International Journal of Industrial Ergonomics 89 (2022) 103295

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

The influence of unpleasant emotional arousal on military performance: An experimental study using auditory stimuli during a shooting task

Leandro L. Di Stasi [a,b,*], Evelyn Gianfranchi [a], Miguel Pérez-García [a], Carolina Diaz-Piedra [a,c,*]

[a] Mind, Brain, and Behavior Research Center-CIMCYC, University of Granada, Campus de Cartuja s/n, 18071, Granada, Spain
[b] Joint Center University of Granada - Spanish Army Training and Doctrine Command, C/ Gran Via de Colon, 48, 18071, Granada, Spain
[c] College of Nursing and Health Innovation, Arizona State University, 550 N. 3rd St., 85004, Phoenix, AZ, USA

ARTICLE INFO

Keywords:
Emotions
Cortisol
Psychophysiology
Thermal imaging
Virtual reality
Marksmanship
Soldiers

ABSTRACT

Due to the intrinsic difficulties associated with simulating extreme events, it remains unclear how unpleasant emotional arousal might affect shooting performance among well-trained high-risk operators. To address this issue, an infantry rifle squad performed two simulated shooting exercises of different complexity (low vs. high) while exposed to unpleasant emotionally charged sound clips. A control group underwent the same experimental procedure without the presence of any sound clips. To externally validate our method of emotional arousal inoculation, we collected infantrymen's salivary cortisol and perceived arousal and valence levels over the experimental phases (*i.e.*, baseline, shooting, and recovery). The dependent variables were their shooting performance (shot-to-hit ratio and instructor's evaluation) and the perceived degree of task complexity. Furthermore, we explored the variations of participants' nasal skin temperature during the shooting exercises. Salivary cortisol concentrations varied over time only for the squad exposed to emotionally charged stimuli. While emotional arousal had an effect on overall infantrymen performance (*e.g.*, precision of movements while shooting), shooting accuracy was not affected. Emotional arousal did not influence nasal skin temperature. Overall, our results suggest that arousal inoculation based on emotionally charged sound clips could serve as a complementary (reliable and ethically appropriate) method to train high-risk operators to deal with emotional arousal. These findings may also contribute to a better understanding of the role of emotional arousal in operational effectiveness.

1. Introduction

The effects of unpleasant emotional arousal, such as experiencing fear or panic, have been long associated to a significant decline in performance (e.g., Easterbrook, 1959; Gradenigo and Gemelli, 1919). In safety-critical environments, such as battlefield scenarios, these effects can be potentially catastrophic (Mujica-Parodi et al., 2004). Indeed, evidence gathered from historical first-hand narrations and post-combat mass interviews (e.g., Marshall, 1947) as well as scientific studies (Gradenigo and Gemelli, 1919; Hamilton et al., 2019) widely shows the deleterious effects of unpleasant emotional arousal on soldiers' performance in life-threatening situations (similar effects are also found in analogous high-risk operators, such as police and security personnel). On a side note, rather anecdotal, after the battle of Gettysburg in the American Civil War, more than 200 of the muzzleloader rifles used were found to have been loaded five or more times without being fired (Walker and Burkhard, 1965; as cited by Baddeley, 1972). Also, during World War II and the Korean conflict, only about 15–25% of the men engaged in firefight fired their weapons at the enemy (Egbert et al., 1957). These examples are just one facet of the more general problem of warfighters' poor performance under highly unpleasant emotional arousal.

Military and law enforcement doctrines have largely relied on training sessions designed to, among other aims, prepare warfighters to preserve optimal performance in any context (see Sanli and Carnahan, 2018 for a review), even under unpleasant emotionally arousing situations. For example, military aircrew members and sailors are specifically trained to deal with unpleasant emotional arousal during life-threating situations (e.g., Helicopter Underwater Escape Training [Hytten, 1989] or the Submarine Escape Training [Van Wijk, 2017]). In the case of the Army, only a selected group of members (e.g., Special Forces [Lieberman et al., 2016]) is specifically schooled on how to enhance

---

* Corresponding authors. Mind, Brain, and Behavior Research Center – CIMCYC, University of Granada, Campus de Cartuja s/n, 18071, Granada, Spain.
E-mail addresses: distasi@ugr.es (L.L. Di Stasi), dipie@ugr.es (C. Diaz-Piedra).

https://doi.org/10.1016/j.ergon.2022.103295
Received 10 October 2021; Received in revised form 2 March 2022; Accepted 7 April 2022

coping and on emotion regulation strategies in highly unpleasant emotionally arousing situations (training in survival, evasion, resistance, and escape [Morgan et al., 2006]). This is mainly due to high costs, as well as safety and ethical reasons (Taverniers et al., 2010). Indeed, to prepare regular high-risk operators to deal with the fear and panic they might experience in engaging scenarios, traditional armed forces trainings are mostly based on simulated (real or virtual) shooting situations, which include exposure to explosions and gunfire (e.g., Giessing et al., 2019; Liu et al., 2018; Nieuwenhuys et al., 2012; Nieuwenhuys and Oudejans, 2010; Oudejans, 2008; Strahler and Ziegert, 2015; Taverniers et al., 2011). However, regular trainings have largely neglected the role of emotional arousal (or other psychological factors) on performance, focusing predominantly on the technical, tactical, and physical aspects (Nieuwenhuys and Oudejans, 2011; Sanli and Carnahan, 2018). Moreover, the trainings that did use emotional arousal present divergent results. That is, shooting performance decrements – independently of shooters expertise – do not always occur as a result of threatening or high-pressure situations (i.e., under unpleasant emotional arousal situations, Giessing et al., 2019; Mosley et al., 2019; Nibbeling et al., 2014). A plausible explanation of the lack of performance degradation due to unpleasant emotional arousal inoculation is that the types of methodologies employed may not have adequately trigger the operator response, being the resulted emotional arousal not comparable to the one experienced during real operations (Di Stasi et al., 2015; Diaz-Piedra et al., 2021; Nibbeling et al., 2014). Thus, complementary, reliable, ethically appropriate, and standardized methods to emotional arousal inoculation are worth to be investigated.

In non-military fields, such as driving or maritime safety, emotional arousal inoculation is often obtained by exposing operators to emotionally charged stimuli, such as specific sound clips (Di Stasi et al., 2010; Fairclough et al., 2014; Fan et al., 2018; Pêcher et al., 2009; Serrano et al., 2014). Results concur on reporting that operating under the effects of highly unpleasant emotional arousal impairs operational safety and performance (e.g., Fan et al., 2018; Serrano et al., 2014). For example, the exposure to short and standardized emotionally charged sounds (International Affective Digitized Sounds [IADS, Bradley and Lang, 1999]) would modulate motor behavior (e.g., motorcycle braking maneuvers; Di Stasi et al., 2010) and some decision-making aspects (e.g., switching on navigation lights in restricted visibility conditions; Fan et al., 2018). Overall, emotionally charged stimuli have been validated and employed mainly in experimental studies among civilian populations (e.g., Gerdes et al., 2014; Libkuman et al., 2007). Because military training and combat exposure have been linked with lower perceived arousal when exposed to emotionally charged stimuli (Goodman et al., 2016), the question of whether emotionally charged sound clips might be a complementary method to actually inoculate emotional arousal and therefore train warfighters more efficiently remains open.

Shooting behavior is considered crucial to military performance in high-achievement settings (Nibbeling et al., 2014). Moreover, a better understanding of unpleasant emotional arousal effects on shooting performance might allow enhancing operational effectiveness (Diaper et al., 2013; Livingston-Booth et al., 1985) by developing coping and emotion regulation strategies. Therefore, here we investigated if training under unpleasant emotionally arousing circumstances – i.e., shooting at a target while presented with negative emotionally charged sound clips – would affect shooting behavior among Spanish Army infantrymen. Two infantry rifle squads (i.e., experimental group *vs.* control group) were evaluated when performing two shooting exercises of different complexity (low *vs.* high) using a rifle simulator. To externally validate our method of unpleasant emotional arousal inoculation, we collected participants' salivary cortisol and subjective ratings of arousal levels (Hellhammer et al., 2009; Pallavicini et al., 2016) across three experimental phases (i.e., baseline, shooting, and recovery). We also recorded shooting accuracy (shot-to-hit ratio), the instructor's assessments of performance, as well as participants' subjective ratings of exercise complexity and fatigue. Finally, facial skin temperature during the shooting exercises was recorded. Because facial skin temperature has been recently proved to be sensitive to emotional arousal and task complexity (Abdelrahman et al., 2017; Kosonogov et al., 2017), we considered worth to investigate this variable here. Therefore, we explored the variations of participants' nasal skin temperature during the shooting exercises. Our main hypothesis was that the emotionally charged sound clips would have been sufficient to inoculate an unpleasant emotional arousal, and, consequently, this manipulation would have deteriorated shooting accuracy and performance independently from the complexity of the exercises.

2. Material and methods

Ethical approval

The study was conducted in conformity with the Code of Ethics of the World Medical Association (Declaration of Helsinki - WMA, 2008). The experiment was carried out under the guidelines of the University of Granada's Institutional Review Board (IRB approval #985/CEIH/2019).

2.1. Participants

Twenty-six full-time professional infantrymen from the Spanish Army (25 non-commissioned officers and one lieutenant, all with active duty status) took part in the study. All participants were male with a mean age of 25.81 years (standard deviation [SD] = 3.07; range 21–31), a mean body mass index of 24.02 (SD = 3.01; range 19–33), and a normal or corrected-to-normal vision. They were members of the 2nd Infantry Regiment "La Reina" of the 10th Mechanized Infantry Brigade Guzmán el Bueno, Spanish Army (Cerro Muriano, Cordoba, Spain).

Participants were instructed not to drink alcohol during the 12 h preceding the experiment and not to drink caffeine-based beverages or eat anything during the previous 2 h. Also, smoker participants ($n = 9$) were asked not to smoke for, at least, a 30-min period immediately preceding the experiment.

For screening purposes, we measured subjective levels of arousal at the beginning of the experiment using the Stanford Sleepiness Scale (SSS; Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973). The SSS consists of one question about alertness at a given moment. Participants must rate their degree of alertness/sleepiness from "Feeling active, vital, alert, or wide awake" (score 1) to "No longer fighting sleep, sleep onset soon, having dream-like thoughts" (score 7), choosing one out of seven statements. None of the participants scored more than 3, which means they had an optimal level of alertness (Diaz-Piedra et al., 2022).

