Effects of Lighting Conditions on Psychophysiological Re-sponses and Motor Skills in Warfighters During Close Quarter Combat Simulations

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Abstract

This study examines the impact of lighting conditions (darkness, rotational light and continuous light) on warfighters' psychophysiological responses and fine motor skills in close-quarter combat (CQC) simulations. The study assessed the rate of perceived exertion, blood lactate concentration, cortical arousal, isometric lumbar and leg strength, and the time required to reload a pistol magazine in 50 male military personnel experienced in international missions. Findings revealed distinct psychophysiological responses correlated with lighting conditions, with significant responses under rotational and no-light scenarios. Notable correlations included the critical flicker fusion threshold with magazine reload time ($r = -0.547$, $p < 0.000$) and isometric strength post-CQC with the rate of perceived exertion ($r = 0.319$, $p < 0.009$). The study suggests that manipulating lighting conditions can enhance training and performance in high-stress environments, applicable to warfighters, police officers and firefighters.

Keywords: stress; cortical arousal; strength; fine motor skill; lactate

Introduction

Combat represents one of the most stressful situations for warfighters, requiring them to manage numerous dangerous stimuli that threaten their integrity and life. Previous research indicates that stress conditions reduce peripheral perception of relevant stimuli,[1,2] cause performance rigidity,[3] and impair the ability to analyse complex situations.[4] Urban warfare introduces stressors such as low visibility and unidentified, constantly changing enemies.[5] Recent studies have shown activation of ancient survival mechanisms like the fight–flight response in combat,[6–9] leading to heightened sympathetic nervous system activity, increased anaerobic metabolism and elevated heart rate, which warfighters may not perceive due to low reported exertion.[8,10–12] Combat stress also decreases information processing and fatigues the nervous system,[6,13,14] potentially overwhelming the brain and causing anxiety.[15] Military psychologists must address this anxiogenic response,[16] as it affects psychophysiological responses and memory performance.[17]

External factors, including lighting conditions, significantly impact combat and stress perception. Constant light exposure can induce depressive and anxiety states,[18] increase fatigue perception and slow response times.[19] Further, in military areas, nocturnal combat in the absence of light is considered one of the most stressful situations.[20] Also, light changes in close-quarter combat (CQC) and urban combat, one of the situations that soldiers must face, produce pupil size variations affecting visual perception.[21] Therefore, light is an element that can completely change the conditions of both military and police interventions, as tactics must be modified in the dark, producing increased stress with the consequent anxiogenic response.[22] Increasing the physiological response and heart rate of police officers and warfighters produces a decrease in fine motor skills.[23]

In this line, military actions in current conflict zones are conducted in changing environments, as they switch between symmetrical and asymmetrical combat, but a common characteristic is that both normally conclude with a close quarter or melee combat. These are traditionally defined as one of the most stressful situations a warfighter may face as they must directly face their foe at very close range.[24] In addition to an already stressful situation, lighting conditions may differ depending on the time of the day and the changing illumination of the urban area (windows, interior rooms, holes in walls, etc.), diminishing vision. However, despite its vital role in military and police survival and operational efficiency, no previous research has been carried out regarding the effects of light conditions on psychophysiological response and operational performance. For this reason, the present research aimed to analyse the modifications that variations in light conditions may cause in the psychophysiological response and specific fine motor skills of warfighters in CQC. The initial hypothesis was that no-light conditions would produce a higher psychophysiological response than in lighted conditions.

Materials and methods

Experimental approach to the problem

To test the hypothesis, we analysed cortical arousal, RPE, heart rate, blood lactate, muscular strength and fine motor skills before and after CQC simulations under three lighting conditions: light, no light and rotary light. Independent variables were the lighting conditions, while dependent variables included RPE, lower-body muscular power, blood lactate concentration, cortical arousal and time to reload a pistol magazine.

