficiency in performance must be maintained under such stressors, and even more so when adversarial contact is imminent, whether anticipated or by surprise. It is essential that the soldier's tolerance to stressors is understood and, equally important, that their impact on performance is documented in order to apply the most appropriate countermeasures to stressors. The focus in this report is on the dismounted soldier's ability to detect, identify, and engage targets under thermal stress (hot and cold conditions), battlefield noise conditions, and fatigue due to physical exertion and sleep deprivation, with caffeine intervention applied in the latter case.

The advent of high resolution interactive simulation has made it possible to bring greater realism into the laboratory where experimental rigour is more easily controlled than in a field setting. Using a small arms trainer, target engagement was measured under the various stressors outlined above. Target presentations were random and varied from standing pop-ups to moving figures of both foe and friendly types. Target engagement was judged according to the detection and identification of targets, and marksmanship, which included accuracy (hit/miss and closeness to center of target criteria) and precision (shot group tightness) in the case of static lane targets.

The first thermal stress study involved moderate levels of heat and cold exposures conducted in separate trials where subjects were initially immersed in a water bath to induce a state of thermal strain prior to testing. Shooting was conducted in an environmentally-controlled chamber at either 5 or 35ºC over a 2 h period. Targets were either moving in an urban setting (50 to 200 m range) or pop-ups in specific lanes at 125 m range. Surprisingly, neither heat nor cold strain caused any degradation in marksmanship. On the contrary, certain measures of accuracy and precision actually improved compared to the control trial, which was conducted at 22ºC.

Follow-up studies were conducted at higher levels of thermal strain to determine the threshold of degradation in marksmanship. The first study involved heat exposure whereby targets were presented randomly in time and location as either friend or foe in field and urban settings that changed in synchrony with the subject's walking pace on a treadmill. Even high levels of heat strain (mean body heart rate and core temperature approaching 150 bpm and 39ºC at the end of 4 h of uncompensatory heat exposure with or without hydration) did not adversely affect target detection, identification, and marksmanship. The cold study was conducted with the subject exposed to a 0ºC air environment in a stationary posture and wearing a body tube suit through which 5ºC water circulated. Despite significant cooling short of uncontrollable shivering (mean finger, hand, and core temperatures of 13, 18, and 36.6 ºC after 3 h), the subjects' performance during high intensity engagements and sentry-duty was not seriously affected.

During the noise study, subjects were exposed to 87 dbA battlefield sounds continuously for 15 min while engaging targets in the scenario described for the heat study above. Few effects of noise were observed compared to a control (quiet) trial, but these were minor and contradictory. More interesting was the behavioural reversal of the subjects when they conducted the task alone vs. when they were teamed in groups of two. As individuals, they increased their target engagement time in an apparent bid to improve hit accuracy, which failed to improve significantly. However, target engagement time decreased significantly during the team trial, but at a cost of decreased accuracy, implicating competitiveness between the subjects that favoured speed over accuracy.

The first fatigue study involved a 2.5 h loaded march followed by 1 h of sandbag wall construction. Subjects were then tested with high intensity shooting and low intensity vigilance/shooting tasks over the next 2.5 h. Additional counterbalanced trials were conducted to test the efficacy of pre-engagement caffeine ingestion. Exercise fatigue did not negatively impact performance during the high intensity sessions. It did, however, delay the detection of targets during vigilance, which caffeine was able to restore. Marksmanship was neither affected by fatigue nor from the use of caffeine during the vigilance task. The second fatigue study involved 22 h of sustained wakefulness, with and without caffeine ingestion, followed by a 1 h test on randomly appearing friend and foe pop-up targets at 200 m. Most measures of performance were degraded in the placebo sleep-deprived trial, but only target engagement time and the number of shots fired were restored by caffeine ingestion.

In summary, the findings involving thermal exposure and physical exertion suggest that marksmanship, which in this case required intense, but short-term focus (i.e., 6 s or less), can be competently managed under significant levels of physiological strain. Fatigue is likely to delay the detection of a target, but not seriously affect its engagement as if detecting a target is sufficiently arousing to negate any potential debilitation that the physiological strain might otherwise cause. Moderately high noise did not adversely affect performance; however, these trials revealed an interesting reversal in subject behaviour whereby they favoured accuracy over speed when performing alone vs. speed over accuracy when paired with another subject. These results are relevant to training, equipment, and doctrine, but with the proviso that they were observed in a 'safe' controlled setting in the absence of the psychological stress of potential harm or lethal danger. The unresolved question is whether physiological stressors, as studied herein, will exacerbate performance under psychological stress in theatre. This remains to be determined either through well-documented case histories or increasingly realistic simulations.

Sommaire

Les effets de divers stresseurs environnementaux sur la détection et l'identification de cible et l'adresse au tir :

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Les soldats sont rarement déployés dans un milieu sans contrainte et doivent être préparés à surmonter diverses difficultés en plus de devoir affronter l'adversaire. Ces dernières comptent des stresseurs externes comme les extrêmes climatiques et des stresseurs internes comme la fatigue due à l'effort physique et à la privation de sommeil. Cela va de soi que la capacité de rendement doit être maintenue sous la contrainte de stresseurs et encore davantage lorsqu'un contact avec l'adversaire est imminent, que l'on s'y attende ou non. Il est essentiel de bien comprendre la tolérance du soldat aux stresseurs et, tout autant, de documenter les répercussions sur le rendement de ces derniers afin d'y appliquer les contre-mesures les mieux adaptées. Le présent rapport se concentre sur les capacités du soldat débarqué à détecter, à identifier et à engager des cibles dans une situation de contrainte thermique (conditions de chaleur et de froid), de bruit sur le champ de bataille et de fatigue causée par l'effort physique et la privation de sommeil, avec consommation de caféine dans le dernier cas.

L'avènement de la simulation interactive haute résolution a permis de faire entrer un plus grand réalisme dans les laboratoires, là où la rigueur expérimentale est plus facilement contrôlée que sur le terrain. À l'aide d'un entraîneur de tir aux armes légères, l'engagement de cible a été mesuré par rapport aux divers stresseurs susmentionnés. La présentation des cibles était aléatoire et variée, allant des cibles bondissantes aux figures mobiles, de types ennemi et ami. L'engagement de cible a été jugé selon la détection et l'identification de cibles ainsi que l'adresse au tir, qui comprend l'exactitude (atteindre ou rater le centre de la cible) et la précision (rigueur du tir) dans le cas de cibles fixes.

La première étude sur les contraintes thermiques comportait des niveaux modérés d'exposition à la chaleur et au froid pendant des essais distincts où les sujets étaient d'abord immergés dans un bain d'eau afin d'induire une contrainte thermique avant le test. Les tirs étaient exécutés dans une chambre à environnement contrôlé, soit à 5 °C ou à 35 °C, pendant une période de deux heures. Les cibles étaient mobiles, à une distance de 5 à 200 m en milieu urbain, ou bondissantes, dans des couloirs précis à une distance de 125 m. Étonnamment, l'adresse au tir n'était en rien diminuée par le stress dû à la chaleur ou au froid. Au contraire, certaines mesures d'exactitude et de précision se sont en fait améliorées par rapport à l'essai témoin, mené à 22 °C.

Des études de suivi ont été menées à des niveaux plus élevés de contrainte thermique afin de déterminer le seuil de dégradation de l'adresse du tir. La première étude portait sur la chaleur : des cibles changeantes ont été présentées de façon aléatoire pour ce qui est du temps et de l'emplacement, de leur nature amie ou ennemie et des milieux urbain ou de campagne, qui changeaient en synchronicité avec le rythme du sujet marchant sur un tapis roulant. Même les niveaux élevés de stress thermique (fréquence cardiaque moyenne et température centrale de près de 150 bpm et 39 °C après quatre heures d'exposition non compensatrice à la chaleur avec ou sans hydratation) n'avaient pas réduit la capacité de détection et d'identification des cibles et

l'adresse au tir. Pour l'étude menée sur l'exposition au froid, le sujet était exposé à une température de 0 °C en position immobile et portait une combinaison à tubes dans laquelle circulait de l'eau à 5 °C. En dépit d'un refroidissement important s'approchant des tremblements incontrôlables (température des doigts et des mains et température centrale moyennes de 13, 18 et 36,6 °C après trois heures), le rendement du sujet pendant les engagements de haute intensité et les fonctions de sentinelle n'a pas été sérieusement touché.

Durant l'étude sur le bruit, les sujets ont été exposés à des bruits de champ de bataille continuels de 87 dbA pendant 15 minutes tout en procédant à l'engagement de cibles, à l'intérieur du scénario décrit plus haut pour l'étude sur l'exposition à la chaleur. Quelques effets causés par le bruit ont été observés par rapport aux essais témoins (silencieux), mais ces derniers étaient mineurs et contradictoires. Le renversement de comportement observé entre le moment où les sujets procédaient à la tâche seuls et celui où ils le faisaient en groupe de deux était plus intéressant encore. Individuellement, ils ont amélioré leur temps d'engagement de cible dans une apparente tentative pour améliorer l'exactitude de leur tir, qui ne s'est pas améliorée de manière significative. Le temps d'engagement de cible a toutefois diminué de façon importante pendant les essais d'équipe, mais au prix d'une exactitude réduite, ce qui laisse supposer qu'une certaine compétitivité entre les sujets a favorisé la rapidité au détriment de l'exactitude.

La première étude sur la fatigue comportait une marche avec charge de 2,5 heures suivie de la construction d'un mur de sacs de sable (1 h). Les sujets ont ensuite été mis à l'épreuve, pendant les 2,5 heures suivantes, dans des tâches de tir à haute intensité et d'autres de tir et de vigilance à basse intensité. Des essais contrebalancés supplémentaires ont été menés afin d'évaluer l'efficacité de l'absorption de caféine avant l'engagement. La fatigue due à l'exercice n'a pas eu d'effets néfastes sur le rendement pendant les séances de haute intensité. Toutefois, elle a retardé le temps de détection des cibles pendant les essais de vigilance, ce que la caféine a pu rétablir. Pendant les tâches de vigilance, l'adresse au tir n'a pas été influencée ni par la fatigue, ni par la caféine. La seconde étude comportait 22 h de veille soutenue, avec et sans consommation de caféine, suivies d'un essai d'une heure où des cibles bondissantes, amies ou ennemies, apparaissaient au hasard, à 200 m. La plupart des mesures de rendement ont baissé au cours de l'essai de privation de sommeil avec placebo, mais seuls le temps d'engagement des cibles ainsi que le nombre de coups tirés ont été rétablis par la consommation de caféine.