2.2. Experimental design

The overall study followed a 2 × 2 mixed factorial design, with unpleasant emotionally induced arousal as the between-participants variable (emotionally induced arousal [experimental] group *vs.* control group), and exercise complexity (low *vs.* high complexity shooting exercises) as the within-participants variable. The dependent variables were shooting accuracy (shot-to-hit ratio), shooting performance (instructor assessment), and soldiers' subjective ratings of exercise complexity. Furthermore, soldiers' nasal skin temperature variations during the shooting exercises (see *2.7 Thermographic recordings* section) were considered as a secondary dependent variable.

To validate our method of emotional arousal inoculation, we collected participants' salivary cortisol and perceived levels of arousal and valence along the experiment (different measuring time points preceding, during, and following the shooting exercises, see Fig. 1). Perceived levels of fatigue were also measured along the experiment.

Trying to minimize the occurrence of an end-spurt effect-reactivation – that may happen when people know they are approaching the end of a task (Bergum and Lehr, 1963) – participants were kept blind about the

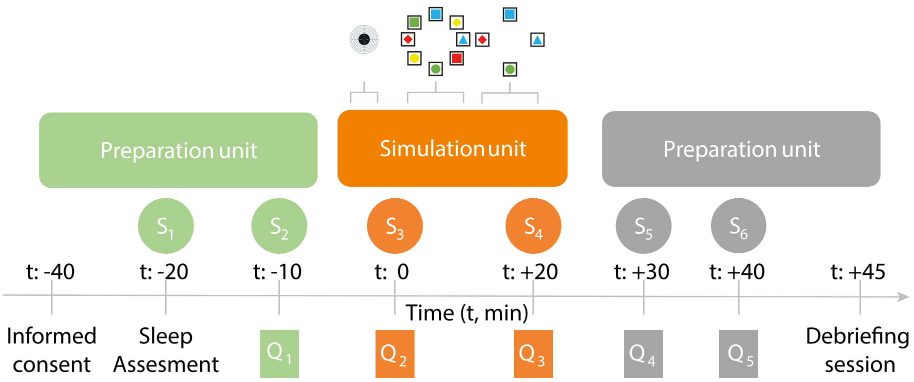

Fig. 1. Experimental procedure overview. The experimental procedure included the baseline, shooting, and recovery phases. Both the baseline and recovery phases took place in the preparation unit, while the shooting phase (i.e., shooting exercises) took part in the simulation unit. Green-colored elements belong to the baseline phase, orange-colored elements to the shooting phase, and gray-colored elements to the recovery phase. Time (t, in minutes) is relative to the onset of the rifle calibration inside the simulation unit. After the first 20 min from the arrival of the participant (i.e., acclimation period), the first saliva sample (S) was collected (S_1). Then, after 10 min the second sample of saliva was collected (S_2). During the shooting phase, after the rifle calibration, the first shooting exercise started. Before starting the first shooting exercise, and after finishing the second one, two samples were collected (S_3 and S_4). Finally, the last two samples (S_5 and S_6) were collected during the recovery period. The length of the recovery period was about 25 min and it included the post-experimental debriefing session. Throughout the three phases, several questionnaires [Q] were administered. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

real duration of the experiment (∼1 h), being instead told that it would have last for ∼2 h, during which they were going to perform a shooting session. Also, in order to avoid diurnal fluctuations that could affect arousal levels (Río-Bermudez, Díaz-Piedra, Catena, Buela-Casal, & Di Stasi, 2014), the experimental protocol was always carried out during the mornings, along different days.

2.3. *Emotionally charged sound clips*

The experiment was conducted following a classical bi-dimensional view of emotions' features, which assumes that emotions can be defined by means of two main dimensions, namely valence and arousal, with valence describing the range from "sad" to "happy" emotions; and arousal from "low activated" vs. "high activated" states (Bradley and Lang, 2000). Thus, we selected 30 highly arousing 6-s sound clips with low valence from the IADS (Bradley and Lang, 2007; # 105; 115; 116; 244; 260; 261; 275; 276; 277; 278; 279; 284; 285; 286; 288; 289; 290; 292; 420; 422; 424; 501; 502; 600; 624; 709; 711; 712; 714; 719). All the selected sound clips have an arousal level higher than 6 (with a mean of 7.03 on a scale of 1–9, with 1 being calming or soothing and 9 being agitating or exciting) and a valence level lower than 3.5 (with a mean of 2.66 on a scale of 1–9, with 1 being highly negative and 9 being highly positive), as reported in the original IADS-2 validation for male participants (Bradley and Lang, 2007). The sound clips refer –among other things– to battlefield (e.g., gunshot [# 289], air raid [# 624]), to human negative reactions (e.g., female scream [# 276; # 277], baby cry [# 261]), to road traffic stressing situations (e.g., car wreck [# 424], siren [# 711; # 714]), and to other general stressing situations (e.g., dentist drill [# 719], plane crash [# 501]). This selection should guarantee the elicitation of unpleasant emotional arousal (Bergman et al., 2016). The sounds were presented in a loop during the shooting exercises (∼20 min, for the emotionally induced arousal group), following a full randomized order, ensuring that each sound was presented approximately six times for each participant.

2.4. *Rifle simulator and shooting exercises*

The participants performed a shooting session using the Assault Rifle Simulator (Victrix, Indra S.A., Alcobendas, Spain; henceforth, the shooting simulator; see Fig. 2A). It simulates all the aspects of an army marksmanship training through a virtual reproduction of a shooting range. It is controlled by an instructor at the operating station, located behind the shooting range.

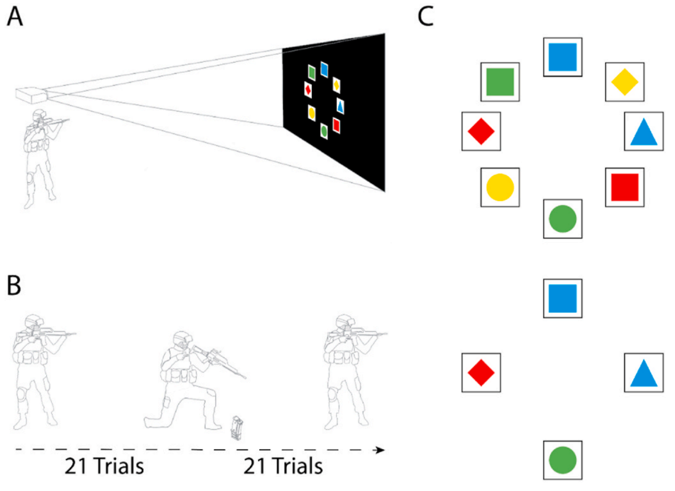

Fig. 2. Rifle simulator and shooting exercises. A) The rifle simulator setting. The projection was presented on a large-format flat screen (wall, 9 × 2.5 m [m]) and the distance between the shooter and the screen was ∼7.5–8 m. We asked the shooter to stand in the middle of a demarcated perimeter of 1.2 × 1.9 m. **B)** Shooting exercises. After loading, the shooter was standing and waiting for the instructions (synthetized voice). Then, he got into position, took the rifle off of safe and fired. After 21 trials, the exercise stopped, giving time to reload the rifle, and, then, it re-started. **C)** The exercise involved firing at multiple dispersed colored 2D geometric figures. Each trial included a different number of distractor figures, depending on the level of complexity (low *vs.* high exercise complexity). For the low complexity exercise (lower panel), the number of distractor figures varied between 2 and 4. For the high complexity exercise, the number varied between 5 and 7 (upper panel). In both cases, only one target figure was presented. The figures could be colored in blue, yellow, red, or green. Their geometric shapes could be a triangle, a circle, a diamond, or a square. For each trial, the color and shape of the figures were randomly matched and presented: any color might be associated to any figure. All figures were presented inside a white square of 0.2 × 0.2 m over a projected black screen. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

The shooting phase lasted ∼ 20 min and consisted of a rifle calibration session and two exercises with different complexity (low *vs.* high exercise complexity, see below). The length of the session and the inclusion of two complexity conditions were chosen in order to mitigate the influence of fatigue (Di Stasi et al., 2016). The exercises resembled those performed by foot soldiers in their everyday military training. Each exercise started with a guiding voice providing instructions regarding the target to shoot at (see Fig. 2C). A 3D-surround digital sound system ensured to the soldier a "total immersion", providing the guiding voice and including the emotionally charged sounds presentation. Once identified the best volume settings to ensure an optimize hearing of the guiding voice over the emotionally charged sounds, the volume settings were kept stable.

Each shooting exercise included 42 trials and, for each trial, only one shot was allowed. Each trial consisted of a set of animated geometrical figures projected on the screen (wall, see Fig. 2C). The animation started from the center of the screen (being all figures superimposed) and expanded up to reaching a maximum distance of 0.55 m (radio) from the center. The maximum time for shooting at the target (i.e., the figure indicated by the guiding voice, once the figures were all still) was set at 2 s. For each set of figures, there was only one target. The expansion time (i.e., the time intercurrent between the moment of appearance of the figures in the center and the moment in which they reach the maximum distance) and the total number of figures displayed were different depending on the complexity of the exercise (low *vs.* high). The high complexity exercise presented 6 to 8 figures (including the target) during an expansion time of 1.5 s. The low complexity exercise presented 3 to 5 figures (including the target) during an expansion time of 3.0 s. The sequence of shooting exercises (low *vs.* high complexity) was randomized across participants to minimized task-switching costs (i.e., the costs associated with going from a complex exercise to an easy one).

2.5. *Salivary cortisol collection and analysis*

Salivary cortisol was collected six times in sampling tubes with cotton swabs (Salivette®; Sarstedt, Leicester, UK). Participants had to keep the cotton swab in their mouth for 2 min, following the manufacturer's instructions. The baseline phase included two saliva sample collections after 20 and 30 min from the arrival. The shooting phase included one sample collection after the rifle calibration (0 min), and one after the two exercises (+20 min). Finally, the recovery phase included two saliva sample collections, 10 and 20 min after the end of the last shooting exercise. Each saliva sample was immediately stored at −30 °C right after being collected. We obtained salivary cortisol levels using an enzyme-linked immunosorbent assay (ELISA; Cooper et al., 1989). Cortisol level are expressed as nmol/L.