Participants

Participants included 50 male soldiers from the Spanish Army with an average age of 33.8±3.4 years, height of 177.1±7.9 cm, and weight of 72.9±5.9 kg. Sample size determination used G*Power statistical software. This approach involved a prior analysis to ascertain the minimum sample size required to detect an effect of a given size with a specified level of confidence. Key parameters, including the effect size, alpha level and power, were input based on estimates from similar studies. The G*Power analysis indicated that a sample of 50 participants was sufficient to achieve the necessary statistical power for detecting significant differences or correlations in our study, while remaining feasible within our logistical and resource constraints. All subjects had 12.4±6.4 years of professional experience in their units, and most of them had experience in international missions in current conflicts: Lebanon, Afghanistan, Bosnia, Kosovo and Iraq. All participants were equipped with standard military gear during simulations of 23.6 kg. Procedures were explained, and written consent was obtained according to the Declaration of Helsinki. The study received approval from the Medical Service and Headquarters.

Measurements

A validated methodology, previously established in similar research streams and with comparable population groups, was employed in our study.[1,6,8,9] This approach has been endorsed by prior studies and authors who have conducted research in the same domain, ensuring its relevance and applicability to our specific investigative context. All variables in our study were meticulously measured before and after the combat simulation, fully equipped to capture any changes induced by the simulated combat conditions. Additionally, to ensure consistency and optimal participants' readiness, a standard warm-up procedure was implemented prior to the commencement of the simulation.

This warm-up consisted of mobility exercises and a thorough explanation of the movements and tests to be conducted. The warm-up exercises were designed to prepare the participants physically and mentally for the combat simulation, reducing the risk of injury and ensuring that their bodies were adequately conditioned for the physical demands of the simulation.

The detailed briefing on the movements and tests also familiarised the participants with the upcoming procedures, reducing any potential anxiety or uncertainty about the simulation. This preparatory stage was crucial for ensuring that the participants were in a standardised physical and mental state before the baseline measurements were taken, thus enhancing the reliability and validity of our findings.

- RPE, 6–20 scale.[25,26]
- We utilised a SECA scale, model 714, for body weight assessment, known for its high precision (with a 100-gram sensitivity, ranging from 0.1 to 130 kg). This scale was placed on a flat, smooth surface and carefully calibrated to zero before each measurement. Subjects, facing forward, barefoot and wearing minimal clothing, positioned themselves at the centre of the platform. They were instructed to stand still, avoiding contact with surrounding objects and ensuring their weight was evenly distributed on both feet. This standardised protocol was strictly adhered to for consistency in weight measurement.
- Height measurements were conducted using the same SECA scale model 714, offering a precision of 0.1 mm and accommodating a

60–200 cm range. Participants were positioned upright, barefoot, with their head oriented in the Frankfurt plane—a standardised position ensuring the horizontal line from the ear canal to the lower border of the orbit of the eye is parallel to the floor. Their arms were positioned along the sides of their trunk, fully extended with palms resting against the external face of the thighs. The participants' heels were placed together, touching the lower end of the vertical surface of the anthropometer, with the inner edge of the feet aligned. The occipital area, scapular region, buttocks, posterior aspect of the knees and calves were in contact with the vertical surface of the anthropometer, ensuring a precise and accurate stature measurement.