En résumé, les conclusions portant sur l'exposition thermique et l'effort physique suggèrent que l'adresse au tir, qui dans le présent cas demandait un effort d'attention intense mais de courte durée (six secondes ou moins), peut être maintenue face à des niveaux de contrainte physiologique importants. La fatigue est susceptible de retarder la détection d'une cible, mais sans sérieusement influencer son engagement, comme si la détection d'une cible est suffisamment stimulante pour annuler les effets débilitants potentiels que pourrait autrement causer la contrainte physiologique. Le bruit modérément élevé n'a pas eu d'effet néfaste sur le rendement; cependant, ces essais ont révélé un renversement intéressant dans le comportement des sujets par lequel ces derniers ont favorisé l'exactitude plutôt que la rapidité lorsqu'ils étaient seuls et la rapidité plutôt que l'exactitude lorsqu'ils étaient jumelés avec un autre sujet. Ces résultats sont pertinents en ce qui a trait à la formation, à l'équipement et à la doctrine, pour autant que l'on tienne compte du cadre sécuritaire et contrôlé, duquel le stress psychologique lié à la souffrance ou au danger mortel potentiels est absent. La question irrésolue est de savoir si les stresseurs psychologiques examinés dans les études présentées ici exacerberont le rendement en situation de stress

psychologique une fois sur le terrain. Cela reste à déterminer par des études de cas ou encore des simulations de plus en plus réalistes.

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Table of contents

List of figures

List of tables

Acknowledgements

1   Introduction

Soldiers rarely operate in a stress-free environment and must be prepared to surmount a variety of challenges beyond facing an adversary. These include external stressors such as climatic extremes and internal stressors such as fatigue from physical effort and sleep deprivation. It is self-evident that proficiency in performance must be maintained under such stressors, and even more so when adversarial contact is imminent, whether anticipated or by surprise. It is essential that the soldier's tolerance to stressors is understood and, equally important, that their impact on performance is documented in order to apply the most appropriate countermeasures to stressors. The focus in this report is on the dismounted soldier's ability to detect, identify, and engage targets under thermal stress (hot and cold conditions), battlefield noise conditions, and fatigue due to physical exertion and sleep deprivation, with caffeine intervention applied in the latter two studies.   Individual vs. team performance was also investigated during the noise trial. Psychological stressors, however, will not be examined herein.

A limited number of studies have documented the detrimental impact on marksmanship due to the various stressors cited above. For example, Johnson and Kobrick (1997) reported a small decrement in shooting accuracy in the case of heat exposure. However, body temperatures were not measured making it impossible to ascertain a threshold effect. In the case of cold exposure, Reading et al. (1994) reported a modest increase in shot deviation despite no decrease in core (deep body) temperature, clearly implicating the role of a cold periphery, but leaving unclear the impact of a cool core. Noise can affect attentiveness (Smith 1989) and therefore possibly affect target detection, but its effect on marksmanship is less certain. The effect of exercise on marksmanship has been examined in conjunction with several confounding or mitigating factors. In one study, for example, Tharion et al. (1997) failed to find an ergogenic benefit from a carbohyrdrate-electrolyte beverage with respect to marksmanship. It would be of interest to extend this work to caffeine, not only for exercise fatigue, but also for sleep deprivation, which has been reported to degrade marksmanship by varying degrees (Haslam, 1982) but reversible with caffeine intervention (Lieberman et al., 2002). The series of studies described herein were conducted to add to this body of knowledge, by extending thermal stress levels along with body temperature measurements, and by further examining the efficacy of caffeine ingestion on target detection, identification, and marksmanship during exercise fatigue and sleep deprivation.

For clarification, physiological stress is defined as the environmental insult to the body whereas strain is the consequential change of state in the body. For example, exposure to heat or cold presents a thermal stress and the resultant physiological change (e.g., hyperthermia or hypothermia) is the strain. However, it is very difficult to separate the contributions of stress and strain to any change in performance. While stress is easily quantified, strain is more challenging, relying, for example, on subjective measures for fatigue and objective measures such as body temperatures for thermal strain.

Rather than present the methods of all the trials under one section followed by the results in another, as customarily done, the methods and results will be presented for each trial under separate sub-sections. This will simplify keeping track of each trial given the number and variation of trials reported herein. Greater details of the trials can be found in the corresponding cited references. This report presents the key findings of each study and a general summation. The findings and data can be used for doctrinal considerations of the tactical/operational

deployment of dismounted soldiers, and for improving the simulation of soldier performance in war gamming and training models.

2 Trials

2.1 General

All trials were conducted using the FATS IV Combat Firing Simulator (FATS Inc., Suwanee, GA) in an environmentally-controlled room. The SAT provides high resolution interactive simulation whereby targets appearing on the screen (2.2 m high x 3.0 m wide) are engaged from a distance of about 5.8 m (horizontal viewing angle of 29º) using laser-firing weapons with authentic blast audio and recoil. All scenarios were designed and installed by the authors. Subjects were relatively young rifle-trained military volunteers with prior experience with the SAT. The subjects were also medically screened and a full explanation of the procedures, discomforts, and risks were given before written informed consents were obtained prior to their participation. All studies were approved by the Human Ethics Research Committee for Defence R&D Canada.

Subjects underwent the following procedure prior to each trial including familarization: i) calibration procedure (zeroing and grouping) of the rifle (C-7A1) and optical scope (C79), ii) donning of clothing required for the study, iii) completion of applicable questionnaires (typically on perceived exertion and thermal sensation), and iv) assumption of position/posture required for the study. In addition for thermally stressful trials, subjects self-inserted a rectal probe (Yellow Springs Instruments, Dayton, OH) for core temperature measurement, had heat flow transducers (Concept Engineering, Old Saybrook, CT) applied for various skin temperature measurements, and had a heart rate monitor (Sports-Tester, Polar Electro Oy, Kempele, Finland) strapped around their chest for heart rate measurement.

All trials were counterbalanced and conducted as a repeated measures ANOVA design, and analyzed accordingly with significance reported at $p < 0.05$. The Newman-Keuls test was used for post-hoc analyses where main differences were found. Textual results will be reported as mean ± SD and figure results will be presented as mean ± SE.

2.2 Moderate thermal exposure

This study created a condition of thermal strain prior to testing in an effort to minimize any distraction due to the stress of the exposure (i.e., subjects were primed to the thermally-stressful condition before the task began). This was achieved by immersing the subject in a water bath to attain either a starting core temperature of 38.2ºC for the HOT trial, a heat loss of 1 W·h·kg^{-1} body mass for the COLD trial, or thermal neutrality (no change) for the CONTROL trial (Tikuisis et al., 2002). Following approximately one hour of water immersion, the subject entered the SAT room respectively held at 35, 5, or 22ºC, changed into combat attire, and assumed a prone position in front of the SAT screen. Twelve healthy subjects (7 male and 5 female: 27 ± 5 yr, 176 ± 11 cm, 78 ± 17 kg) participated in this study.

Over the next approximately 1.5 h, the subject underwent 16 shooting sessions of 5 min each in mixed order, half involving 5 randomly appearing pop-up lane targets (1.14 m high x 0.45 m wide) at 125 m range (vertical angle of target was 0.5º) and the other half involving 20 randomly appearing running targets from 50 to 200 m away in an urban scene (Figure 1). In each case, the

subject was instructed to fire at the target when it was perceived to have the best chance of a direct hit, and was discouraged from using suppression fire. Performance was based on shooting accuracy (closeness to target centre of mass) and precision (shot group tightness) during the lane engagements, and on the number of shots fired and successful hits of the running targets.
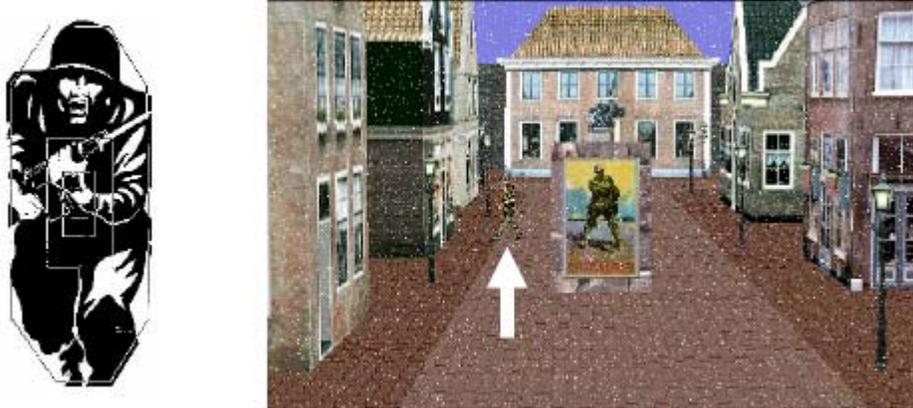
Figure 1. Views of the pop-up target and urban scenario used for marksmanship testing. The arrow indicates a walking target and the centrepiece depicting a poster of a soldier was a permanent display that was used to hide targets.