2.6. *Thermographic recordings and analysis*

For the thermographic recording, we used the ThermoVision A325sc Researcher Infrared Camera (FLIR Systems, Nashua, NH, USA). The camera (320 × 240 pixels resolution, 30 Hz) was placed on a tripod 1.4 m above the floor and ~2.2 m from the participants' faces (angle ~ 45°). For each participant, we slightly adjusted its position to better capture his face. The automatic focus option of the camera was always employed to focus the image recording. We stored the recorded signal using the program Researcher TermaCAMP 2.9 (FLIR Systems, Nashua, NH, USA).

We selected the middle of the nasal tip (Diaz-Piedra et al., 2019a) as the main relevant point (pixel) of interest (POI). To avoid any differences induced by body movements when rising the rifle – from a steady to a shooting position – we selected, for each of the 42 trials, the thermogram just before raising of the rifle. Furthermore, to control for possible room temperature changes, we selected other two POIs on the wall/structures behind the soldiers. The coordinates for these POIs were kept constant within the recording sessions. The analyses of these temperatures confirm that inside the simulation unit the temperature was kept stable across the experimental sessions (data not shown).

Two researchers, not involved in the data collection and blind about the manipulation, inspected the videos produced by the thermographic camera and manually annotated the temperature for each POI and participant every 50 frames. The intraclass correlation coefficient (ICC) estimate for the tip of the nose was 0.970 [95% C.I. 0.911–0.985], which indicates excellent reliability between researchers. For the statistical analyses, we used the mean value of two researchers and its variance.

2.7. *Questionnaires*

At the beginning of the experimental procedure (see Fig. 1), participants completed a set of questionnaires in order to collect sociodemographic (e.g., age, sex, hand dominance), health (e.g., eyes or hear impairments, sleep problems, medications alcohol and nicotine use), and work-related information (e.g., regimental affiliation, experience with the simulator, past participation to abroad military missions).

Because sleep patterns can influence arousal, an extensive screening of sleep parameters was conducted. Beside the SSS (see 2.2. *Participants* section), all the participants filled in the Spanish versions of the Pittsburgh Sleep Quality Index (PSQI; Royuela and Macías, 1997), the Epworth Sleepiness Scale (ESS; Ferrer et al., 1999), and the reduced version of the Morningness-Eveningness Questionnaire (MEQr; Adan and Almirall, 1991). The **PSQI** assesses participants' sleep quality across 19 items combined to form seven score areas, each with a 0–3 point range, leading to a 0–21 point global score, with 0 indicating "no sleep difficulty" and 21 "severe sleep difficulty". The **ESS** assesses daytime sleepiness levels through eight items with a four-point scale (0–3 range). It investigates the self-report chance to doze in different situations (e.g., while watching TV, as a passenger in a car), leading to a score that ranges from 0 to 24, with higher values indicating higher levels of daytime sleepiness. The **MEQr** includes five items investigating the participants' chronotype as a function of their self-report preference for time of day. The total score ranges from 4 ("definitely evening type") to 25 ("definitely morning type"). In addition, we administered the Peace or Life Balance Questionnaire (CPEV), a 69-item questionnaire (De la Rubia, Medina, & Bravo, 2011) that investigates the participants' overall quality of life. We administered this long screening tool in order to maintain a consistent basis within and between participants during the saliva samples collection times in the preparation room (see Fig. 2). Data collected from the CPEV have not been analyzed.

Across five measuring times (starting from the 2nd saliva sample collection, see Fig. 1), each participant filled in the Borg Rating of Perceived Exertion scale (BORG; Borg, 1998) and the Self-Assessment-Manikin arousal and valence scales (SAM) (Lang, 1980). The **BORG** indicates the perceived levels of fatigue associated with a task. It consists of a numerical scale (ranging from 6 to 20) anchored by "no exertion at all" (score 6) to "maximal exertion" (score 20). The **SAM** scale**s** ask participants to describe their emotional state, rating both the perceived levels of arousal and valence using two 9-point scales (with 1 indicating the lowest activated/sad, and 9 the highest activated/happy).

Finally, after performing each shooting exercise, participants filled in the NASA-Task Load Index (NASA-TLX; Hart and Staveland, 1988). The **NASA-TLX** was used as a global index of the perceived degree of task complexity (Diaz-Piedra et al., 2020). Its values range between 0 and 100, with higher values indicating higher task complexity. At the same time, the range shooting instructor used a modified version of the **operative rating scale** (Grantcharov et al., 2004) to evaluate the soldier's shooting performance, with scores ranging from 1 (better performance) to 15 (worse performance). This scale was adapted to only focus on psychomotor skills, procedures, and movements showed during the exercise. Thus, the instructor assessed shooting participants' performance as the amount of incorrect and/or unnecessary movements/procedures (*i.e.*, errors) exhibited during each exercise (Diaz-Piedra et al., 2021).

2.8. *Procedure*

The experiment took place at the Spanish Army base home of 10th Mechanized Infantry Brigade "Guzmán el Bueno" (Cerro Muriano, Cordoba, Spain). The facility used for this study consists of two adjacent rooms connected by a windowless corridor: the preparation unit and the simulation unit. The transition from the preparation unit (lighted room) to the simulation unit (i.e., the shooting range, a darkened room where the only light was provided by the projected image on the wall) was made through a connecting dimly lit corridor. The simulation unit was hidden behind two closed doors.

All participants were asked to wear their standard camouflage uniform, including boots, tactical fighting load carriers, body armor, shackles, and a backpack with 12 kg to simulate the equivalent weight of a standard march. Once in the simulator facilities, they received a simulated Heckler & Koch G36 rifle (including the rifle loader). The total load (including the rifle) was up to ~ 30 kg.

Upon their arrival to the preparation unit, once the participants signed the informed consent form, they received a short briefing on the study. After approximately 20 min (acclimation period), the first saliva sample was collected. During this period, we collected sociodemographic, health, and work-related information, as well as sleep data (see *2.8 Questionnaires* section). After another 10 min, another saliva sample was taken and participants were asked to fill in, in this order, the BORG and SAM arousal and valence scales.

Approximately 40 min after their arrival, the participants were conducted to the simulation unit and the thermographic camera was turned on to allow for its sensor to be stabilized. Then, the rifle range instructor (a First Sargent, the same for all the shooting sessions) gave to each participant a pre-exercise briefing about the simulated shooting exercises. First, he asked participants to perform a rifle calibration procedure. The procedure consisted in two rounds of 5 shoots each, to allow the participant to see and feel the behavior of the rifle (see Fig. 1). Afterwards, the rifle range instructor instructed the participants on how to execute the shooting exercises: they had to hold a standing firing position and to perform instinctive shooting (one shoot per trial, see below). Furthermore, they were asked to perform so-called tactical (e.g., kneeling unsupported position) unloading and loading procedures. For each shooting exercise, participants performed one tactical unloading/load procedure. The same rifle range instructor assessed each soldier's performance as the percentage of correct required movements/procedures that were executed during each exercise.

Before starting the shooting exercise, the participants filled in the BORG and SAM scales, and the third sample of saliva was collected. Then, we calibrated the thermographic camera, and the first exercise started. Once the first shooting exercise finished, participants filled in the NASA-TLX. Then, the second shooting exercise started. Once finished, participants filled again in the NASA-TLX, the BORG and SAM scales (in this order), and the fourth (out of six) saliva sample was collected. Then, we drove the participant again to the preparation unit. After 10 min, the fifth saliva sample was collected and participants filled in again the BORG and SAM scales. Approximately 20 min from the end of the second shooting exercise, the last sample of saliva was collected and the participants filled in the BORG and SAM scales. After that, the participants underwent a post-experimental debriefing session and, at this point, they were free to leave the shooting simulator facilities. All participants had the order to not share the contents of the experiment with their colleagues.

To sum up, the experiment was carried out according to the following sequence (see Fig. 1):

- **Baseline phase (2 saliva samples):** The participant entered the preparation unit and, after approximately 20 min (acclimation period), the first saliva sample was collected. After 10 min, another sample of saliva was taken. The overall baseline phase lasted 30 min (Allen et al., 2014). Up to this point all participants had gone through the same experimental conditions. Then, each participant was randomly assigned to one out of two groups (emotionally induced arousal [experimental] *vs.* control group).
- **Shooting phase (2 saliva samples):** The participant was led into the simulation unit. The transfer procedures were standardized for all participants. For the experimental group, the emotionally charged sound clips were already playing once they arrived at the simulation unit. All the participants were told that, after the rifle calibration phase, they were going to perform several exercises under the supervision of a shooting instructor. Here, we collected two samples of saliva, one after the rifle calibration (+10 min from the second sample collected during the baseline phase) and another at the end of the shooting (+20 min).
- **Recovery phase (2 saliva samples):** The participant was led back to the preparation unit to recover. Ten and 20 min after the shooting phase was finished, we collected saliva samples and the participant completed again the BORG and SAM scales. The last step was the post-experimental debriefing session.

2.9. *Statistical analysis*

Given the reduced sample size, the non-continuous nature of some of our dependent variables (such as the operative rating and the SAM scales), and after checking that our data set violated one or more of the assumptions of parametric statistics (*i.e.*, normality of the residual [by performing Q-Q Plots], the sphericity [by performing Mauchly's Tests] and the homogeneity of variances [by performing Levene's tests]), we selected a non-parametric approach for the statistical analysis (DePoy and Gitlin, 2016; Di Stasi et al., 2011). Thus, to examine the overall effectiveness of the unpleasant emotional arousal inoculation, we analyzed infantrymen' salivary cortisol concentrations along the experimental phases (6 measurement times, three preceding and three following the shooting exercises) and their responses at the SAM-arousal and valence scales, BORG-scale (5 measurement times, two preceding and three following the shooting exercises) using a repeated measures Friedman-ANOVA on ranks, considering as the within-subject repeated factor the respective measurement time (one test for each group: emotionally induced arousal group and control group). For multiple comparisons, we used Wilcoxon matched-pairs tests, performing the Bonferroni alpha-inflation correction. Values of cortisol concentrations were transformed using Box–Cox power transformation for time series, $X' = (X^{0.26}–1)/0.26$ (Miller and Plessow, 2012).