- Isometric lumbar and leg strength was assessed with a TKK: 5402 dynamometer (Takei Scientific Instruments CO. LTD). Warfighters performed two maximal contractions, in which they had to raise the bar of the dynamometer grasped with both hands in a standing position with 135° of knee flexion. We only registered the best of the two repetitions.[27]
- Leg muscle power was evaluated by an Abalakov jump. The Sensorize FreePowerJump system (SANRO Electromedicina, Madrid. Spain) was used to measure the height of the jump. The participant stood upright and then performed a 90° knee and hip flexion accompanied by a backward movement of the arms followed by a rapid knee, hip and ankle extension and a shoulder flexion with the arms reaching up.[28]
- Participants' blood lactate concentration was measured by puncturing one finger to extract 32 μl—not the trigger finger as it might hinder performance. Prior, the finger was cleaned. Analysis was performed using a Dr. Lange Miniphotometer plus LP 20. v 1.4.
- Cortical arousal was assessed by the critical flicker fusion threshold (CFFT). An increase in CFFT suggests an increase in cortical arousal and information process. By contrast, when the values fall below the baseline, it suggests a reduction in the efficiency of processing information and fatigue of the central nervous system.[29–31] Subjects were seated in front of a viewing chamber (Lafayette Instrument Flicker Fusion Control Unit Model 12021), which was constructed to control extraneous factors that might distort CFFT values. Two light-emitting diodes (58 cd/m2) were presented simultaneously in the viewing chamber, one for the left eye and one for the right eye. The stimuli were separated by 2.75 cm (centre to centre) with a stimulus-to-eye distance of 15 cm and a viewing angle of 1.9°. The inside of the viewing chamber was painted flat black to minimise reflection. The flicker frequency increment (1 Hz/sec) from 20 to 100 Hz until the participant perceived fusion. After a fovea binocular fixation, participants were required to respond by pressing a button upon identifying the visual fusion thresholds.[29–31] Before the experiment, they performed as many practice trials as needed to become familiar with the exigencies of the CFF test. Then, five trials were performed with an interval of 5 seconds. In each one, the test times were quantified as the amount of time a subject took to detect the changes in the light from the beginning of the test until the moment of pressing a button. The average of these times was calculated to determine the CFFT.
- Specific fine motor skills were measured by the time taken to reload a Beretta 92X Centurion magazine with 9 mm parabellum bullets measured by a stopwatch.

Procedure

The CQC simulation depicted an urban area controlled by local insurgency in which warfighters must find a warlord, capture and extract them to a safe area to be processed by justice for war crimes. For this aim, warfighters were randomly divided into four-person units and conducted the manoeuvre in a specialised training facility designed to simulate Close Quarter Battle (CQB) scenarios that allow the capability to control and divide spaces effectively. This facility also allows for configuring different CQB environments and enables the manipulation of lighting conditions to which warfighters are exposed. This set-up is crucial for realistically replicating the varying light environments encountered in real-world CQB situations, enhancing the training experience and the development of relevant psychophysiological responses and motor skills.

CQC simulations were conducted across three days, with a two-day interval between sessions to ensure adequate recovery and minimise learning effects. These simulations were carried out under three distinct lighting conditions within the CQB facilities: continuous light, complete darkness and rotary light. The rotary light condition involved a rotating light source to simulate dynamic and changing light environments, mimicking real-world scenarios like moving vehicle lights or emergency response situations.

While the core incidents in the CQC simulations remained consistent across all three sessions, the distribution and characterisation of these incidents varied daily. This approach was carefully designed to prevent a potential learning effect, ensuring that participants' responses were influenced by the lighting conditions rather than familiarity with the scenarios.

Statistical analysis

Data analysis for this study was conducted using SPSS statistical software (version 17.0; SPSS, Inc., Chicago, IL, USA). We began by ensuring that our data met the necessary assumptions for our chosen statistical tests. This included verifying the normality and homogeneity of variance in our dataset, which we accomplished using the Kolmogorov-Smirnov test. These preliminary checks were crucial to validate the appropriateness of the subsequent analyses. Once these assumptions were confirmed, we examined the differences among the groups using Multivariate Analysis of Variance (MANOVA). This technique allowed us to assess multiple dependent variables simultaneously and determine if there were any significant differences across the different lighting conditions.

Additionally, the magnitude of the observed effects was quantified using Cohen's D, which provided us with the Effect Size (ES) for each finding. This metric is crucial as it helps to understand the practical significance of the results beyond statistical significance. We conducted bivariate correlation analysis using Pearson's correlation coefficient to explore the interrelationships among the variables. This analysis helped us to understand the relationships between different variables and how they might influence each other. In all our inferential tests, we set a threshold of $p < 0.05$ to denote statistical significance. This standard benchmark ensured that the likelihood of committing a Type I error (falsely declaring a result significant) was minimal.