The heating and cooling protocols caused significant separations in core temperature (Figure 2), as expected. The trend of a decreasing core temperature in all trials is a normal response when assuming a prone position due to heat redistribution in the body and does not imply that the individual was cooling during HOT and CONTROL (Tikuisis et al., 1996). The exaggerated cooling rate of the core during COLD reflects true cooling during the 5ºC air exposure. Top of the hand temperature reached 19.4 ± 3.0ºC by the end of COLD. Subjective thermal sensations were based on a 10-point scale and were rated as comfortable, cold and warm at the end of CONTROL, COLD, and HOT, respectively. Perceived exertions were slightly tired (CONTROL and COLD) and moderately tired (HOT).
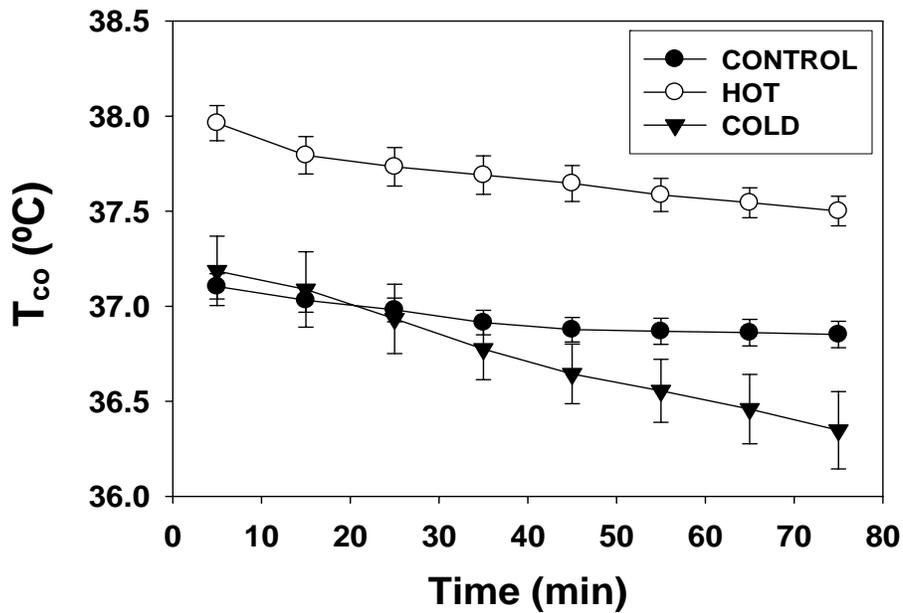
Figure 2: Mean ± SE of core temperature plotted against time.

Despite the thermal strains imposed during HOT and COLD, neither condition degraded shooting performance of the pop-up lane targets (Figure 3) and running targets. In the former case, shooting error (SE, average shot distance from centre of mass – measure of shooting accuracy) was fairly consistent at about 25 cm or 0.11º, but did tend to be higher during CONTROL. Shot mean radius (MR, average of the straight line distance between each shot and the center of impact or shot group tightness – measure of shooting precision) was also fairly consistent at about 14 cm or 0.06º. The overall hit percentage of running targets averaged 84.2%, which was quite consistent across all trials, and the ratio of shots fired over the number of targets hit averaged 51.3%.
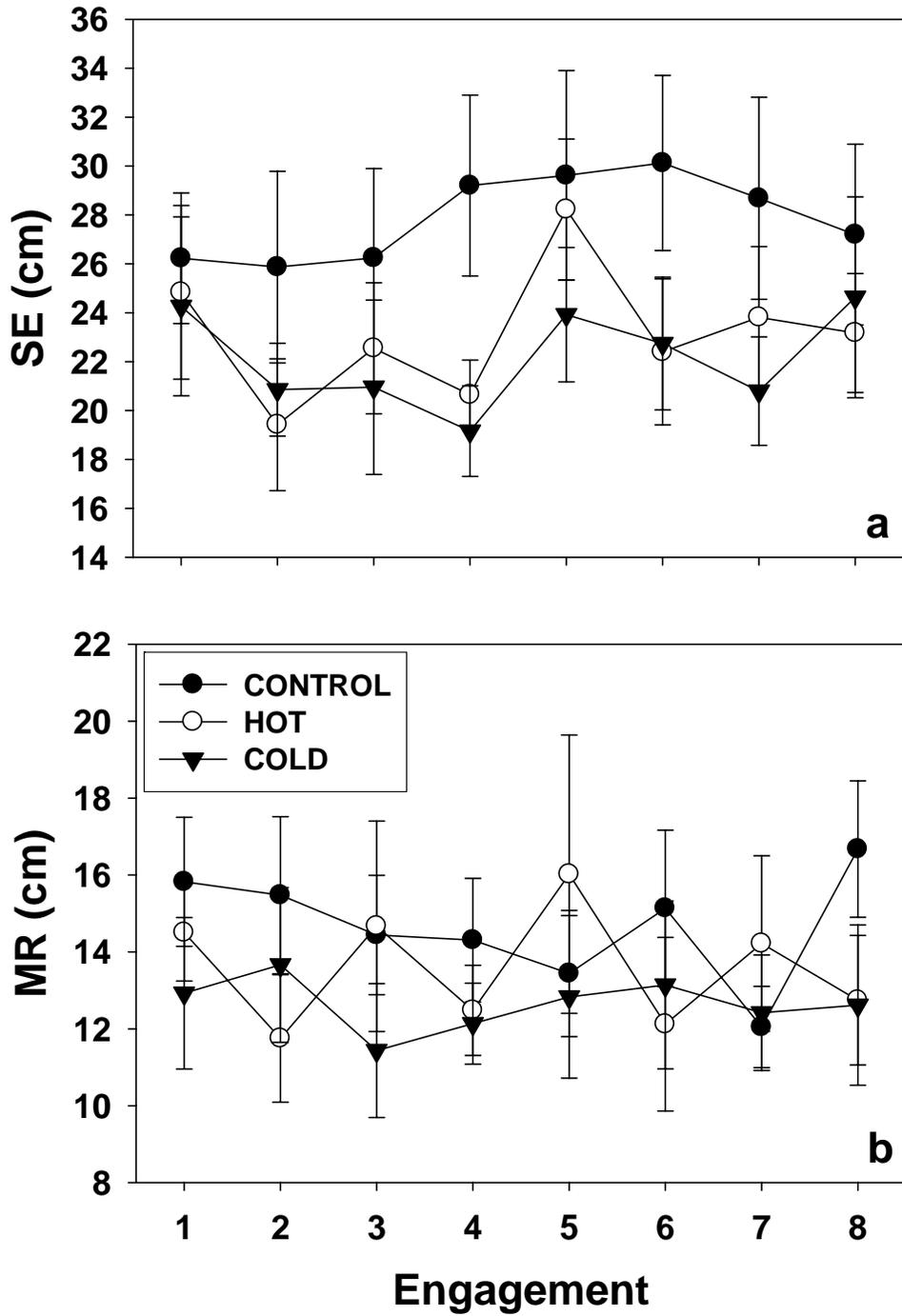
Figure 3: Mean ± SE of a) shooting error (SE) and b) shot mean radius (MR) plotted against engagement session of pop-up lane targets.

The lack of any detrimental impact on marksmanship performance, despite significant objective and subjective measures of thermal strain, was the impetus for the subsequent two trials that approached the limits of human tolerance to thermal strain.

2.3   Hot exposure

Eleven healthy male subjects (29 ± 6 yr, 177 ± 10 cm, and 81 ± 19 kg) were exposed to uncompensable heat strain at 29ºC during two trials, one with hydration (HYD, where subjects were given water without restriction) and the other without (DYD) (Tikuisis et al., 2005). Uncompensable heat strain refers to blockage of sweat evaporation, which was achieved by having the subjects wear a vapour-impermeable protective garment, thereby preventing body cooling by sweat evaporation. Subjects walked on a treadmill at 3 km·h^{-1} for 25 min every half hour of the trial. In addition, water at 42ºC was circulated through a tube suit (TUBESuit, Med-Eng Systems, Ottawa, Canada) worn underneath the protective garment to control the rate of increase of core temperature. A third trial was conducted at 22ºC without any water circulation for control purposes (CONTROL). Each trial lasted 4 h unless the subject was removed due to complaint or upon reaching a core temperature of 39.5ºC.

During 15 min every half hour, the subject viewed a moving landscape in synchrony with their walking pace (Figure 4), and traversed through an open field (Figure 5), entered a small rural village (Figure 5), and exited through open field again. During these segments of 5 min each, 8 foe and 4 friendly targets would appear randomly in time and location along an arc at 60 m range. Performance was based on target detection and engagement time, friend/foe discrimination, and shooting accuracy. Foe targets were identified by a disruptive dark green patterned uniform in a standing posture or disruptive light green patterned uniform in a kneeling posture; friendly target uniforms and postures were the opposite of the foes. These arbitrary target designations were chosen to challenge the subject with non-obvious presentations. The subjects were instructed to immediately squeeze the trigger of the rifle upon sighting a target. If friendly, they were to continue walking. If foe, they were required to quickly dismount the treadmill to secure a stable shooting position and take one well-aimed shot at the target (Figure 4), and resume walking immediately afterwards. Dismounting the treadmill was practiced and took an average of ~ 0.7 s.

Figure 4: Experimental set-up showing the subject walking on the treadmill and dismounted on the raised platform after detecting a foe target.

Figure 5: Views of the open field and rural village that the subject traversed through. Arrows indicate the presence of targets.