Once the effectiveness of the emotional arousal manipulation was confirmed, we performed two separate analyses, considering independently group and exercise complexity, to examine the effects of the unpleasant emotional arousal inoculation (emotionally induced arousal group *vs.* control group) and the exercise complexity (low vs. high) on the main dependent variables (shooting accuracy and shooting performance, NASA-TLX scores, as well as the nasal skin temperature variations). To assess the effect of unpleasant emotional arousal inoculation, we performed Mann-Whitney U tests (*i.e.,* independently from the exercise complexity). To assess the effect of exercise complexity, we performed separate Wilcoxon matched-pairs tests (i.e., independently from the groups). Finally, we performed independent Mann-Whitney U tests to assess if the total sleep time, sleep debt (ESS), as well as the perceived participants' sleep quality (PSQI) differed between the two groups.

For the sake of clarity and simplicity, while the following tables report the mean, median, and standard deviation (SD) values, Fig. 3 displays only the mean and the standard error of the mean (SME) values. Significance levels were set at $p < 0.05$.

3. Results

3.1. *Effectiveness of the emotional arousal manipulation*

Only the presence of emotionally arousing sound clips influenced salivary cortisol concentrations along the measurement times, $\chi^2_{Fexp}(5) = 11.32$, $p = 0.045$ (Fig. 3A). That is, cortisol median values were statistically different along the six measurement times (Table 1). Furthermore, as expected, for the emotionally induced arousal group, salivary cortisol concentrations increased following the shooting exercises, measurement time 4_{exp} *vs.* measurement time 5_{exp}, $T = 20$; $Z = 2.04$, $p = 0.040$ (Fig. 3A and Table 1). Nevertheless, this difference was no longer significant after Bonferroni correction.

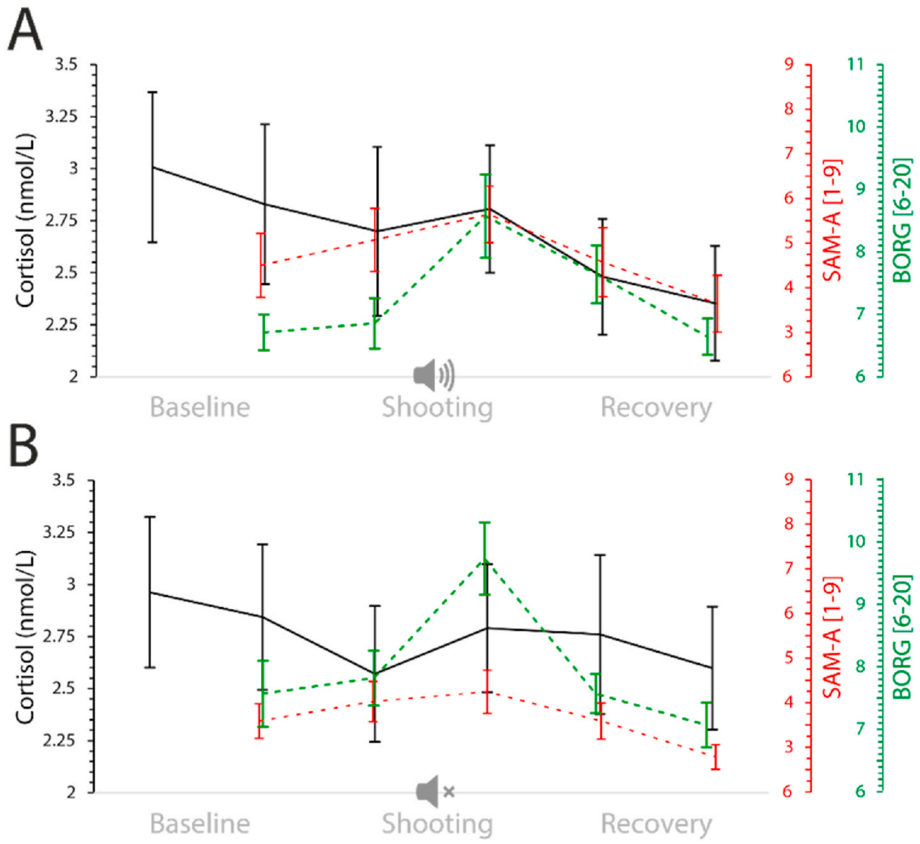

Fig. 3. Effects of emotional arousal on salivary cortisol concentrations, perceived levels of arousal and fatigue over the three experimental phases (baseline [measurement times **1–2**]**, shooting** [measurement times **3–4**]**, and recovery** [measurement times **5–6**] **). A)** The experimental group ($n = 14$) underwent the shooting phase (rifle calibration and two shooting exercises) while unpleasant emotionally charged sound clips were displayed. **B)** The control group ($n = 12$) underwent the same conditions of the experimental group with the exception that no emotionally charged sound clips were displayed during the shooting phase. **A, B)** The black line represents the mean salivary cortisol levels (Box-Cox transformed data) over the three experimental phases (six measurement times). The dotted red line represents the mean perceived levels of arousal over the three experimental phases (five measurement times). Finally, the dotted green line represents the mean perceived levels of fatigue over the three experimental phases (five measurement times). Error bars represent the SEM across participants. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1

Mean, median, and standard deviations (SD) of the salivary cortisol concentrations (Box-Cox transformed data), perceived levels of arousal, valence, and fatigue over of the three experimental phases (baseline, shooting, and recovery: six measuring times [MTs]) for the experimental ($n = 14$) and control ($n = 12$) groups.

		Baseline		Shooting		Recovery	
		MT1	MT2	MT3	MT4	MT5	MT6
		Mean; *Median* (SD)					
Cortisol [nmol/L]	Experimental	3.01; *2.71* (1.35)	2.83; *2.67* (1.44)	2.70; *2.21* (1.52)	2.81;*2.67* (1.15)	2.48;*2.73* (1.04)	2.35; *2.27* (1.03)
	Control	2.96; *2.61* (1.25)	2.84; *2.66* (1.21)	2.57; *2.08* (1.13)	2.79; *2.48* (1.07)	2.76; *2.56* 1(1.32)	2.60; *2.56* (1.02)
Arousal rating [1–9]	Experimental	–	4.50; *4.50* (2.68)	5.07; *5.50* (2.64)	5.64; *6.00* (2.37)	4.57; *4.00* (2.90)	3.64; *3.00* (2.37)
	Control	–	2.83; *2.50* (1.53)	3.33; *3.50* (1.78)	3.58; *3.50* (1.93)	2.83; *2.00* (1.59)	1.92; *2.00* (1.08)
Valence rating [1–9]	Experimental	–	7.64; *8.00* (1.22)	7.79; *8.00* (1.25)	7.86; *8.00* (1.23)	7.57; *8.00* (1.50)	7.71; *8.00* (1.33)
	Control	–	7.25; *7.00* (0.87)	7.17; *7.00* (0.72)	6.75; *7.00* (1.14)	7.00; *7.00* (1.13)	7.42; *8.00* (1.08)
BORG [6–20]	Experimental	–	6.71; *6.00* (1.07)	6.86; *6.00* (1.51)	8.57; *8.50* (2.50)	7.64; *7.00* (1.74)	6.64; *6.00* (1.08)
	Control	–	7.58; *7.00* (1.83)	7.83; *7.00* (1.53)	9.75; *9.00* (2.01)	7.58; *7.00* (1.08)	7.08; *7.00* (1.24)

For the control group, there were no significant differences in cortisol median values along the measurement times, $\chi^2_{Fcontrol}(5) = 4.09$ $p = 0.535$ (Fig. 3B and Table 1).

Independently from the presence of emotionally arousing sound clips, infantrymen' perceived levels of arousal (SAM-arousal) changed along the measurement times, $\chi^2_{Fexp}(4) = 18.68$, $p < 0.001$; $\chi^2_{Fcontrol}(4) = 15.39$, $p = 0.004$ (Fig. 3 and Table 1), reaching its peak following the shooting exercises (measurement time 4), minimum Z-value = 2.66, all p-values < 0.05, after Bonferroni correction. Similarly, infantrymen' perceived levels of fatigue (Borg-scale) changed across the measurement times, $\chi^2_{Fexp}(4) = 28.40$, $p < 0.001$; $\chi^2_{Fcontrol}(4) = 16.95$, $p = 0.002$ (Fig. 3 and Table 1), reaching its peak following the shooting exercises (measurement time 4), minimum Z-value = 2.70, all p-values < 0.05, after Bonferroni correction. Finally, both experimental and control groups reported stable valence (SAM-valence) levels along the measurement times, $\chi^2_{Fexp}(4) = 7.692$, $p = 0.103$; $\chi^2_{Fcontrol}(4) = 8.46$, $p = 0.076$ (Table 1). Overall, the presence of emotionally arousing sound clips (experimental group) and carrying out the shooting exercises (experimental and control group) had an effect on the participants' arousal levels (both physiological and perceived, experimental group; only perceived, control group).

3.2. *The effect of emotional arousal inoculation and exercise complexity on shooting accuracy (shot-to-hit ratio) and performance, perceived exercise complexity and nasal skin temperature*

While overall shooting accuracy (shot-to-hit ratio) was similar between the groups, $U = 69$; $Z = 0.77$, $p = 0.440$, shooting performance (as measured by the soldier's operative rating scale) differed between them, $U = 39.5$; $Z = 2.28$, $p = 0.022$. That is, the presence of unpleasant emotionally arousing sound clips induced the infantrymen to make more errors (i.e., incorrect and unnecessary movements/procedures) during the overall shooting exercises without compromising accuracy, however. Furthermore, although shooting accuracy (shot-to-hit ratio), for both groups, was worse during the most complex exercise, $T = 40.5$; $Z = 2.19$, $p = 0.028$, exercise complexity did not influence shooting performance, $T_{exp} = 17$; $Z_{exp} = 1.42$, $p_{exp} = 0.150$; $T_{\text{control}} = 5.5$; $Z_{\text{control}} = 1.750$, $p_{\text{control}} = 0.080$.

Perceived shooting complexity, as measured by NASA-TLX scores, was similar between groups, $U = 64$; $Z = 1.028$, $p = 0.303$ (Table 2). However, as expected, the most complex exercise was perceived as the most difficult one, $T = 76.5$; $Z = 2.51$, $p = 0.011$.

