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# Stressful Military Training: Endocrine Reactivity, Performance, and Psychological Impact

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**Introduction:** We examined the responsiveness of both cortisol and dehydroepiandrosterone sulfate (DHEAS) to the stress of survival training in military men and evaluated relationships to performance, peritraumatic dissociation, and the subsequent impact of stressful events. **Methods:** Baseline salivary cortisol samples were self-collected by 19 men at 0900 and 1930 in a free-living (FL) environment. DHEAS samples were also collected in a subset of this sample ( $N = 12$ ). Samples were subsequently taken at similar time points during a stressful captivity (SC) phase of training. Repeated-measures analyses of variance with follow-up paired  $t$ -tests examined differences across time and conditions. **Results:** Significant increases were observed at both time points (0900 and 1930) from FL to SC in both cortisol (0900:  $9.2 \pm 3.4 \text{ nmol} \cdot \text{L}^{-1}$  vs.  $18.4 \pm 10.5 \text{ nmol} \cdot \text{L}^{-1}$ ; 1930:  $3.5 \pm 3.0 \text{ nmol} \cdot \text{L}^{-1}$  vs.  $27.7 \pm 10.9 \text{ nmol} \cdot \text{L}^{-1}$ ) and DHEAS (0900:  $1.7 \pm 1.3 \text{ ng} \cdot \text{ml}^{-1}$  vs.  $6.7 \pm 3.5 \text{ ng} \cdot \text{ml}^{-1}$ ; 1930:  $1.5 \pm 0.84 \text{ ng} \cdot \text{ml}^{-1}$  vs.  $4.5 \pm 3.0 \text{ ng} \cdot \text{ml}^{-1}$ ). Also, overall performance during a high-intensity captivity-related challenge was inversely related to the DHEAS–cortisol ratio; conversely, overall performance during a low-intensity captivity-related challenge was positively related to DHEAS at the 0900 time point during SC. Dissociation was unrelated to endocrine indices measured during SC, while total impact of events was inversely related to percent change in DHEAS from FL to SC. **Conclusions:** Cortisol and DHEAS increase in response to allostatic load, and may relate to human performance during SC as well as PTSD symptoms.

**Keywords:** cortisol, DHEAS, hormones, survival.

CORTISOL IS the end product of hypothalamic-pituitary-adrenal stimulation and is responsible for stimulating blood glucose for energy and increasing blood pressure in support of the stress response, and has known relationships to physical as well as mental stress. Acutely, increased cortisol release can degrade perceptual processes important for encoding information (e.g., tunnel vision) and may even enhance memory for particularly salient information (28). Excessive or chronically high cortisol levels, however, have adverse neural consequences characterized by reduced hippocampal volume and function (27,28), decreased neurogenesis, decreased brain-derived neurotrophic factor, and impaired memory (3,4). The hippocampus is populated with cortisol receptors, and it is through this mechanism that extreme and/or extended cortisol secretion may result in neurotoxicity and degraded cognitive function.

Cortisol is the most widely studied marker of the endocrine stress response.

Morgan and colleagues have pioneered endocrine research in the military survival context. Their recent work has demonstrated robust increases in cortisol concentrations in response to Survival, Evasion, Resistance, and Escape training (SERE)—a harsh and realistic environment in which students are taught to survive, evade enemy captors, resist exploitation, and escape during captivity (19,20,22). In one study, Morgan and colleagues found inverse relationships between percentage of free (plasma) cortisol and dissociative symptoms during stress (retrospectively recalled at conclusion of training, with specific reference to the stressful event), but positive relationships between the retrospectively recalled dissociative and percentage of free cortisol values obtained after the conclusion of training (22). Another study yielded positive relationships between salivary cortisol and dissociative symptoms (retrospectively recalled in reference to the entire captivity experience) (20). Subtle methodological differences, then, may explain these discrepant findings. With respect to human performance, these researchers have observed positive relationships between percentage of free (plasma) cortisol and military performance during captivity-related challenges (22) and, by contrast, inverse relationships between salivary cortisol and performance in a different sample (20). Salivary cortisol concentrations have been shown to closely approximate plasma values (8). The relationships between cortisol, dissociation, and human

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performance during military stress remain unclear and may be sensitive to subtle methodological differences. Additionally, the relationship of cortisol reactivity to the subsequent impact of captivity-related events has not been explored.