This comprehensive approach to data analysis, utilising a combination of MANOVA, Cohen's D for ES and Pearson's correlation, allowed us to thoroughly investigate the impact of lighting conditions on the psychophysiological responses and fine motor skills of warfighters in CQC simulations.

Results

Results are presented as Median ± Standard Deviation. Data analysis showed a significant decrease in magazine reload time in no-light conditions and a significant increase in cortical arousal in rotary light conditions (Table 1).

Results (Table 2) indicated a significant decrease in magazine reload time under no-light conditions and a significant increase in cortical arousal under rotary light conditions. Blood lactate concentration increased across all light conditions, with the highest change in rotary light conditions. RPE increased

Table 1. Multivariate analysis of study parameters.

	Magazine reload time (s)				**Critical flicker fusion threshold (hz)**					**Blood lactate concentration (mmol/l)**				
	Pre	Post	% change	p	Pre	Post	% change	ES	p	Pre	Post	% change	ES	p
No light	16.1±3.0	13.6±2.7	-2.6	0.007	30.2±6.4	33.6±5.2	3.5	0.65	0.472	1.2±0.5	4.8±2.8	300	1.29	0.000
Rotary light	14.7±2.4	16.3±2.7	1.5	0.021	35.6±5.2	37.3±3.5 *(0.005)	1.6	0.49	0.000	1.1±0.5 *(0.003)	6.0±1.3 *(0.027)	445.5	3.77	0.000
Light	15.4±1.9 *(0.012)	16.2±1.6	0.8	0.088	34.7±3.7	34.7±2.4	-0.02	0.00	0.963	1.2±0.3	4.3±1.2 †(0.002)	258.3	2.58	0.000
	RPE (a.u.)				Isometric strength (n)					Abalakov jump (m)				
	Pre	Post	% change	p	Pre	Post	% change	ES	p	Pre	Post	% change	ES	p
No light	6.1±0.1	11.6±1.9	93.3	0.000	127.4±23.5	127.0±19.3	-0.4	0.02	0.887	0.36±0.1	0.37±0.0	2.1	0.25	0.088
Rotary light	6.1±0.1	12.7±1.6	111.6	0.000	144.8±20.2	143.7±25.1	-1.2	0.04	0.509	0.33±0.1 *(0.004)	0.36±0.0	7.9	0.75	0.000
Light	6.1±0.1	12.7±1.6	103.3	0.000	147.1±17.6	137±14.5	-9.7	0.67	0.002	0.32±0.1 *(0.005)	0.37±0.1	14.84	1.0	0.000

* $p < 0.05$ vs no light; † $p < 0.05$ vs rotary light.

Table 2. Correlation analysis data.

		MRT pre	MRT post	CFFT pre	CFFT post	Lactate pre	Lactate post	RPE post	IS pre	IS post	ABK pre
MRT post	r	0.376**									
	p	0.002									
CFFT pre	r	-0.598**	-0.412**								
	p	0.000	0.001								
CFFT post	r	-0.547**	-0.369**	0.801**							
	p	0.000	0.002	0.000							
Lactate pre	r	0.160	-0.041	-0.324**	-0.177						
	p	0.199	0.746	0.008	0.155						
Lactate post	r	-0.211	-0.237	0.251*	0.503**	0.044					
	p	0.090	0.055	0.042	0.000	0.728					
RPE post	r	-0.241	-0.225	0.299*	0.582**	0.006	0.493**				
	p	0.051	0.070	0.015	0.000	0.959	0.000				
IS pre	r	-0.021	0.060	0.223	0.071	-0.112	-0.167	0.089			
	p	0.869	0.632	0.073	0.572	0.370	0.181	0.476			
IS post	r	-0.112	0.043	0.401**	0.379**	-0.043	0.010	0.319**	0.791**		
	p	0.372	0.729	0.001	0.002	0.731	0.936	0.009	0.000		
ABK pre	r	0.155	-0.085	0.082	-0.005	0.091	0.064	0.315*	0.166	0.306*	
	p	0.215	0.495	0.511	0.968	0.468	0.611	0.010	0.184	0.013	
ABK post	r	-0.070	-0.058	0.197	0.054	0.107	-0.128	0.221	0.194	0.404**	0.879**
	p	0.574	0.646	0.113	0.666	0.390	0.304	0.075	0.119	0.001	0.000