Finally, nasal skin temperature (mean [M] and variance [v]) did not differ between the groups, $U_M = 80$; $Z_M = 0.205$, $p_v = 0.83$; $U_v = 63$; $Z_v = 1.080$, $p_v = 0.280$ (Table 2). However, while mean nasal skin temperature was not affected by the complexity of the exercises, $T_M = 167$; $Z_M = 0.215$, $p_M = 0.829$, it was less stable during the low complexity exercise, $T_v = 94$; $Z_v = 2.069$, $p_v = 0.038$.

3.3. *Sleep parameters*

There were no differences in the median ESS score and the PSQI global score between the two groups (all *p-values* > 0.05, Table 3). Also, groups did not differ in the median total sleep time the night before the experiment ($p > 0.05$, Table 3). Overall, the median values for both groups were not statistically different. The distribution of morningness/eveningness preference (**MEQr**) was also similar ($p > 0.05$), with most participants being “neither type” (60%) or “moderately morning type” (36%). Thus, both groups showed similar characteristics of sleep patterns and habits, minimizing differences in cortisol, arousal, as well as fatigue variations.

4. Discussion

Our aim was to explore warfighters’ psychophysiological and behavioral responses to a shooting simulation under unpleasant emotional arousal elicited by sound clips. At the beginning of the 20th century, Italian researchers already used pistol shots, automobile claxons, and explosions of firecrackers as emotionally charged stimuli to study emotional arousal changes in flying cadets (Gradenigo and Gemelli, 1919). Since these pioneering studies, new methods, more reliable and standardized, such as the one used in this work (IADS; Bradley & Lang, 1999), seem a good alternative to arouse military personnel during training (e.g., Yang et al., 2018). Although training sessions usually focus on the technical, tactical, and physical aspects of performance and have largely neglected the role of psychological factors such as emotional arousal (e.g., Nieuwenhuys and Oudejans, 2011; Paul et al., 2015), there has been progressively more interest in training sessions that are designed in such a way that they expose warfighters to arousal levels sufficient to activate their psychological and biological coping mechanisms. Always, without overwhelming warfighters beyond the possibility of recovery (Lin et al., 2019).

Table 2
The effects of emotional arousal inoculation and exercise complexity on the dependent variables. Mean, median, and standard deviations (SD) of the shooting accuracy and performance, perceived shooting complexity, and nasal skin temperature for the experimental ($n = 14$) and control ($n = 12$) groups.

	Experimental group		Control group	
	Exercise complexity			
	Low	High	Low	High
	Mean; *Median* (SD)			
Accuracy [shot-to-hit ratio]	0.84; *0.89* (0.12)	0.70; *0.70* (0.14)	0.90; *0.92* (0.08)	0.73; *0.77* (0.15)
Performance [0–15 errors]	8.21; *8.00* (1.93)	9.00; *9.50* (1.81)	5.83; *4.50* (2.51)	6.75; *5.50* (2.65)
NASA-TLX [0–100]	39.40; *38.33* (12.82)	44.88; *42.91* (18.16)	41.46; *43.75* (15.15)	52.29; *53.33* (16.38)
Temperature [C°, mean]	20.57; *20.21* (1.38)	20.53; *20.22* (1.41)	20.78; *20.04* (2.32)	20.80; *20.45* (1.96)
Temperature [C°, variance]	0.10; *0.07* (0.12)	0.06; *0.04* (0.04)	0.11; *0.09* (0.08)	0.08; *0.07* (0.05)

Table 3
Mean, median, and standard deviations (SD) of the scores of the Epworth Sleepiness Scale (ESS), the Pittsburgh Sleep Quality Index (PSQI), and total sleep time (TST) the night before the experiment for both the experimental ($n = 14$) and the control ($n = 12$) groups.

	Experimental	Control
	Mean; *Median* (SD)	
ESS scores, 0–24	5.14; *5.00* (3.03)	7.81; *7.66* (3.45)
PSQI scores, 0–21	4.64; *5.00* (1.86)	5.36; *5.00* (1.69)
TST, hours	6.80; *7.00* (0.41)	6.63; *6.75* (0.63)

4.1. *Effectiveness of the emotional arousal manipulation*

We examined the effects of unpleasant emotional arousal inoculation on infantrymen’ salivary cortisol concentrations and subjective levels of arousal, fatigue, and pleasantness over the three experimental phases (baseline, shooting, and recovery).

Salivary cortisol concentrations indicated a successful manipulation of emotional arousal, as trends were different between the experimental and the control group. Only for the experimental group, under unpleasant emotional arousal, a significant time effect was observed, with the highest values of cortisol concentrations at the beginning of the experiment and steadily decreasing values thereafter. Similar results were found in several studies run with law enforcement officers and recruits exposed to mock training sessions that simulated either school shooting (Strahler and Ziegert, 2015), or real-life, critical incidents (Arble et al., 2019; Giessing et al., 2019). On the other hand, cortisol concentrations were stable in the control group, with no significant differences over time. Overall, these results seem to strengthen the validity of this biomarker to monitor arousal variations, as previously reported for civil (Park et al., 2020) and military (Taverniers and Suss, 2019) shooters, as well as for other populations (e.g., navy officers, Balters et al., 2020; medical staff; Lai et al., 2014), although with some limitations. Indeed, the decrease of the cortisol levels in the shooting phase for the participants in the experimental group, as compared to the baseline concentrations, might seem counterintuitive. A plausible explanation, might account for this effect. The military training received by the participants may have indirectly influenced their physiological response to the stimuli (Gifford et al., 2019; Strahler and Ziegert, 2015). Indeed, the military training seems able to modulate, among others, a series of cortisol-related hormones, by reducing the hypothalamus—pituitary—adrenal (HPA) axis activation when facing external stressors (Beckner et al., 2021). This reduction would be a consequence of a better training-induced homeostatic control, able to ensure an emotionally adaptive resilient response (Beckner et al., 2021). Furthermore, military populations seem to perceive emotionally charged stimuli as overall less intense and less arousing than expected (see Goodman et al., 2016 for a detailed discussion). Therefore, the decrease in the cortisol levels under emotionally arousing conditions may be an effect of military training on participants’ physiological response (e.g., reduction in the HPA axis activation, Beckner et al., 2021; see also Najström and Högman, 2003 for an example with skin conductance data). On the other hand, the fact that the cortisol concentrations were stable over time for the control group may indicate that the HPA reduction may be activated only during emotionally arousing situations. Finally –in both groups– the motor behavior requested by the shooting task may have mediated the overall arousal levels. Indeed, a significant decrease in the emotionally-induced cortisol levels produced by low-intensity body movements has been reported both in healthy and in clinical populations (*e.g.*, Beserra et al., 2018; Hill et al., 2008).

Further studies should try to deepen the biological and physiological mechanisms elicited by military training.

The subjective ratings of arousal only differed over experimental phases, increasing after performing the shooting exercises in both groups. This (divergent) result supports the hypothesis that despite the intuitive and neurological plausibility of a close link between perceived and physiological arousal responses, the associations reported between the two metrics are generally weak (Hellhammer et al., 2009; Oldehinkel et al., 2011; Strahler and Ziegert, 2015). Perceived levels of fatigue mimicked these results, being similar in both groups and reaching its highest point after performing the shooting exercises. It seems correct to suppose that fatigue increased progressively after 20 min of continuous rising, holding, and lowering the rifle (~4 Kg) while wearing a 30 kg simulated fighting load (Kemnitz et al., 2001; Pal et al., 2020). Moreover, the repetitiveness of the movements may have had a role in increasing the perceived fatigue (Santos et al., 2016). Finally, the perceived levels of valence (i.e., pleasantness of the situation) were stable in both groups. Again, the low life-threatening conditions of our experimental setting (Trousselard et al., 2009), as well as the differences in experiencing emotions among military populations, compared to civilians (Goodman et al., 2016), might in part explain this specific result.

4.2. Effects of emotional arousal inoculation and exercise complexity on shooting accuracy and performance, subjective ratings of task complexity, and nasal skin temperature

We examined the effects of unpleasant emotional arousal inoculation and task complexity on shooting accuracy (shot-to-hit ratio) and performance (instructor assessment), on the perceived levels of task complexity after each shooting exercises, and on the nasal skin temperature during the exercises.

The presence of external stressors (i.e., emotionally charged sound clips) did not affect shooting accuracy. This finding connects to earlier studies showing that accuracy seems to be more resilient to external stressors than others shooting metrics (Giessing et al., 2019; Mosley et al., 2019; Nibbeling et al., 2014). Although a straightforward comparison with other works is not possible, due to the differences in experimental procedures and/or in shooting performance indices, the stability of the shooting accuracy (shot-to-hit ratio) in the present study might be a consequence of the increased effort made by the soldiers to maintain an acceptable behavioral performance under high arousal levels (Hockey, 1997). Exercise complexity did affect shooting accuracy, with the most demanding exercise associated to less accuracy. That is, in line with classical studies using a visual search paradigm (for an overview on this topic, see Davis and Palmer, 2004), the perceptual load of the target-irrelevant distractors (the perceptual load in this case roughly corresponds to the number of items and the timing of the visual search array) would have interfered with shooter accuracy.

On the other hand, the presence of external stressors, but not exercise complexity, did affect shooting performance (defined as the amount of incorrect and/or unnecessary movements/procedures observed by the shooting instructor), showing an increment of procedural errors for the emotionally induced arousal group, independently from the exercise complexity. This is in line with our hypothesis and with previous evidence that reported a detrimental effect of emotional arousal on operator performance (e.g., Nieuwenhuys and Oudejans, 2010, 2011; Nieuwenhuys et al., 2012; Serrano et al., 2014; Sterkenburg and Jeon, 2020), independently from the complexity of the task (see also Liu and Li, 2012 for a review of task complexity as a predictor of human behavior). In our study, it seems that external stressors might have interfered with preparatory movements (i.e., rituals or mannerisms, such as keeping the finger on the trigger when not engaging a target) without compromising shooting accuracy. It is plausible to assume that these movements preceded or followed the firing movement's beginning (Vickers, 1996). Taken together, shooting behavior (accuracy and performance) results seem to partially corroborate our initial working hypothesis, with unpleasant emotional arousal affecting only procedural errors without compromising shooter accuracy. However, it is worth noting how previous studies suggested that arousal-related responses among high-risk operators might have differential effects on shooting metrics (*e.g.,* Head et al., 2017). While some studies report a decremented effect of high arousal levels on overall shooting behaviors, such as the correctness of tactical position or shooting decisions (e.g., Liu et al., 2018; Nieuwenhuys et al., 2012), impairments of shooting accuracy have not always been reported (Giessing et al., 2019; Nibbeling et al., 2014). Disentangling this issue requires further research efforts.