Dehydroepiandrosterone (DHEA) and its sulfated version, dehydroepiandrosterone sulfate (DHEAS) are cosecreted with cortisol from the adrenal gland (1), serve as precursors for androgenic and estrogenic steroids (11), and have also been used as markers of the endocrine stress response. DHEAS is considered the most abundant steroid in the body (1). Both substances peak at 20–25 yr of age in humans and then decline to reach values of 20–30% at 70–80 yr (23).

Findings from animal studies suggest that DHEA and DHEAS confer neurogenesis (25) as well as neuroprotection during stress (14,15,17), although the precise mechanisms of action remain to be confirmed (1). Roberts et al. (25) first reported the neurogenic effects of DHEA and DHEAS. In that animal study, when cultures of dissociated brain cells of mouse embryos were cultured with either DHEA or DHEAS, increases were found in the numbers of two specific types of nerve cells, neurofilament-positive neurons and glial fibrillary acid protein-positive astrocytes, along with extensions of the processes of both types of cells. Additionally, Kimonides et al. (15) found that both DHEA and DHEAS prevent or reduce the neurotoxic actions in the hippocampus of the glutamate agonists *N*-methyl-D-aspartate (NMDA) and  $\alpha$ -amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid although DHEA was more effective. More recently, Kurata (17) examined possible neuroprotective effects of  $\beta$ -estradiol, DHEA, and DHEAS against NMDA-induced neurotoxicity in rat hippocampal neurons, observing that all three exerted neuroprotective effects, albeit via different mechanisms. In other work, Hajszan et al. (12) showed that DHEA induces hippocampal spine synapse changes (i.e., remodeling), with DHEA treatment resulting in a significant decrease in the number of GABAergic axosomatic terminals while non-GABAergic terminals were unaffected, thus suggesting a protective effect against neuroexcitability. Further work has confirmed that DHEA and DHEAS regulate neuronal function via influence on neuronal excitability (26), and both of these neurosteroids may also confer protection against the neurotoxic effects of corticosterone (14). Further, DHEA has been identified as a direct buffer against the neurotoxic effects of cortisol (13).

Human studies have examined the clinical and therapeutic applications of these neurosteroids (16,24), their possible stress-buffering roles during stressful military training (20), as well as possible relationships to post-traumatic stress disorder (PTSD). Clinically oriented work has examined the role of endogenous and exogenous (administered) DHEA and DHEAS in depression, mood regulation, and stress reactivity. Rasmusson and colleagues (24), for example, studied the effects of adrenocorticotrophic hormone administration on the DHEA responses of women with PTSD, and found that increased adrenal DHEA release is associated with de-

creased avoidance and negative mood in this population. Other work has examined the stress-buffering role of DHEAS during acute military stress. Morgan et al. (20), for instance, examined relationships between plasma DHEAS, cortisol, dissociation, and performance during military survival training. In this sample of 25 military personnel, DHEAS was increased by operational stress, and the DHEAS-cortisol ratio was higher in participants who reported fewer symptoms of dissociation and demonstrated superior military performance. Finally, cortisol, DHEA, and DHEAS are thought to contribute to the neurobiological dysregulations underlying PTSD. Notably, PTSD patients tend to exhibit lower levels of cortisol, increased responsiveness of glucocorticoid receptors, and enhanced cortisol-induced negative feedback (33). Additionally, Charney (9) suggested a negative correlation between DHEA reactivity to adrenal activation and the severity of PTSD. Taken together, the current literature suggesting the clinical and therapeutic applications of these neurosteroids, their possible stress-buffering roles during military stress, and possible relationships to PTSD provide a clear rationale for further clarifying the endocrine responses to military stress as well as relationships to human performance and PTSD risk factors.