The subjects attained high values of heat strain as attested by their significant rises in core temperature and heart rate during both HYD and DYH (Figure 6), reaching average values of about 38.8ºC and 138 bpm by the end of the trials.
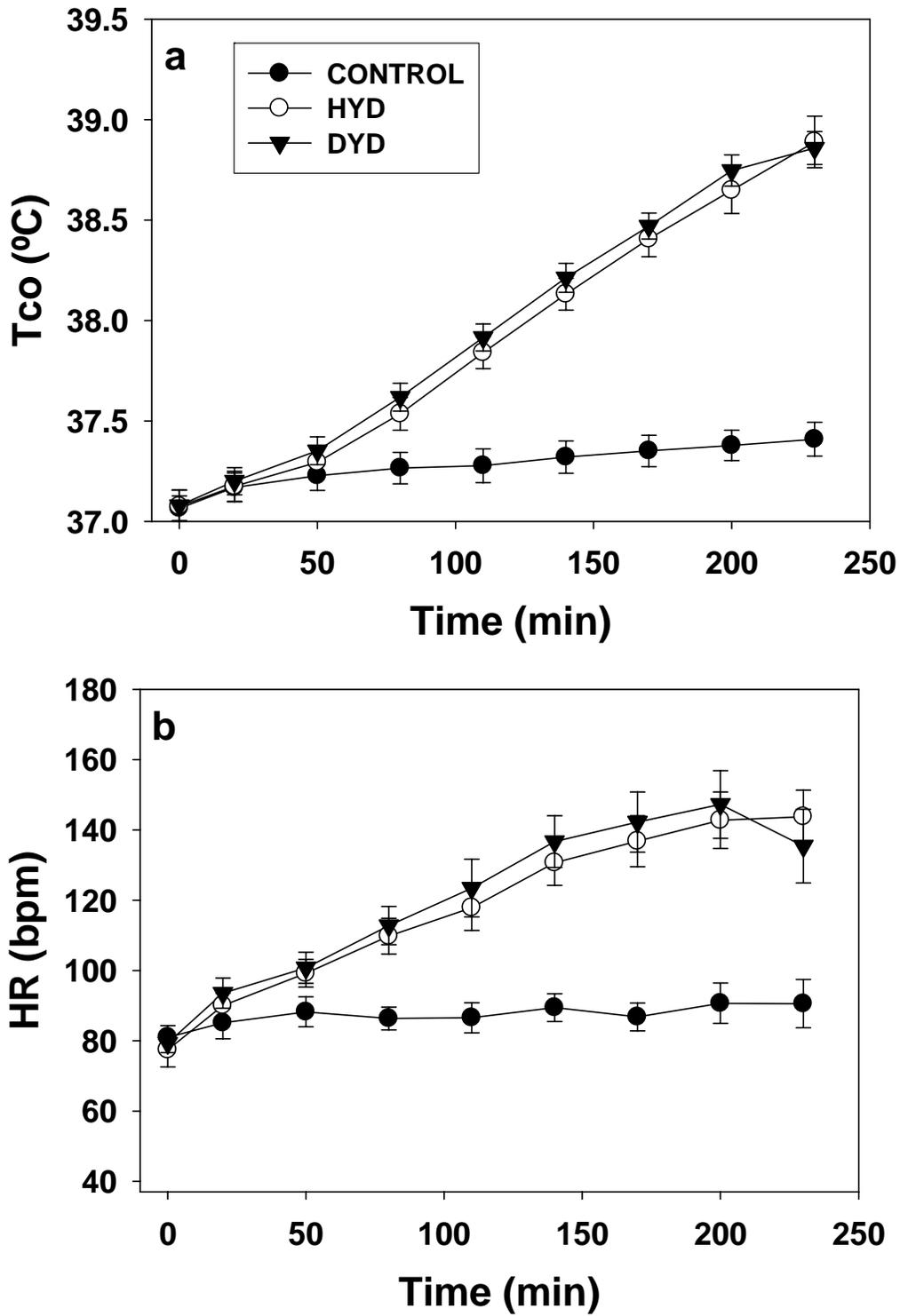
Figure 6: Mean ± SE of a) core temperature and b) heart rate against time.

Surprisingly, however, neither trial nor time on task degraded the subjects' performance, as shown in Table 1 (not shown are the detection of friendly target results, which were similar to the foes). Target detection time, engagement time, and hit accuracy consistently averaged about 1.2 s, 4.7 s, and 75%, respectively. In conclusion, significant heat strain failed to adversely affect the detection, identification, and engagement of targets.

Table 1: Mean ± SD initial and final (between 215 and 230 min) measures of foe target detection and marksmanship where engagement time includes ~0.7 s required for dismounting the treadmill (Figure 4) before aiming and firing could take place, and %hit per target detected. HYD and DYD refer to the hydration and dehydration conditions, respectively.

Measure	Time	CONTROL	HYD	DYD
% Detected	**Initial**	94.7 ± 4.6	96.4 ± 3.9	96.2 ± 4.4
	Final	95.2 ± 5.7	96.1 ± 4.0	95.8 ± 3.7
% Identified	**Initial**	94.8 ± 6.1	89.9 ± 12.3	94.8 ± 3.8
	Final	92.5 ± 5.5	96.3 ± 4.6	96.8 ± 2.8
Detection time (s)	**Initial**	1.19 ± 0.26	1.27 ± 0.19	1.22 ± 0.23
	Final	1.28 ± 0.24	1.17 ± 0.27	1.15 ± 0.24
Engagement time (s)	**Initial**	4.65 ± 0.42	4.65 ± 0.40	4.75 ± 0.40
	Final	4.68 ± 0.31	4.64 ± 0.34	4.62 ± 0.37
% Hit	**Initial**	75.1 ± 14.4	76.9 ± 12.8	74.5 ± 15.6
	Final	75.4 ± 17.5	71.2 ± 14.9	77.3 ± 10.3

2.4   Cold exposure

Twelve male subjects (28 ± 6 yr, 178 ± 6 cm, and 88 ± 18 kg) were exposed to cold (COLD) via a combination of 0ºC air environment while wearing shorts, a t-shirt, and a tube suit (Figure 7 - same as used for the Hot Exposure study) through which water at 5ºC circulated (Tikuisis et al., 2007). Additional trials were conducted under thermal-neutral conditions (room at 22ºC) for control (CONTROL) purposes and to test the efficacy of adding a secondary (dual) task to enhance attentiveness during the sentry duty portion of the trial (DUAL). The secondary task was

the FAAF (Four Alternative Auditory Feature) word recognition test (Foster and Haggard, 1987), which was administered every 15 min, took less than 1 min to complete, and was unrelated to the main task of target detection.

Figure 7: Views of the torso portion of the tube suit for cooling and placement of thermistors for skin temperature measurements of the finger, hand, and arm.

Subjects were challenged by two separate scenarios, one that involved engaging frequently appearing targets in an urban scene and the other involving the detection of fewer targets during sentry duty. The urban scenario, which lasted 15 min, was conducted at the beginning, mid-point, and end of the trial. The second scenario lasted 1 h and was applied twice, sandwiched between the urban segments. Sixty, mostly moving targets appeared in the urban scene anywhere from 25 to 250 m away (Figure 8), and of these 15 displayed hostile intent upon raising a weapon and aiming it at the subject. Further, 6 and 9 of these hostiles were civilians and soldiers, respectively. The subject was tasked with engaging all hostile targets. During sentry duty, the subject overlooked a 45º arc 3 x 3 km mountainous/desert terrain (Figure 8) that contained 4 stationary targets that were always present and 8 moving targets that appeared randomly and briefly (10 s) during each 1 h observation period. The subject was tasked with detecting, identifying, and locating all targets, and assessing their threat (on a scale from 0 to 100), which was compared to an expert's opinion. The threat was based on a combination of the location and lethality of the target.

Figure 8: Views of the urban scene and mountainous/desert terrain during the urban scenario and sentry duty tasks, respectively. The arrow in the latter scene indicates a moving target (vehicle).

The subjects were significantly cold-strained during COLD (Figure 9). Core, finger (top side of the middle finger; Figure 7), hand (top side), forearm (mid-point top side), and upper arm (mid-point top side) temperatures reached 36.3 ± 0.7, 10.8 ± 1.9, 17.5 ± 3.8, 22.4 ± 2.3, and 23.0 ± 3.1ºC, respectively, by the end of the trial, compared with overall mean values of 36.7, 25.7, 29.0, 32.6, 31.5ºC for CONTROL and DUAL. Further, finger temperature was less than 15°C during COLD at all times except during the first 15 min of the exposure. Hand temperature was less than 19°C during COLD after the first sentry duty session. Heart rate was fairly consistent throughout all trials, averaging around 74 bpm. The subjects rated their thermal sensation during COLD as very cold by the end of the trial, yet their perceived exertion remained 'little' throughout all trials.
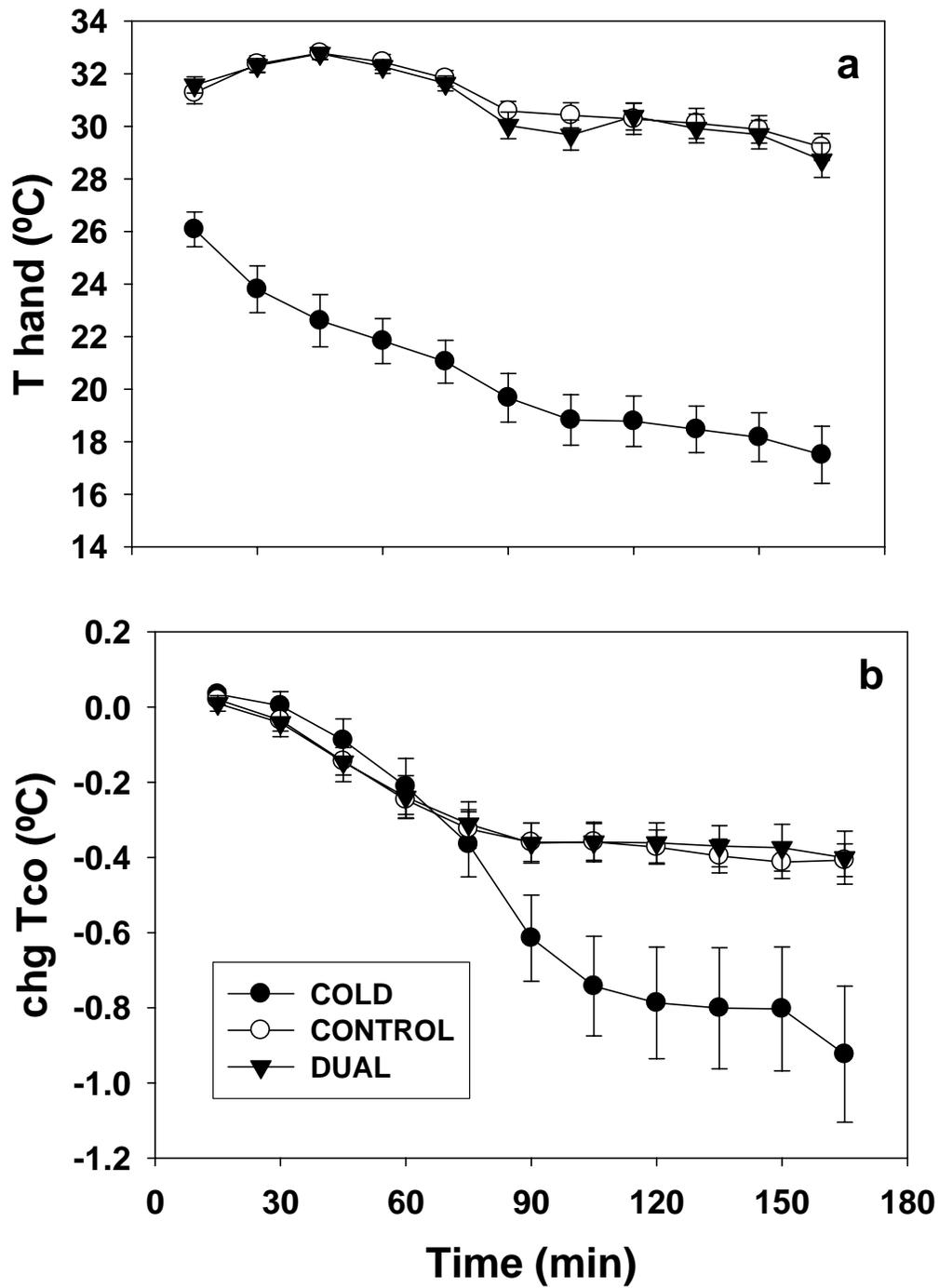
Figure 9: Mean ± SE of a) hand temperature and b) change in core temperature against time.