Perceived task complexity levels (i.e., NASA-TLX scores) reflected the complexity of the shooting exercises, independently from the presence of external stressors. This result confirmed the high sensitivity of this index in discriminating task complexity also in military operational settings (Braarud, 2020; Hart, 2006; Hertzum, 2021; Diaz-Piedra et al., 2019b, 2021, 2022). However, even though the NASA-TLX scores and the instructor's assessment of shooting performance partially reflected the experimental manipulations, we cannot disregard the methodological limitations of self-reported measures (Matthews et al., 2015). That is, personal and motivational factors (e.g., social desirability bias, halo and leniency effects) might have jeopardized the validity and reliability of these subjective evaluations (Vera et al., 2019).

Nasal skin temperature (mean values) was stable between groups. That is, contrary to previous studies, the presence of external stressors did not affect skin temperature (e.g., Kosonogov et al., 2017). Intrinsic limitations of the measure itself (e.g., motion noise artifacts when recording interactions that requires unrestrained movements) or the lack of a valid baseline (needed to define the directionality of the physiological change during emotional arousal) might, in part, account for this no result (Diaz-Piedra et al., 2019a; Ioannou et al., 2014). However, whatever the reason for the lack of effects of unpleasant emotion arousal inoculation on this variable, it is worth noting that it applies to both to the perceived arousal levels (SAM-arousal) and nasal skin temperature, thereby lending additional support to the hypothesis that emotionally charged stimuli might be experienced as less arousing among military populations (Goodman et al., 2016). Future studies should disentangle the issue including civilian shooters. While the mean values of nasal skin temperature were not affected by the complexity of the shooting exercises as expected (see, for example, Abdelrahman et al., 2017), its variance was more heterogeneous during the low complexity shooting exercise. It is plausible to assume that differences in breathing and rifle aiming strategies between both exercises may explain, at least, some of the differences observed in the skin temperature variances. Because shooters are taught to hold their breath and their rifle steady prior to shooting (e.g., Laaksonen et al., 2011), and because the time prior to shooting was double for the low complexity exercise (3 s *vs.* 1.5 s), participants might have more freedom to adjust their posture/rifle and to perform more breathing cycles. Thus, higher skin temperature variances might have been (in part) caused by (1) the frequent participants' body movements, as suggested by a study highlighting the role of muscle work demand on skin-temperature (Govindu and Babski-Reeves, 2012), and (2) breathing patterns during the low complexity shooting exercise (Lin et al., 2019). Unfortunately, no metabolic parameters neither stability measures were recorded during the shooting exercises. Therefore, future studies should also disentangle this issue.

Finally, the results produced by our metrics did partially diverge. That is, salivary cortisol was partially sensitive to both emotional arousal and measurement times, whereas subjective ratings of arousal and fatigue only discriminated among measurement times. While shooting accuracy (hit-to-shot ratio) was insensitive to emotional arousal manipulations, it discriminated between task complexity levels. Contrarily, shooting performance differed between groups without differencing between task complexity levels. Perceived levels of task complexity and nasal skin temperature behaved similarly to shooting performance: they were insensitive to the emotional arousal manipulation but were able to discriminate between task complexity levels. Thus, although the failure to find convergence among metrics might not be an ideal outcome, our results are consistent with previous reports showing how challenging it is for multidimensional metrics to converge in complex experimental setting (e.g., Diaz-Piedra et al., 2021; Matthews et al., 2015).

5. Conclusions

The human's capacity to deal with life-threatening circumstances is not well understood in science, due to the intrinsic difficulties and ethical constraints associated with simulating extreme situations (Strahler and Ziegert, 2015; Vickers and Lewinski, 2012). Our findings suggest that unpleasant emotional arousal inoculation based on emotionally charged sound clips could potentially serve as a complementary (reliable and ethically appropriate) method to train high-risk operators to deal with emotional arousal and its consequences. The work may also contribute to a better understanding of the role of emotional arousal in operational effectiveness, and to improve operational safety by minimizing the deleterious effects of unpleasant emotional arousal on soldiers' performance through the design of specific military trainings. Furthermore, our findings might be applied to other safety critical-systems (e.g., aviation and maritime operations) where emotional arousal is frequently neglected (Bendak and Rashid, 2020; Yan et al., 2019), despite its decisive role in the management of emergency/abnormal operations.

CRediT authorship contribution statement

Leandro L. Di Stasi: Conceptualization, Methodology, Data curation, Formal analysis, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing, Project administration. **Evelyn Gianfranchi:** Data curation, Writing – original draft, Writing – review & editing. **Miguel Pérez-García:** Methodology, Writing – review & editing. **Carolina Diaz-Piedra:** Conceptualization, Methodology, Formal analysis, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

This study was funded by a Santander Bank - CEMIX UGR-MADOC grant (Project PINS 2018–15 to CDP & LLDS and PIN 5/2/20 F2F to CDP) and the Ramon y Cajal fellowship program (RYC-2015-17483 to LLDS). The sponsors had no role in the design or conduct of this research. We thank personnel from the 10th Mechanized Infantry Brigade Guzmán el Bueno, Spanish Army (Cerro Muriano, Cordoba, Spain), particularly Jesús Aguilera Ruiz, Francisco de Borja Aguado Jiménez, and Jose Rafael Egusquiza Fernandez, for their help during the data collection. We also thank Colonel Francisco de Asís Vázquez Prieto (currently at the USBAD "Teniente Ruiz") for his help in organizing the study. We thank Cristina Morato, Eva Pulido and Federico Marafin (University of Granada) for their help in data processing. Furthermore, we want to thank the General Archive for the History and the Historical Archives Service of Università Cattolica del Sacro Cuore (Milan, Italy) for providing access to the original documents by Dr. Agostino Gemelli.

References

Abdelrahman, Y., Velloso, E., Dingler, T., Schmidt, A., Vetere, F., 2017. Cognitive heat: exploring the usage of thermal imaging to unobtrusively estimate cognitive load. Proc. ACM Interact. Mob.Wearable Ubiquitous Technol. 1 (3) https://doi.org/10.1145/3130898. Article 33.

Adan, A., Almirall, H., 1991. Horne and Östberg morningness-eveningness questionnaire: a reduced scale. Pers. Indiv. Differ. 12, 241–253. https://doi.org/10.1016/0191-8869(91)90110-W.

Allen, A.P., Kennedy, P.J., Cryan, J.F., Dinan, T.G., Clarke, G., 2014. Biological and psychological markers of stress in humans: focus on the trier social stress test. Neurosci. Biobehav. Rev. 38, 94–124. https://doi.org/10.1016/j.neubiorev.2013.11.005.

Arble, E., Daugherty, A.M., Arnetz, B., 2019. Differential effects of physiological arousal following acute stress on police officer performance in a simulated critical incident. Front. Psychol. 10, 759.

Baddeley, A.D., 1972. Selective attention and performance in dangerous environments. Br. J. Psychol. 63, 537–546. https://doi.org/10.7771/2327-2937.1010.

Balters, S., Geeseman, J.W., Tveten, A.K., Hildre, H.P., Ju, W., Steinert, M., 2020. Mayday, Mayday, Mayday: using salivary cortisol to detect distress (and eustress!) in critical incident training. Int. J. Ind. Ergon. 78, 102975.

Beckner, M.E., Main, L., Tait, J.L., Martin, B.J., Conkright, W.R., Nindl, B.C., 2021. Circulating biomarkers associated with performance and resilience during military operational stress. Eur. J. Sport Sci. https://doi.org/10.1080/17461391.2021.1962983 (in press).

Bendak, S., Rashid, H.S., 2020. Fatigue in aviation: a systematic review of the literature. Int. J. Ind. Ergon. 76, 102928.

Beserra, A.H.N., Kameda, P., Deslandes, A.C., Schuch, F.B., Laks, J., Moraes, H.S.D., 2018. Can physical exercise modulate cortisol level in subjects with depression? A systematic review and meta-analysis. Trends Psychiatr. Psychother. 40, 360–368.

Bergman, P., Västfjäll, D., Tajadura-Jiménez, A., Asutay, E., 2016. Auditory-induced emotion mediates perceptual categorization of everyday sounds. Front. Psychol. 7, 1565. https://doi.org/10.3389/fpsyg.2016.01565.

Bergum, B.O., Lehr, D.J., 1963. End spurt in vigilance. J. Exp. Psychol. 66, 383–385. https://doi.org/10.1037/h0044865.

Borg, G., 1998. Borg's Perceived Exertion and Pain Scales. Human Kinetiks Publishers.

Bradley, M.M., Lang, P.J., 1999. International Affective Digitized Sounds (LIDS): Stimuli, instruction manual and affective ratings (Tech. Rep. No. B-2). University of Florida, Gainesville, FL.

Bradley, M.M., Lang, P.J., 2000. Affective reactions to acoustic stimuli. Psychophysiology 37, 204–215. https://doi.org/10.1111/1469-8986.3720204.

Bradley, M.M., Lang, P.J., 2007. The International Affective Digitized Sounds (IADS-2): Affective Ratings of Sounds and Instruction Manual. University of Florida.

Braarud, P.Ø., 2020. An efficient screening technique for acceptable mental workload based on the NASA Task Load Index—development and application to control room validation. Int. J. Ind. Ergon. 76, 102904.

Cooper, T.R., Trunkfield, H.R., Zanella, A.J., Booth, W.D., 1989. An enzyme-linked immunosorbent assay for cortisol in the saliva of man and domestic farm animals. J. Endocrinol. 123, R13–R16. https://doi.org/10.1677/joe.0.123R013.

Davis, E., Palmer, J., 2004. Visual search and attention: an overview. Spatial Vis. 17, 249–255. https://doi.org/10.1163/1568568041920168.

De la Rubia, J.M., Valdez Medina, J.L., Alvarado Bravo, B.G., 2011. Instrumentación métrica del concepto de paz. Int. J. Good Conscience 6, 11–39.