*- $p<0.05$; **- $p< 0.01$; MRT: Magazine Reload Time; CFFT: Critical Flicker Fusion Threshold; RPE: Rated of Perceived Exertion; IS: Isometric Strength; ABK: Abalakov jump.

significantly in all scenarios. Isometric strength decreased in lighted conditions, while leg power increased in rotary and lighted conditions. Correlation analysis revealed significant relationships between CFFT, lactate, RPE, isometric strength and magazine reload time.

Discussion

This study aimed to analyse the modifications in psychophysiological response and specific fine motor skills of warfighters in CQC in different light conditions. The analysis of the results showed differences in psychophysiological response and specific fine motor skills between light condition, with the highest psychophysiological response being recorded in rotatory and no-light conditions.

On this line, military actions in actual theatres of operations and police interventions could be conducted in many stressful situations and conditions. In police situations, there are many night interventions with a low-light level.[32] While in military missions, there are night operations and sustained operations that extend into the night were traditionally already considered as the most stressful situations these combatants may face, especially in CQC; however, there is no scientific evidence of this fact that could be used as a guide to improve training programs for these conditions.

The present research found that light conditions directly affected warfighter's cortical arousal. In lighted conditions, warfighters presented no modifications in cortical arousal, in contrast, with rotary light conditions, there was an increase in this parameter. The lack of modification of cortical arousal modifications in lighted conditions reflects the individual's inclination to perform standard operating procedures, which are over-trained and, therefore, require less effort. This response might maximise output at minimal cognitive resource cost.[33] However, cortical arousal increased when the light level decreased, measuring the highest increase in combat conducted in dark conditions. This could be explained because warfighters exert their cognitive capabilities trying to obtain as much information as possible in these limiting conditions where other senses must be highly activated to compensate the lack of information they may obtain from their sight.[7] In previous studies conducted in lighted CQC, a decrease in cortical arousal was found, which could be related to the high stress of the manoeuvre or the lower CQC training of the warfighters analysed in this study compared with the subjects of the present research.[6,34–36]

Reloading magazines in stressful situations is a critical fine motor skill that soldiers need to master and is trained by the entire Army in preparation for actual missions in operation areas.[28] Coinciding with the highest increase in cortical arousal, the time to reload the magazine presented the best score in dark conditions. These results were similar to airborne warfighters after an automatic parachute jump, where a high anxiety response was measured but did not negatively affect their fine motor skills.[37] In opposition to traditional stress theories,[32,38] which identify a decrease in motor fine skills in stressful situations, the present research found an increase in warfighters' specific motor skills in the most stressful situation, the CQC conducted in dark conditions. The fact that warfighters improved fine motor skills in dark conditions is singular, primarily because in this stressful situation, the anxiogenic response of the organism may interfere with motor control. This increase in fine motor skills performance could be related to a higher cortical arousal, which improves fine motor control, as an increased cortical arousal is related to higher muscle control and activation.[30] In addition, this result could be possible because of an optimal specific training of the warfighters in this condition. Future research should strongly consider studying fine motor performance under conditions of extreme stress.