Surprisingly, no degradation in performance occurred despite the considerable decreases in core and skin temperatures during COLD. Overall performance results are summarized in Table 2. The average percentage of hostile targets hit relative to the number engaged was 80% during the urban scenario. The percentage of targets detected during sentry duty was considerably higher for stationary vs. moving targets, yet their identifications and relative location errors were similar. The subjects' threat assessments of these respective targets were close to the expert's, differing on average by only +0.4 and -11.1 (+/-ve = over/under estimated) on a scale of 0 to 100. Cold exposure, in this study, failed to adversely affect the detection, identification, and engagement of targets.

Table 2: Mean results across all trials; % relative location error refers to the distance from the target to its estimated position relative to the target's distance from the subject.

Measure	Mean ± SD	Range
Urban Scenario		
% Hostiles engaged	76.7 ± 8.7	62.0 – 90.0
% Non-hostiles engaged	0.9 ± 0.9	0 – 2.5
% Hostile targets hit	61.3 ± 14.7	22.7 – 80.7
Hostile engage time (s)	4.0 ± 0.5	3.4 – 5.0
Sentry Duty		
Stationary Targets		
% Targets detected	78.8 ± 11.5	60.0 – 91.8
% Correctly identified	95.0 ± 6.8	83.3 - 100
Detection time (min)	8.5 ± 3.7	4.3 – 16.6
% Relative location error	42.4 ± 19.4	21.5 – 89.7
Moving Targets		
% Targets detected	12.0 ± 8.9	0 – 25.0
% Correctly identified	98.6 ± 2.4	93.8 - 100
% Relative location error	39.1 ± 25.3	11.0 – 84.3

The number of correct word recognitions (FAAF test) tended to decrease after the first sentry duty session during DUAL (from $25.0 ± 24.3$ to $16.7 ± 22.3\%$), but the change was not significant. This secondary task failed, however, to enhance target detection compared to CONTROL, although only the moving targets were relevant in this case since most of the stationary targets were detected before the first FAAF was administered.

2.5   Noise

Noise is ubiquitous in the battlefield and is known to affect performance (Smith 1989), more often negatively, in several different tasks that are common to key components of military operations. However, specific knowledge of its effect on target detection, identification, and marksmanship, is limited. This study was undertaken to document such effects in addition to exploring differences between individual and team performance and determining whether an incentive could improve individual performance.

Twenty male subjects (24 ± 4 yr, 182 ± 5 cm, and 84 ± 14 kg) underwent four trials held one per day over 4 consecutive days. The first trial involved basic anthropometric measurements and familarization with the noise protocol and shooting task. The next two trials tested the subjects either as individuals (IT) or in teams of two (TT) in a counterbalanced order. Target detection was recorded by the first trigger squeeze by either subject and marksmanship was assessed by the first shot taken, regardless of who detected or who engaged the target during TT; hence these data were analyzed as if the team represented a single subject. The last trial was a repeat of IT, but with a monetary incentive (RT, reward trial) for the subject to outperform their previous individual attempt. Amounts rewarded (after all subjects conducted the study) were based on a pro-rated basis of relative improvement (i.e., compared to the other subjects) using an equally-weighted composite of target detection time, percentage of correct target identifications, and number of foe targets hit.

Each trial [conducted as described in the Hot Exposure study (section 2.3) except for heating] comprised six 20 min cycles of walking at a 3 km·h-1 pace for 15 min, during which testing occurred, and then resting for 5 min when water could be consumed without restriction. Constant small and large arms battlefield noise of 87 dBA (refers to decibels A-weighted to model the frequency response of the human ear) was present during alternate testing periods, which is denoted as the noise condition (NO). Low level background sound (< 54 dBA) was presented during the balance of these alternating periods that served as the 'quiet' control condition (CN). Half of the subjects began their trials under NO while the other half started under CN. Each pair of CN and NO test periods is referred to chronologically by time blocks TB1, 2, and 3, as shown in Figure 10.
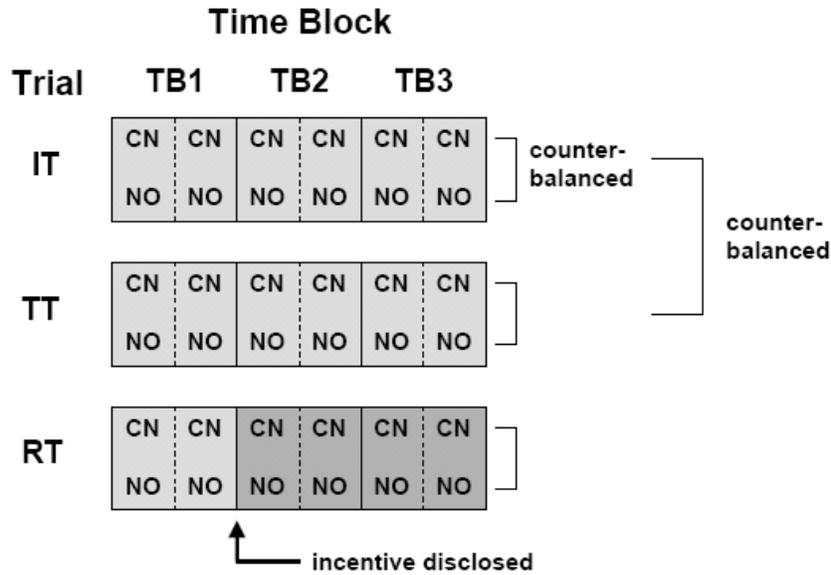
Figure 10: Order of trials and conditions where IT, TT, and RT represent the individual, team, and reward trials, TB represents the time block (20 min each), and CN and NO represent the control and noise conditions, respectively.

Overall, there were few minor, but mixed effects of noise on performance. Friendly target detections were faster during CN (0.94 ± 0.13 s) vs. NO (1.00 ± 0.12 s) during IT, in contrast their respective detection times of 0.79 ± 0.09 and 0.74 ± 0.09 s during TT. Also, slightly but significantly fewer friendly targets were detected during CN ($95.2 \pm 6.1\%$) vs. NO ($97.2 \pm 6.7\%$) during RT. No other effects of noise were observed.

Analysis of IT results indicated some changes between the first time block (TB1) and the remaining two (which were not different). The most striking was an increase in target (foe) engagement time from 4.47 ± 0.31 to 4.64 ± 0.33 s, but with no improvement in hit accuracy although the trend indicated so (Figure 11). Given that the IT results of TB2 and TB3 were not different, they were combined for comparison with the first time block of RT to check for a learning/order effect (recall that the incentive was not disclosed until after TB1; Figure 10). The only significant finding was a further increase in target engagement time to 4.92 ± 0.08 s (Figure 11). Comparison with the remaining time blocks of RT indicated no further increase. Although hit accuracy tended to improve for RT as expected (Figure 11), the increase was not significant suggesting that the evolved strategy of accuracy for speed trade-off failed. No other performance measure changed between time blocks indicating that the monetary incentive had no effect. Table 3 provides the mean results of all performance measures during the latter two time blocks of IT and RT.

*Figure 11: Mean ±SE of a) foe target engagement time and b) hit accuracy across time blocks for the initial and reward individual trials. * indicates a significant difference.*
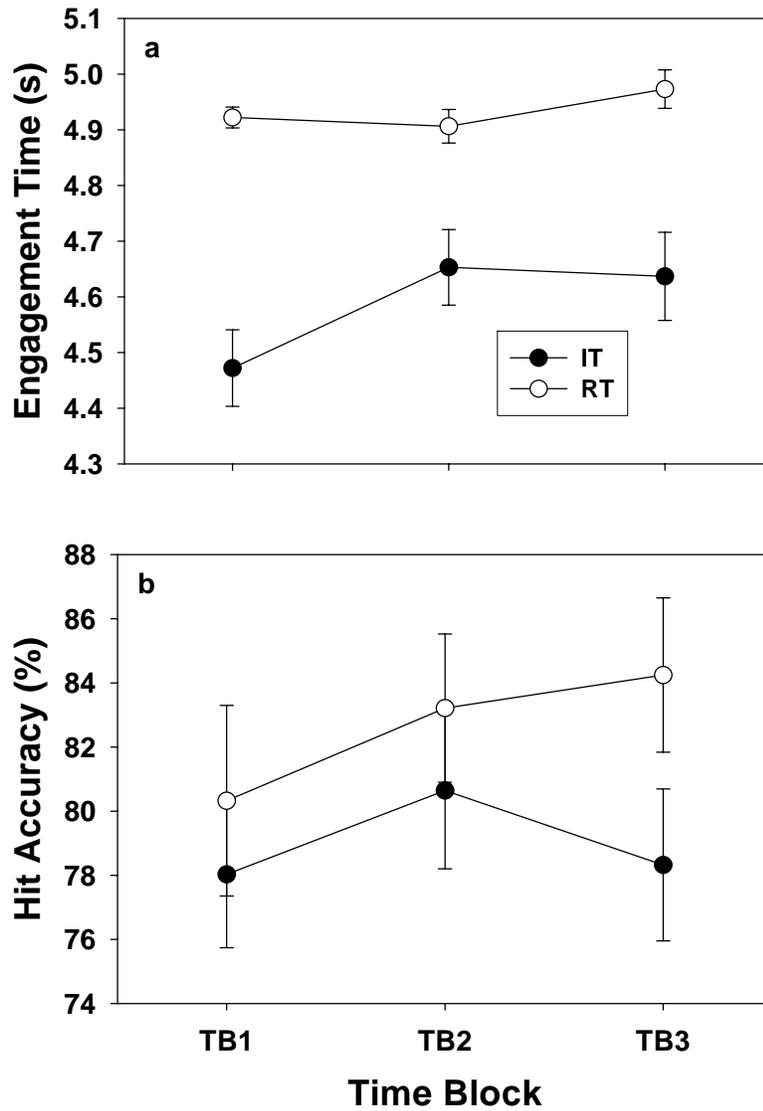
*Table 3: Mean ± SD performance measures during the last two time blocks (TB2 and TB3) under control (CN) and noise (NO) conditions for the individual and reward trials. * indicates a significant difference.*