Del Rio-Bermudez, C., Diaz-Piedra, C., Catena, A., Buela-Casal, G., Di Stasi, L.L., 2014. Chronotype-dependent circadian rhythmicity of driving safety. Chronobiol. Int. 31, 532–541. https://doi.org/10.3109/07420528.2013.876427.

DePoy, E., Gitlin, L.N., 2016. Introduction to Research: Understanding and Applying Multiple Strategies. Elsevier Health Sciences.

Di Stasi, L.L., Diaz-Piedra, C., Suárez, J., McCamy, M.B., Martinez-Conde, S., Roca-Dorda, J., Catena, A., 2015. Task complexity modulates pilot electroencephalographic activity during real flights. Psychophysiology 52 (7), 951–956.

Di Stasi, L.L., McCamy, M.B., Martinez-Conde, S., Gayles, E., Hoare, C., Foster, M., Catena, A., Macknik, S.L., 2016. Effects of long and short simulated flights on the saccadic eye movement velocity of aviators. Physiol. Behav. 153, 91–96. https://doi.org/10.1016/j.physbeh.2015.10.024.

Di Stasi, L.L., Contreras, D., Cañas, J.J., Cándido, A., Maldonado, A., Catena, A., 2010. The consequences of unexpected emotional sounds on driving behaviour in risky situations. Saf. Sci. 48, 1463–1468. https://doi.org/10.1016/j.ssci.2010.07.006.

Diaper, A., Nutt, D.J., Munafò, M.R., White, J.L., Farmer, E.W., Bailey, J.E., 2013. Effects of 7.5% CO_2-induced anxiety on individual performance during a group computer combat game. Mil. Psychol. 25, 615–622. https://doi.org/10.1037/mil0000017.

Diaz-Piedra, C., Gianfranchi, E., Catena, A., Di Stasi, L.L., 2022. Electrophysiological correlates of the reverse Stroop effect: Results from a simulated handgun task. Int. J. Psychophysiol. 175, 32–42.

Diaz-Piedra, C., Gomez-Milan, E., Di Stasi, L.L., 2019a. Nasal skin temperature reveals changes in arousal levels due to time on task: an experimental thermal infrared imaging study. Appl. Ergon. 81, 102870. https://doi.org/10.1016/j.apergo.2019.06.001.

Diaz-Piedra, C., Rieiro, H., Cherino, A., Fuentes, L.J., Catena, A., Di Stasi, L.L., 2019b. The effects of flight complexity on gaze entropy: An experimental study with fighter pilots. Appl. Ergon. 77, 92–99.

Diaz-Piedra, C., Rieiro, H., Di Stasi, L.L., 2021. Monitoring army drivers' workload during off-road missions: an experimental controlled field study. Saf. Sci. 134, 105092. https://doi.org/10.1016/j.ssci.2020.105092.

Diaz-Piedra, C., Sebastián, M.V., Di Stasi, L.L., 2020. EEG theta power activity reflects workload among army combat drivers: an experimental study. Brain Sci. 10, 199. https://doi.org/10.3390/brainsci10040199.

Di Stasi, L.L., Antolí, A., Gea, M., Cañas, J.J., 2011. A neuroergonomic approach to evaluating mental workload in hypermedia interactions. Int. J. Ind. Ergon. 41, 298–304.

Easterbrook, J.A., 1959. The effect of emotion on cue utilization and the organization of behavior. Psychol. Rev. 66, 183–201. https://doi.org/10.1037/h0047707.

Egbert, R.L., Meeland, T., Cline, V.B., Forgy, E.W., Spickler, M.W., Brown, C., 1957. Fighter I: an Analysis of Combat Fighters and Non-fighters. Human Resources Research Office. The George Washington University Press.

Fairclough, S.H., van der Zwaag, M., Spiridon, E., Westerink, J., 2014. Effects of mood induction via music on cardiovascular measures of negative emotion during simulated driving. Physiol. Behav. 129, 173–180. https://doi.org/10.1016/j.physbeh.2014.02.049.

Fan, S., Zhang, J., Blanco-Davis, E., Yang, Z., Wang, J., Yan, X., 2018. Effects of seafarers' emotion on human performance using bridge simulation. Ocean. Eng. 170, 111–119. https://doi.org/10.1016/j.oceaneng.2018.10.021.

Ferrer, M., Vilagut, G., Monasterio, C., Montserrat, J.M., Mayos, M., Alonso, J., 1999. Measurement of the perceived impact of sleep problems: the Spanish version of the functional outcomes sleep questionnaire and the Epworth sleepiness scale. Med. Clínica 113, 250–255.

Gerdes, A.B.M., Wieser, M.J., Alpers, G.W., 2014. Emotional pictures and sounds: a review of multimodal interactions of emotion cues in multiple domains. Front. Psychol. 5, 1351. https://doi.org/10.3389/fpsyg.2014.01351.

Giessing, L., Frenkel, M.O., Zinner, C., Rummel, J., Nieuwenhuys, A., Kasperk, C., Brune, M., Engel, F.A., Plessner, H., 2019. Effects of coping-related traits and psychophysiological stress responses on police recruits' shooting behavior in reality-based scenarios. Front. Psychol. 10, 1523. https://doi.org/10.3389/fpsyg.2019.01523.

Gifford, R.M., O'leary, T.J., Double, R.L., Wardle, S.L., Wilson, K., Boyle, L.D., et al., 2019. Positive adaptation of HPA axis function in women during 44 weeks of infantry-based military training. Psychoneuroendocrinology 110, 104432.

Goodman, A.M., Katz, J.S., Dretsch, M.N., 2016. Military Affective Picture System (MAPS): a new emotion-based stimuli set for assessing emotional processing in military populations. J. Behav. Ther. Exp. Psychiatr. 50, 152–161. https://doi.org/10.1016/j.jbtep.2015.07.006.

Govindu, N.K., Babski-Reeves, K., 2012. Reliability of thermal readings of the skin surface over the anterior deltoid during intermittent, overhead tapping tasks. Int. J. Ind. Ergon. 42, 136–142.

Gradenigo, G., Gemelli, A., 1919. I testi per la scelta del personale militare navigante dell'aria. G. Med. Mil. 1, 31–48.

Grantcharov, T.P., Kristiansen, V.B., Bendix, J., Bardram, L., Rosenberg, J., Funch-Jensen, P., 2004. Randomized clinical trial of virtual reality simulation for laparoscopic skills training. Br. J. Surg. 91, 146–150. https://doi.org/10.1002/bjs.4407.

Hamilton, J.A., Lambert, G., Suss, J., Biggs, A.T., 2019. Can cognitive training improve shoot/don't-shoot performance? Evidence from live fire exercises. Am. J. Psychol. 132, 179–194. https://doi.org/10.5406/amerjpsyc.132.2.0179.

Hart, S.G., 2006. Nasa-task load index (NASA-TLX); 20 years later. Proc. Hum. Factors Ergon. Soc. Annu. Meet. 50, 904–908. https://doi.org/10.1177/154193120605000909.

Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (task load index): results of empirical and theoretical research. Adv. Psychol. 52, 139–183. https://doi.org/10.1016/S0166-4115(08)62386-9.

Head, J., Tenan, M.S., Tweedell, A.J., LaFiandra, M.E., Morelli, F., Wilson, K.M., Ortega, S.V., Helton, W.S., 2017. Prior mental fatigue impairs marksmanship decision performance. Front. Physiol. 8, 680. https://doi.org/10.3389/fphys.2017.00680.

Hellhammer, D.H., Wüst, S., Kudielka, B.M., 2009. Salivary cortisol as a biomarker in stress research. Psychoneuroendocrinology 34, 163–171. https://doi.org/10.1016/j.psyneuen.2008.10.026.

Hertzum, M., 2021. Reference Values and Subscale Patterns for the Task Load Index (TLX): A Meta-Analytic Review. Ergonomics. https://doi.org/10.1080/00140139.2021.1876927 (in press).

Hill, E.E., Zack, E., Battaglini, C., Viru, M., Viru, A., Hackney, A.C., 2008. Exercise and circulating cortisol levels: the intensity threshold effect. J. Endocrinol. Invest. 31, 587–591.

Hockey, G.R.J., 1997. Compensatory control in the regulation of human performance under stress and high workload: a cognitive-energetical framework. Biol. Psychol. 45, 73–93. https://doi.org/10.1016/S0301-0511(96)05223-4.

Hoddes, E., Zarcone, V., Smythe, H., Phillips, R., Dement, W.C., 1973. Quantification of sleepiness: a new approach. Psychophysiology 10, 431–436. https://doi.org/10.1111/j.1469-8986.1973.tb00801.x.

Hytten, K., 1989. Helicopter crash in water: effects of simulator Escape training. Acta Psychiatr. Scand. 80 (s355), 73–78. https://doi.org/10.1111/j.1600-0447.1989.tb05256.x.

Ioannou, S., Gallese, V., Merla, A., 2014. Thermal infrared imaging in psychophysiology: potentialities and limits. Psychophysiology 51, 951–963. https://doi.org/10.1111/psyp.12243.

Kemnitz, C.P., Johnson, R.F., Merullo, D.J., Rice, V.J., 2001. Relation of rifle stock length and weight to military rifle marksmanship performance by men and women. Percept. Mot. Skills 93, 479–485.

Kosonogov, V., De Zorzi, L., Honoré, J., Martínez-Velázquez, E.S., Nandrino, J.-L., Martinez-Selva, J.M., Sequeira, H., 2017. Facial thermal variations: a new marker of emotional arousal. PLoS One 12, e0183592. https://doi.org/10.1371/journal.pone.0183592.

Laaksonen, M.S., Ainegren, M., Lisspers, J., 2011. Evidence of improved shooting precision in biathlon after 10 weeks of combined relaxation and specific shooting training. Cognit. Behav. Ther. 40, 237–250. https://doi.org/10.1080/16506073.2011.616217.

Lai, V., Theppitak, C., Makizuka, T., Higuchi, Y., Movahed, M., Kumudini, G., et al., 2014. A normal intensity level of psycho-physiological stress can benefit working memory performance at high load. International. J. Ind. Ergon. 44, 362–367.

Lang, P.J., 1980. Behavioral treatment and bio-behavioral assessment: computer applications. In: Sidowski, J.B., Johnson, J.H., Williams, T.A. (Eds.), Technology in Mental Health Care Delivery Systems, pp. 119–167. https://doi.org/10.1111/j.1469-8986.1993.tb03352.x. Ablex.