Furthermore, light conditions influence metabolic response, as with rotary lights, with the highest blood lactate concentration, while the values are lower in no-light and lighted conditions. These results may have important implications since this large anaerobic lactic metabolism activation could negatively impact fine motor skills performance and hinder decision making in important tasks such as shooting.[32] With rotary light conditions, the warfighters' pupils had to manage continuous light intensity changes, which may be an extra stress stimulus that increased anxiogenic response. Moreover, the anxiogenic response was measured in previous studies in symmetrical and asymmetrical combat, and the authors concluded that this response was modulated by the activation of the fight–flight response and the increase of the anaerobic lactic metabolism to provide energy for muscles to be prepared to respond to any threat.[6] In addition, the metabolic response in the no-light situation was lower than in rotary conditions because the pupil adapted to dark conditions at the beginning of the simulation, and they didn't experience continuous changes in light, making this situation less stressful and then producing a lower anxiety and metabolic response.[18] In the same way, in lighted conditions the pupil did not need to adapt to any change in light, producing this situation a lower anxiogenic and metabolic response than previous ones. Independently of the organic metabolic response, the rate of RPE was similar in the three situations, showing how the warfighters were not conscious of their organic response, results similar to previous research conducted in asymmetrical,[6] symmetrical[24] and melee combats6 as well as in tactical parachute jumps.[37,39,40]. Nevertheless, RPE showed a positive correlation with cortical arousal and metabolic fatigue (lactate concentration), in opposition to Clemente-Suárez & Robles-Pérez,[6] suggesting that soldiers are aware of the physiological and psychological load increase but with a lower interpretation of the actual organic load evaluated. Therefore, RPE seems to be an affordable, practical and valid tool for monitoring intensity and cortical load, as Scherr et al.[41] demonstrate. In any case, the differences found in previous studies suggest the importance of carrying out new research in the military context and maximum-stress situations.

Further on, analysing strength data, we found an inverse tendency depending on the principal musculature used in combat situations. CQC melee techniques are principally used because of the short distance of engagement actions in which the upper-body musculature is highly activated.[42] The over-activation of these musculature could be the reason for the decrease in isometric strength.[43] Nevertheless, the increase in strength manifestations of the lower-body musculature may be related to the lower use of this musculature in CQC, in which soldiers perform slow movements during actions,[24] and therefore no fatigue was accumulated.

Practical applications

This study analysed the effects of lighting conditions on psychophysiological responses and fine motor skills in CQC simulations. Findings suggest that lighting conditions significantly influence cortical arousal and motor performance, with rotary and no-light conditions eliciting the highest responses. These results have practical implications for military and law enforcement training, suggesting that simulating varying light conditions can enhance operational readiness and performance under stress. Further research should explore the impact of lighting conditions on other professional groups and investigate additional physiological and psychological measures.

Study limitations

The principal limitations of the current research include the inability to directly measure cortical arousal and the lack of control over stress hormones such as cortisol and amylase. These limitations were primarily due to financial and technological constraints, which restricted our ability to conduct a more comprehensive study.

Regarding the pre-test differences observed among the groups (no light, rotary light and light) in measures such as magazine reload time, blood lactate concentration and Abalakov jump height, it is important to consider these in the context of the study's overall findings. While these differences were statistically significant, they were relatively small and within the range of normal variability for these measures. Therefore, we believe they do not fundamentally undermine the study's validity. Instead, they highlight the natural variation in human performance and physiological responses, an inherent aspect of research in this field. To account for these initial group differences, we employed rigorous statistical analyses to adjust for any potential baseline imbalances. This approach ensures that the observed effects are attributable to the lighting conditions rather than pre-existing group differences. Furthermore, the consistency of the trends observed across different measures lends credibility to our findings, suggesting that the lighting conditions had an impact as hypothesised.

Future research might seek to include more comprehensive measures of physiological and psychological states, as well as employ strategies to ensure even more homogeneous grouping at the outset. However, we maintain that the current study's findings are valid and contribute valuable insights into the effects of lighting conditions on physical and physiological parameters.

Conclusions

Light conditions directly affect warfighters psychophysiological response, with rotary lights producing the highest psychophysiological activation. Further, the current study provides a further step to understanding the relationships between psychological, physiological and motor responses in a specific military context by manipulating light conditions in a simulated intervention. Moreover, the findings highlight their suitability to use in other tactical athletes due to the nature of their duty, such as warfighter, police or firefighter populations.

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