Measure	Condition	IT	RT
% Targets detected	**CN**	96 ± 3.1	95.8 ± 6.1
	NO	96.5 ± 4.3	97.0 ± 5.5
% Targets correctly identified	**CN**	97.7 ± 2.5	97.1 ± 2.5
	NO	96.0 ± 5.2	96.1 ± 6.1
Target detection time (s)	**CN**	0.98 ± 0.12	0.96 ± 0.10
	NO	1.03 ± 0.11	0.97 ± 0.07
Foe target engagement time (s)	**CN**	4.63 ± 0.35	4.92 ± 0.16*
	NO	4.66 ± 0.33	4.96 ± 0.18*
% Foe targets hit	**CN**	78.9 ± 10.7	83.9 ± 10.1
	NO	79.1 ± 10.6	83.5 ± 9.4

Team results of engagement time and hit accuracy were compared to the results of the individual in the team who was more accurate in hitting the target during common test periods of IT since these performance measures are coupled. That is, it would be less meaningful to compare the team result to the mean of the subjects' individual results considering that the hit accuracy for the team pertains to the subject who engaged the target. In essence, the team results for a specific test condition (i.e., either CN or NO for a specific time block) were compared to the IT results of the individual that achieved the higher hit accuracy for the same test condition. It turns out that target engagement time and hit accuracy were both lower during TT compared to the hit-biased IT results (Figure 12). The decrease in engagement time for TT was a reversal of the strategy seen in the individual trials, suggesting that the team situation evoked competitiveness that superseded accuracy for speed.
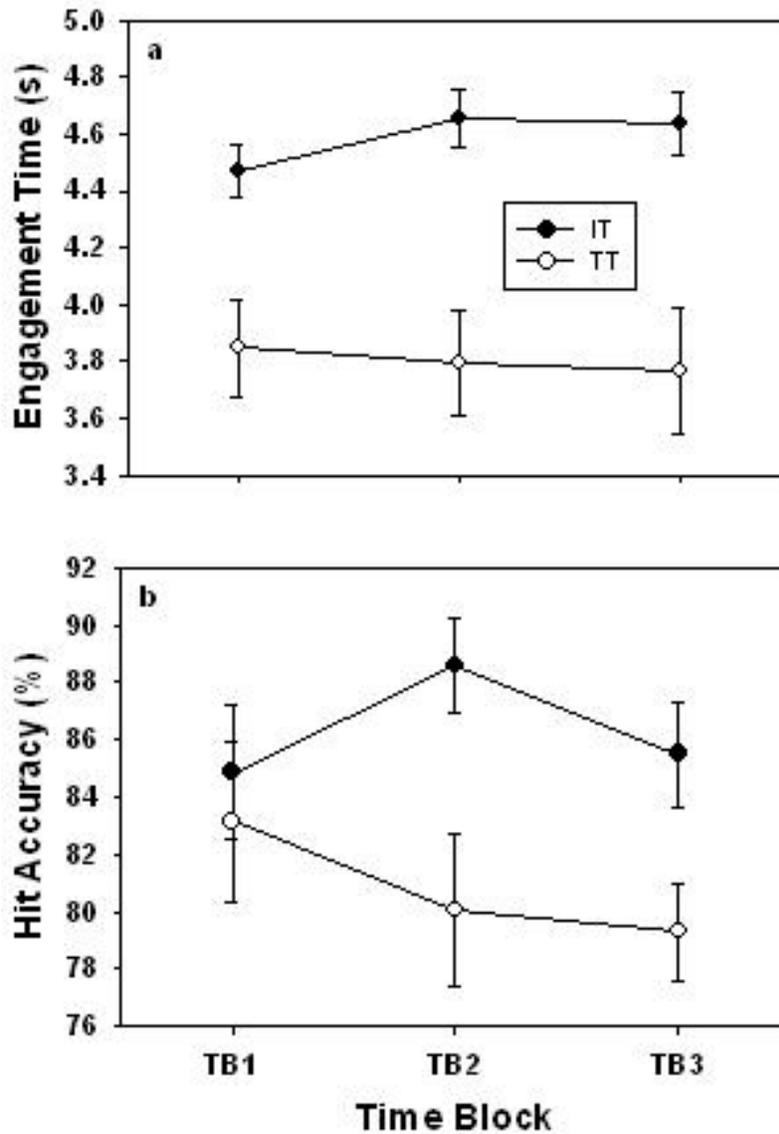
*Figure 12: Mean ± SE of a) foe target engagement time and b) hit accuracy across time blocks for the individual (hit-biased results) and team trials. * indicates a significant difference.*

2.6 Exercise fatigue

Twelve (27 ± 6 yr, 180 ± 11 cm, and 86 ± 13 kg) subjects (9 male and 3 female) underwent an exercise regime (Fig. 2.6.1) that began with a 2.5 h loaded (25 kg backpack) march at 6 km·h^{-1} and ended with a 1 h period of sandbag wall construction (20 x 15 kg bags moved back and forth across a 4.5 m room). Subjects completed 4 trials (Gillingham et al., 2004): PP, PC, CP, and CC where P and C refer to placebo and caffeine ingestion, respectively. The first and second letters designate which was given, by capsule, at the start and at the end of the exercise period (if

caffeine, then at 5 and 2.5 mg·kg-1 body mass, respectively). 100 mg of caffeine is approximately equivalent to the caffeine in a regular cup of coffee, hence, the initial and re-dose caffeine ingestions represent 4 and 2 cups of coffee, respectively, for an 80 kg individual.

Figure 13: Views of the loaded march and sandbag wall construction portions of the exercise activity.

Following exercise, the subject conducted a marksmanship task that began and ended with a 10 min urban scenario where 48 randomly appearing targets at 30 – 60 m range walked or ran across a street (similar to the scene shown in Figure 1, but with different target characteristics) taking between 1.5 and 2.8 s. Between these sessions, the subject was presented with 30 lane pop-up targets (again similar to that shown in Figure 1) at 200 m range appearing randomly for 4 s over two consecutive 1 h periods. The subject was tasked with engaging targets with unlimited rounds during the urban scenario and engaging targets with a single shot during the 2 h vigilance scenario. Performance was based on the number of shots fired, number of targets hit, and engagement time.

Pre-shooting caffeine levels in the blood were 3.5 ± 3.9, 19.8 ± 13.2, 28.8 ± 12.0, and 40.4 ± 16.5 μmol·L-1 for PP, PC, CP, and CC, respectively. Despite these differences, caffeine had no effect on marksmanship for both the urban and vigilance scenarios, except that the number of shots fired during vigilance was slightly, but significantly, higher compared to PP (Figure 14a). Caffeine also lowered the engagement time slightly (Figure 14b), but significantly for CC (2.8 ± 0.3 s) compared to PP (3.0 ± 0.3 s) during the vigilance scenario (engagement times for PC and CP were not affected). The overall ratios of hits to shots fired were 41.3 and 56.0% for the urban and vigilance scenarios, respectively.
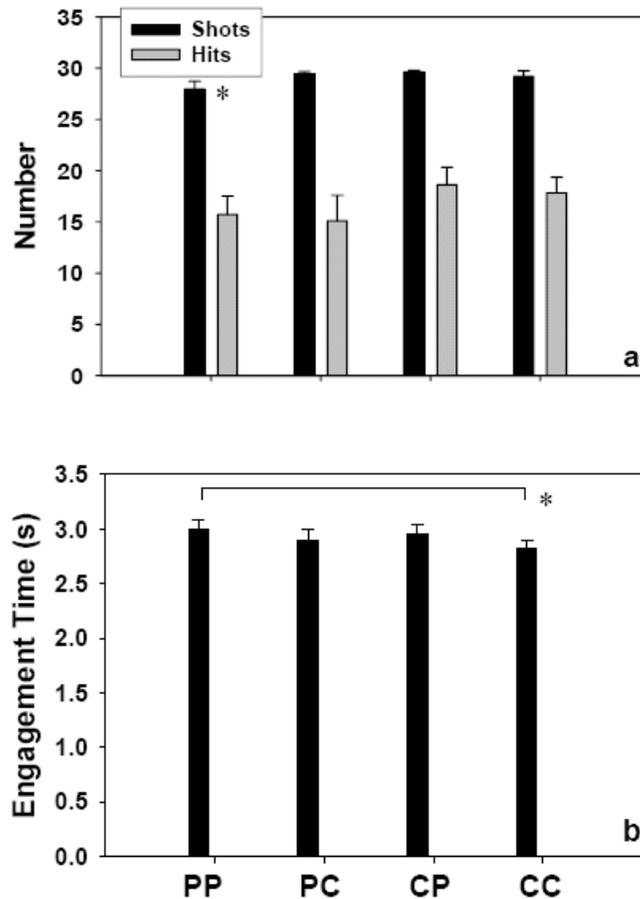
*Figure 14: Overall mean ± SE of the a) number of shots and hits, and b) engagement time of targets (out of 30 per session) during the vigilance scenario; * indicates a significant difference.*

2.7   Sleep deprivation

Twenty male subjects (27 ± 7 yr, 179 ± 6 cm, and 85± 11 kg) underwent two separate trials each involving 22 h of active wakefulness before being tested on target detection and marksmanship (Tikuisis et al., 2004). Pre-testing activities included a mixture of mental and physical tasks (McLellan et al., 2004). Subjects were also given 400, 100, and 100 mg of CAFFEINE (via chewing gum) or PLACEBO at 7.5, 3, and 0 h prior to testing during the respective trials.