Libkuman, T.M., Otani, H., Kern, R., Viger, S.G., Novak, N., 2007. Multidimensional normative ratings for the international affective picture system. Behav. Res. Methods 39, 326–334. https://doi.org/10.3758/BF03193164.

Lieberman, H.R., Farina, E.K., Caldwell, J., Williams, K.W., Thompson, L.A., Niro, P.J., Grohmann, K.A., McClung, J.P., 2016. Cognitive function, stress hormones, heart rate and nutritional status during simulated captivity in military survival training. Physiol. Behav. 165, 86–97. https://doi.org/10.1016/j.physbeh.2016.06.037.

Lin, K., Xia, F., Li, C., Wang, D., Humar, I., 2019. Emotion-aware system design for the battlefield environment. Inf. Fusion 47, 102–110. https://doi.org/10.1016/j.inffus.2018.07.008.

Liu, P., Li, Z., 2012. Task complexity: a review and conceptualization framework. Int. J. Ind. Ergon. 42, 553–568.

Liu, Y., Mao, L., Zhao, Y., Huang, Y., 2018. Impact of a simulated stress training program on the tactical shooting performance of SWAT Trainees. Res. Q. Exerc. Sport 89, 482–489. https://doi.org/10.1080/02701367.2018.1526003.

Livingston-Booth, A., Oakes, F., Sylvester-Evans, R., Williams, J., 1985. Engineering decisions under stress. Reliab. Eng. 13, 211–238. https://doi.org/10.1016/0143-8174(85)90059-9.

Marshall, S.L.A., 1947. Men against Fire: the Problem of Battle Command. University of Oklahoma Press.

Matthews, G., Reinerman-Jones, L.E., Barber, D.J., Abich, J., 2015. The psychometrics of mental workload: multiple measures are sensitive but divergent. Hum. Factors: J. Hum. Factors Ergon. Soc. 57, 125–143. https://doi.org/10.1177/0018720814539505.

Miller, R., Plessow, F., 2012. Transformation techniques for crosssectional and longitudinal endocrine data: application to salivary cortisol concentrations. Psychoneuroendocrinology 38, 941–946.

Morgan, C.A., Doran, A., Steffian, G., Hazlett, G., Southwick, S.M., 2006. Stress-induced deficits in working memory and visuo-constructive abilities in special operations soldiers. Biol. Psychiatr. 60, 722–729. https://doi.org/10.1016/j.biopsych.2006.04.021.

Mosley, E., Laborde, S., Kavanagh, E., 2019. The contribution of coping related variables and cardiac vagal activity on prone rifle shooting performance under pressure. J. Psychophysiol. 33, 171–187. https://doi.org/10.1027/0269-8803/a000220.

Mujica-Parodi, L.R., Greenberg, T., Kilpatrick, J.L., 2004. A multi-modal study of cognitive processing under negative emotional arousal. Proc. Annu. Meet. Cogn. Sci. Society 26, 30–35.

Najström, M., Högman, L., 2003. Skin conductance response in Swedish United Nations soldiers exposed to fear-relevant stimuli. Cognit. Behav. Ther. 32 (4), 161–165.

Nibbeling, N., Oudejans, R.R.D., Ubink, E.M., Daanen, H.A.M., 2014. The effects of anxiety and exercise-induced fatigue on shooting accuracy and cognitive performance in infantry soldiers. Ergonomics 57, 1366–1379. https://doi.org/10.1080/00140139.2014.924572.

Nieuwenhuys, A., Oudejans, R.R.D., 2010. Effects of anxiety on handgun shooting behavior of police officers: a pilot study. Hist. Philos. Logic 23, 225–233. https://doi.org/10.1080/10615800902977494.

Nieuwenhuys, A., Oudejans, R.R.D., 2011. Training with anxiety: short- and long-term effects on police officers' shooting behavior under pressure. Cognit. Process. 12, 277–288. https://doi.org/10.1007/s10339-011-0396-x.

Nieuwenhuys, A., Savelsbergh, G.J.P., Oudejans, R.R.D., 2012. Shoot or don't shoot? Why police officers are more inclined to shoot when they are anxious. Emotion 12, 827–833. https://doi.org/10.1037/a0025699.

Oldehinkel, A.J., Ormel, J., Bosch, N.M., Bouma, E.M.C., Van Roon, A.M., Rosmalen, J.G. M., Riese, H., 2011. Stressed out? Associations between perceived and physiological stress responses in adolescents: the TRAILS study: perceived and physiological stress responses. Psychophysiology 48, 441–452. https://doi.org/10.1111/j.1469-8986.2010.01118.x.

Oudejans, R.R.D., 2008. Reality-based practice under pressure improves handgun shooting performance of police officers. Ergonomics 51, 261–273. https://doi.org/10.1080/00140130701577435.

Pal, M., Yadav, A., Arya, K., Chatterjee, T., Bhattacharyya, D., Kumar, B., 2020. Optimization of load carriage at desert environment. Int. J. Ind. Ergon. 79, 102986.

Pallavicini, F., Argenton, L., Toniazzi, N., Aceti, L., Mantovani, F., 2016. Virtual reality applications for stress management training in the military. Aerosp. Med. Hum. Perform. 87, 1021–1030. https://doi.org/10.3357/AMHP.4596.2016.

Park, S.H., Park, I.H., Lim, S.T., Lee, E., 2020. Changes in psychological anxiety and physiological stress hormones in Korea National shooters. Brain Sci. 10, 926. https://doi.org/10.3390/brainsci10120926.

Paul, S., Bhattacharyya, D., Chatterjee, T., Pal, M.S., Majumdar, D., Singh, S.N., Majumdar, D., 2015. Physiological and biochemical responses during incremental uphill load carriage. Int. J. Ind. Ergon. 50, 26–33.

Pêcher, C., Lemercier, C., Cellier, J.M., 2009. Emotions drive attention: effects on driver's behaviour. Saf. Sci. 47, 1254–1259. https://doi.org/10.1016/j.ssci.2009.03.011.

Royuela, A., Macías, J.A., 1997. Propiedades clinimétricas de la versión castellana del cuestionario de Pittsburgh [Clinimetric properties of the Spanish version of the Pittsburgh questionnaire]. Vigilia-Sueño 9, 81–94.

Sanli, E.A., Carnahan, H., 2018. Long-term retention of skills in multi-day training contexts: a review of the literature. Int. J. Ind. Ergon. 66, 10–17.

Santos, J., Baptista, J.S., Monteiro, P.R.R., Miguel, A.S., Santos, R., Vaz, M.A., 2016. The influence of task design on upper limb muscles fatigue during low-load repetitive work: a systematic review. Int. J. Ind. Ergon. 52, 78–91.

Serrano, J., Di Stasi, L.L., Megías, A., Catena, A., 2014. Affective-sound effects on driving behaviour. Transport 29, 100–106. https://doi.org/10.3846/16484142.2013.815133.

Sterkenburg, J., Jeon, M., 2020. Impacts of anger on driving performance: a comparison to texting and conversation while driving. Int. J. Ind. Ergon. 80, 102999.

Strahler, J., Ziegert, T., 2015. Psychobiological stress response to a simulated school shooting in police officers. Psychoneuroendocrinology 51, 80–91. https://doi.org/10.1016/j.psyneuen.2014.09.016.

Taverniers, J., Smeets, T., Van Ruysseveldt, J., Syroit, J., von Grumbkow, J., 2011. The risk of being shot at: stress, cortisol secretion, and their impact on memory and perceived learning during reality-based practice for armed officers. Int. J. Stress Manag. 18, 113–132. https://doi.org/10.1037/a0023742.

Taverniers, J., Suss, J., 2019. A user-centred assessment of a less-lethal launcher: the case of the FN 303 in a high-pressure setting. Ergonomics 62, 1162–1174. https://doi.org/10.1080/00140139.2019.1626916.

Taverniers, J., Van Ruysseveldt, J., Smeets, T., von Grumbkow, J., 2010. High-intensity stress elicits robust cortisol increases, and impairs working memory and visuo-spatial declarative memory in Special Forces candidates: a field experiment. Stress 13, 324–334. https://doi.org/10.3109/10253891003642394.

Trousselard, M., Cian, C., Barraud, P.A., Ferhani, O., Roux, A., Claverie, D., Canini, F., Baert, P., 2009. Physiological and psychological effects of escape from a Sunken submarine on shore and at sea. Aviat Space Environ. Med. 80, 850–856. https://doi.org/10.3357/ASEM.2503.2009.

Van Wijk, C.H., 2017. Psychological considerations in submarine escape training: brief overview and future directions. Int. Marit. Health 68, 168–173. https://doi.org/10.5603/IMH.2017.0030.

Vera, J., Diaz-Piedra, C., Jiménez, R., Sanchez-Carrion, J.M., Di Stasi, L.L., 2019. Intraocular pressure increases after complex simulated surgical procedures in residents: an experimental study. Surg. Endosc. 33, 216–224. https://doi.org/10.1007/s00464-018-6297-7.

Vickers, J.N., 1996. Visual control when aiming at a far target. J. Exp. Psychol. Hum. Percept. Perform. 22, 342–354. https://doi.org/10.1037/0096-1523.22.2.342.

Vickers, J.N., Lewinski, W., 2012. Performing under pressure: gaze control, decision making and shooting performance of elite and rookie police officers. Hum. Mov. Sci. 31, 101–117. https://doi.org/10.1016/j.humov.2011.04.004.

Walker, N.K., Burkhard, J.F., 1965. The combat effectiveness of various human operator controlled systems. Proc. 17th US Mil. Oper. Res. Symp. 58–66.

WMA, 2008. WMA Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Subjects. http://www.wma.net/en/30publications/10policies/b3/.

Yan, S., Wei, Y., Tran, C.C., 2019. Evaluation and prediction mental workload in user interface of maritime operations using eye response. Int. J. Ind. Ergon. 71, 117–127.

Yang, W., Makita, K., Nakao, T., Kanayama, N., Machizawa, M.G., Sasaoka, T., et al., 2018. Affective auditory stimulus database: an expanded version of the International Affective Digitized Sounds (IADS-E). Behav. Res. Methods 50, 1415–1429. https://doi.org/10.3758/s13428-018-1027-6.