Fifteen hostile and five non-hostile lane pop-up targets at 200 m range (Figure 15) appeared for 4 s randomly in time over two consecutive 30 min periods. Performance was based on friend/foe discrimination, target engagement time, and marksmanship. Comparisons were also made with BASELINE measurements taken 18 h prior to testing (i.e., after 4 h of wakefulness during both CAFFEINE and PLACEBO trials).
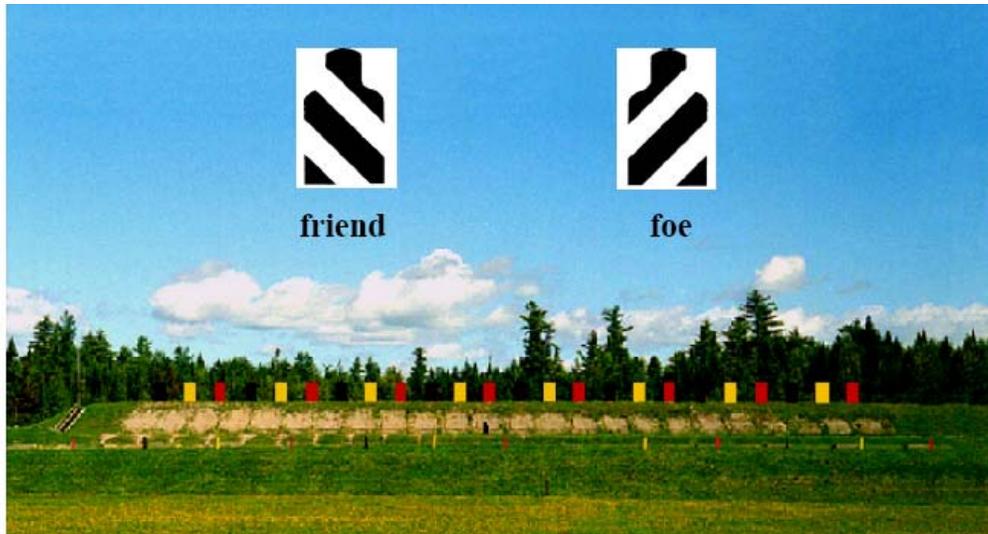
Figure 15: View of the shooting range and targets.

BASELINE measures were not different between trials and therefore its mean value was used for comparison to the trial conditions. The number of friend/foe errors was consistently low throughout the trials (0.9 ± 1.4, 0.8 ± 1.4, and 0.9 ± 1.7% for BASELINE, PLACEBO, and CAFFEINE, respectively). Target engagement time, on the other hand, was affected by sleep deprivation, increasing from a BASELINE value of 3.03 ± 0.26 s to 3.29 ± 0.17 s during PLACEBO (Figure 16). However, it was restored (3.04 ± 0.25 s) during CAFFEINE.
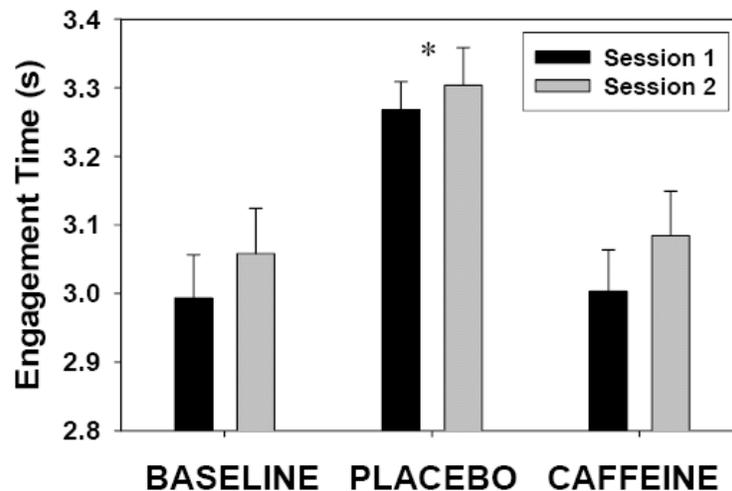
Figure 16: Mean ± SE of target engagement times during both 30 min sessions, which was significantly higher (*) during PLACEBO than the other two conditions.

Similarly, caffeine also restored the number of shots fired (Figure 17), but not the number of hits (although it tended to be higher than PLACEBO). The overall ratios of hits to shots fired were

fairly consistent across all conditions (56.8, 55.4, and 53.1% for BASELINE, PLACEBO, and CAFFEINE, respectively) thus indicating no affect on relative marksmanship.
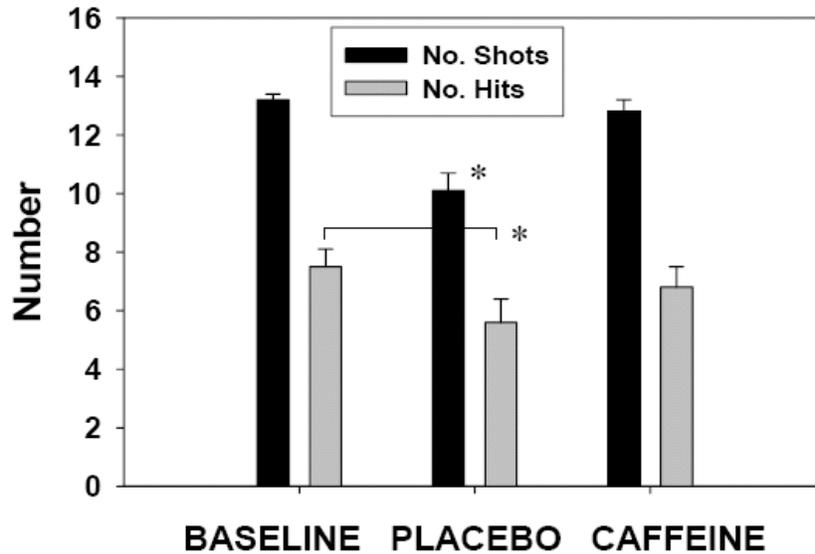
*Figure 17: Mean ± SE of the number of shots fired and number of hits during both 30 min sessions; * indicates a significant difference.*

Shooting error (SE) and shot mean radius (MR) were affected by sleep deprivation (Figure 18). SE increased during the second session in both trials compared to BASELINE, independent of caffeine ingestion. MR was higher for both PLACEBO and CAFFEINE compared to BASELINE; collectively these results indicate that caffeine was neither advantageous nor disadvantageous with respect to marksmanship.
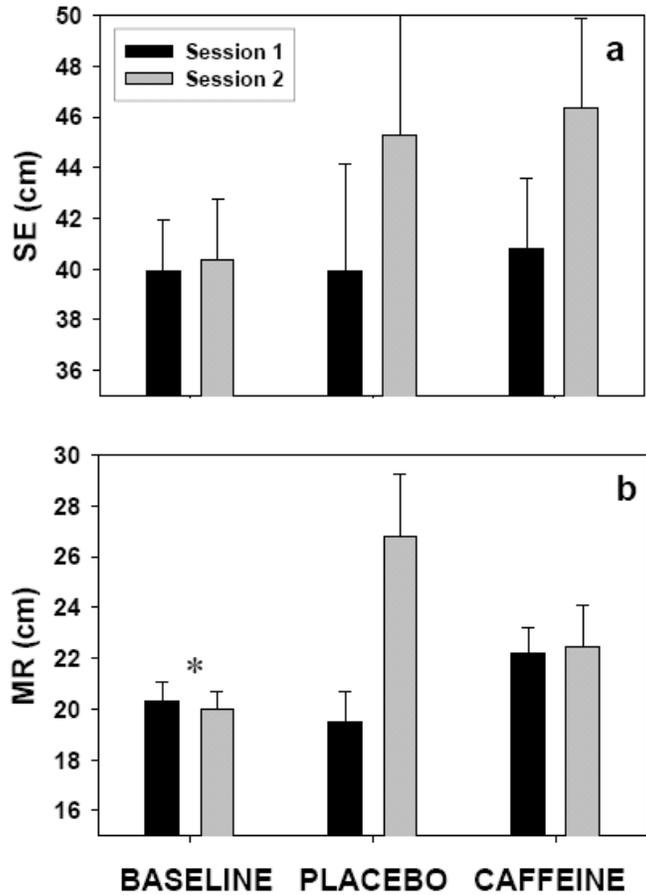
Figure 18: Mean ± SE of shooting error (SE) and shot mean radius (MR) during both 30 min shooting sessions. SE was significantly higher during session 2 compared to session 1 for PLACEBO and CAFFEINE.

3   Discussion

The overwhelming impression that emerges from this series of studies is that humans can be highly tolerant to various stressors despite significant measures of physiological strain when tasked with target detection, identification, and marksmanship. The exceptions to this are fatigue, which impairs one's ability to detect targets and to a lesser extent specific aspects of marksmanship seen in the sleep deprivation study. However, attention deficit due to fatigue can be largely reversed with caffeine ingestion. On the other hand, attempts to enhance attention during sentry duty using a secondary task (FAAF in this case) did not succeed.

The first study in this series involved moderate levels of heat and cold exposure that not only failed to demonstrate performance impairment, but actually indicated that certain aspects of marksmanship improved (Tikuisis et al., 2002). This was attributed to a beneficial, albeit discomforting, arousal that promoted task-focusing (Enander and Hygge, 1990). That no degradation in performance occurred was also attributed to thermal strains that were perhaps insufficiently severe according to Ramsey (1995) with regard to the heat exposure, and to Reading et al. (1994) who suggested that suppression of shivering can mitigate poor aim during cold stress. These findings were the impetus for increasing thermal strain in search of a threshold effect.

Objective and subjective measures in the subsequent hot and cold trials confirmed that significantly higher levels of heat and cold strain were achieved than in the previous study. Indeed, only 7 out of the original 11 subjects lasted the 4 h heat exposure, reaching a mean core temperature of 38.8ºC, yet again without any decrement in performance. That the subjects were at or very close to the end of their heat tolerance suggests that any degradation in performance would not likely occur until physiological heat collapse. During the cold exposure trial, core and skin temperatures evoked a noticeable shivering response, but marksmanship was still largely unaffected, which can again be attributed to a conscious suppression of shivering tremor given that engagement times were brief. Indeed, the briefness of target engagement is perhaps the key to the subjects' ability to perform well under thermal strain in contrast to several other reports of degradation involving psychomotor performance of longer duration (eg., Enander, 1987; Epstein et al., 1980). In other words, the subjects were able to surmount their thermal strain and engage targets at or near baseline level performance during the 6 s or less of target detection and engagement periods.

This still leaves open the threshold for marksmanship degradation during cold exposure. Clearly, cold strain must be more severe than finger, hand, and core temperatures of 10, 17, and 36ºC, respectively, attained in the cold study. Yet, to achieve hand/arm incapacitation and/or uncontrollable shivering requires prolonged or very intense exposure to either cold air or immersion in cold water, which must be balanced against the likelihood of such cold strain occurring operationally. Sentry duty and missions that require traversing cold water are possible candidates that might warrant further investigation in this area.

The detection of targets during sentry duty in the cold study displayed an interesting dichotomy unrelated to any actual exposure to cold. Nearly 80% of stationary targets were detected (across all trials) in contrast to only 12% of moving targets. This difference can perhaps be explained by noting that stationary targets were detected relatively early (mean time of 8.5 min) whereas the

moving targets required attention throughout the 1 h sentry duty. It is conceivable that the subjects lost focus/interest soon after the task began, or that the detection of moving targets was more difficult than anticipated (it turned out that the detected moving targets were half as far away as the detected stationary targets). That the stationary targets were detected quickly can also help explain why the secondary task was inconsequential during DUAL, since the first FAAF was administered 15 min after the task began, long after most targets were detected. However, this does not diminish the failure of the FAAF test to improve the detection rate of the moving targets throughout the 1 h task.

While noise did not affect performance, this study recorded an interesting behavioural difference between individual and team efforts. First, individuals increased their target engagement times (during IT and into RT) in an apparent bid to improve hit accuracy, which tended to increase, but not significantly. This shift towards longer engagement times was not surprising given the subjects' training, which emphasized accuracy over speed (i.e., rapid and snap fire skills are acquired only after basic marksmanship is mastered, and even then rapid shooting is calibrated to achieve one shot in about 3 s (SHOOT-TO-LIVE 2000). Yet, when paired with another individual, team engagement time decreased significantly at the cost of accuracy, suggesting that competitiveness trumped training doctrine. Of course, these results were obtained in a 'safe' controlled environment and are subject to validation in theatre.

Neither exercise fatigue nor sleep deprivation caused any serious degradation in target identification and marksmanship (notwithstanding the minor increases in shooting error and shot mean radius due to sleep deprivation). Target engagement time, on the other hand, was delayed by fatigue, which was effectively restored with caffeine ingestion. Further, there was no evidence that caffeine consumption adversely affected marksmanship. These findings concur with other studies that, for example, have demonstrated that 200 - 250 mg of caffeine can be used to enhance cognitive and psychomotor performance (Lieberman, 2001; Rees et al., 1999). Johnson and Merullo (2000) found that 200 mg of caffeine reduced friend-foe discrimination errors and diminished the decrement in target detection time associated with time on the task during sentry duty, while not affecting marksmanship. Similarly, Lieberman et al. (2002) found that the administration of 200 and 300 mg of caffeine did not negatively affect marksmanship in sleep-deprived Navy SEAL Trainees, but did improve their performance of a visual vigilance task.

Not cited thus far in this report was a study conducted by the authors that tested the efficacy of caffeine as an ergogenic aid (i.e., boost to performance) under cold field conditions (Gillingham et al. 2003). Thirteen healthy male subjects lay prone facing pop-up targets 200 m away (similar to the scene shown in Fig. 2.7.1) on a live firing range for about 2.5 h at outdoor temperatures ranging from during two trials, one where 300 mg of caffeine was ingested 1 h prior to one trial and ingestion of a placebo on another that served as control. Subjects were instructed to engage foe targets (25 out of 40) during four 4 min friend/foe discrimination tasks, two at the beginning and two at the end of the trial, and 15 foe targets during four consecutive 30 min vigilance tasks between the friend/foe tasks. Caffeine failed to improve target engagement time compared to placebo, and it neither improved nor degraded friend/foe discrimination and marksmanship. However, engagement time improved (by about 10% from 2.2 to 2.0 s) during the second half of the trials, which was attributed to an arousal effect of cold, but at the expense of shooting accuracy by a similar proportion. It is doubtful that the poorer marksmanship was due to the cold per se given the results of the other cold exposure studies. Instead, insufficient aim time is the likely culprit, although it is not clear why this occurred since the subjects of the other cold

studies engaged their targets at longer times, suggesting that shivering could be suppressed for at least 4 s.

4   Conclusion

These findings involving thermal exposure, noise, physical exertion, and sleep deprivation suggest that marksmanship, which in this case required intense, but short-term focus (i.e., 6 s or less), can be competently managed under significant levels of physiological strain. Still unknown is the threshold for performance degradation due to cold or noise, which would have to be substantially severe beyond the strain documented herein. Fatigue might delay the detection of a target, but not seriously affect its engagement, as if the individual becomes sufficiently aroused and therefore invariant to their state of physiological strain after they have detected a target. This also suggests that it would be naïve to simply extrapolate the negative effects of stressors on psychomotor performance, as reported by others (Enander, 1987; Epstein et al., 1980), to marksmanship. In other words, the effects on performance, or lack of, due to various stressors should be considered task-specific. Further, the reversal of accuracy for speed trade-off witnessed during the noise trial between individual and team engagements suggests a competitiveness characteristic of the latter that might interfere with doctrinal practice.

It would also be prudent to be aware of the absence of the psychological stress of lethal danger when conducting experimental studies as described herein. It is known that the sympathetic nervous system, which is activated under unanticipated imminent threat of deadly force, will compromise vision, cognitive processing, and motor skill performance [ref: L.Col. Grossman, "Psychological Effects of Combat/The Physiology of Close Combat", killology.com/art_psych_combat.htl]. The unresolved question is whether physiological strain due to environmental factors will exacerbate performance under psychological stress, as opposed to not having a substantive influence under non-threatening conditions. This remains to be determined either through well-documented case histories or increasingly realistic simulations.

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
OPI	Office of Primary Interest
R&D	Research & Development
SAT	Small Arms Trainer
ANOVA	Analysis of Variance
SD	Standard Deviation
MR	Mean Radius
HYD	Hydrated
DYD	Dehydrated
T_{co}	Core Temperature
HR	Heart Rate
CN	Control Noise
NO	Noise
FAAF	Four Alternative Auditory Feature
P	Placebo
C	Control
T_{hand}	Hand Temperature
$chgT_{co}$	Change in Core Temperature
IT	Individual Trial
TT	Teams of Two Trial
RT	Reaction Time
TB	Time Blocki

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The advent of high resolution interactive simulation has made it possible to bring greater realism into the laboratory where experimental rigour is more easily controlled than in a field setting. Using a small arms trainer (SAT), the detection, identification, and engagement of targets were tested under a variety of environmentally stressful conditions including heat and cold exposure, noise, fatiguing exercise, and sleep deprivation, with caffeine intervention applied in the latter two trials. Additional investigations on the efficacy of a monetary incentive on individual performance, and on differences between individual and team performances were also conducted during the noise study. Target presentations were randomized and varied from standing pop-ups to moving figures of both foe and friendly types appearing seldom or frequently. Performance was judged according to the number of targets detected, correct target identifications, and marksmanship. Surprisingly, none of the physiological strains caused any serious degradation in performance except fatigue, which adversely affected target detection but not when caffeine was ingested to alleviated the fatigue. Generally, once a target had been detected (with or without fatigue), its engagement, which required intense but short-term focus (i.e., 6 s or less), was competently managed under significant levels of physiological strain, as if the act of detecting a target obviated the strain. The monetary incentive during the noise study failed to improve performance, which validated the use of the SAT in so far as extracting a best effort is concerned. However, an interesting dichotomy emerged during the same study whereby target engagement time increased with time on task during the individual trials in a failed speed vs. accuracy trade-off, yet the opposite occurred during the team trial, which appeared to invoke competitiveness between the subjects. Implications of all the findings are discussed from a military perspective.

L'avènement de la **simulation interactive** haute résolution a permis de faire entrer un plus grand réalisme dans les laboratoires, là où la rigueur expérimentale est plus facilement contrôlée que sur le terrain. À l'aide d'un entraîneur de tir aux armes légères, la détection, l'identification et l'engagement de cibles ont été éprouvés dans diverses conditions environnementales difficiles, dont l'exposition à la chaleur et au froid, le bruit, l'exercice épuisant et la privation de sommeil, avec absorption de caféine dans les deux derniers cas. Des études supplémentaires sur l'efficacité des mesures incitatives financières par rapport au rendement individuel et sur les différences entre le rendement individuel et le rendement de groupe ont également été effectuées pendant l'étude sur le bruit. La présentation de cibles était variée et répartie au hasard, allant des cibles bondissantes aux formes mobiles, de types ennemi et ami, apparaissant rarement ou fréquemment. Le rendement a été évalué selon le nombre de cibles détectées, la bonne identification des cibles et l'adresse au tir. Étonnamment, aucune des contraintes physiologiques n'a causé de sérieuse dégradation du rendement, à l'exception de la fatigue, qui a eu un effet défavorable sur la détection des cibles, sauf en cas d'absorption de caféine afin de surmonter la fatigue. De façon générale, une fois une cible détectée (avec ou sans fatigue), son engagement, qui exige une concentration intense mais de courte durée (six secondes ou moins), était géré avec compétence dans des conditions de contraintes physiologiques importantes, comme si le fait de détecter une cible permettait de parer aux contraintes. Les mesures incitatives financières mises en place pendant l'étude sur le bruit n'ont pas permis d'améliorer le rendement, ce qui a prouvé le bien-fondé de l'utilisation d'un entraîneur de tir à armes légères pour ce qui est de mobiliser l'effort maximum d'un soldat. Cependant, une dichotomie intéressante est ressortie pendant la même étude, alors que le temps d'engagement des cibles a

augmenté avec le temps de la tâche lors des essais individuels, dans une vaine tentative d'échange de vitesse contre de la précision. Pourtant, le contraire s'est produit lors de l'essai en équipe, lequel a semblé réveiller la compétitivité entre les sujets. Les répercussions de toutes les conclusions sont exposées d'un point de vue militaire.

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Heat exposure, cold exposure, performance, fatigue, noise, sleep deprivation, caffeine, small arms shooting

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