The present study was initiated to extend our understanding of cortisol and DHEAS responses to the stress of harsh military training, and to evaluate relationships to human performance as well as key risk factors for PTSD (peritraumatic dissociative symptoms and subsequent impact of events). Based on previous research, we hypothesized that cortisol and DHEAS concentrations would substantially increase in response to the allostatic load imposed by survival training; we also expected that cortisol would relate positively to symptoms of dissociation during stress. Although the assessment of the effects of endocrine responses on subsequent impact of events is an unprecedented area of inquiry, it was expected that cortisol responses would exacerbate, and DHEAS responses would ameliorate, the subsequent impact of stressful events.

## METHODS

### *Participants*

As part of a program of research examining individual differences in stress resilience during military survival training, the participants in this study included 19 healthy, male, active-duty Navy personnel whose mean age was 21.5 yr  $\pm$  1.7 SD. Participants were recruited from a secure list of incoming trainees who were scheduled to report to survival training in the San Diego area. Participation was voluntary and prospective participants were notified that the study was being performed independent of the survival training curriculum. Those who expressed a desire to participate and reported no history of head trauma or PTSD, or addiction to any substances (e.g., tobacco products) were scheduled for an in-person meeting to review the details of the study and provide written informed consent approved by the Naval Health Research Center Institutional Review

Board. All participants were subjected to rigorous medical and psychological reviews by a medical officer and psychologist prior to enrollment in survival training.

#### *Survival, Evasion, Resistance, and Escape (SERE) Training*

We have described SERE training in a previous report (31). Briefly, United States military members at high risk of capture (e.g., aircrew, special operations personnel) are required to attend the 12-d SERE course, which includes a period of confinement in a Resistance Training Laboratory (RTL). After an initial phase of classroom-based didactic training, students are taken to the field where they receive applied training in survival, evasion, resistance, and escape techniques. Students are then released into the field and tasked with the goal of evading enemy captors. Upon eventual capture, students are taken to the RTL, where they are expected to apply their recently learned skills of resistance to political indoctrination and captivity-related problems. The structured, choreographed nature of this training platform provides a unique and unprecedented medium in which to systematically and scientifically examine human stress and performance in a realistic military context. Although the participants were exposed to a broad spectrum of environmental and psychological stressors throughout training, they were given continuous access to water and were encouraged to remain hydrated throughout all phases of the curriculum.

#### *DHEAS and Cortisol Assessment*

Baseline salivary samples were obtained over the course of 2 consecutive days, 1–3 wk prior to the start of survival training. The saliva samples were self-collected by participants in a free-living (FL) setting and collected in Salivette tubes (Sarstedt, Inc., Newton, NC), which were individually labeled with the date and time of sampling. Specifically, the samples were collected during the workweek (either Mon-Tues or Wed-Thur), and all participants participated in typical daily work routines (approximately 0730 to 1630). On each of the 2 d, samples were obtained at 0900 and 1930. Participants were instructed not to brush or floss their teeth, eat, or drink, and to rinse their mouth with cool water immediately prior to sampling. They were also asked not to engage in physical activity during the 2-d sampling period. Participants signed a statement of compliance during this period stating that they had not used any substances or medications 12 h prior to or during the data collection period. Salivary cortisol was measured using a Coat-A-Count radioimmunoassay kit (Diagnostic Products Corporation, Los Angeles, CA). It was measured with sensitivity (detectability) of  $0.7\text{--}55.2\text{ nmol} \cdot \text{L}^{-1}$  and intra and interassay coefficients of variation of 3–7% and 5%, respectively. Additionally, salivary DHEAS was measured using a radioimmunoassay kit (Diagnostic Systems Laboratories, Inc., Webster, TX). It was measured with sensitivity of  $0.1\text{--}30.0\text{ ng} \cdot \text{mL}^{-1}$  and intra and interassay coefficients of variation of 5–7% and 6%, respectively. The assessment of DHEAS was added to our

protocol later in our study with the intent of more fully characterizing the endocrine response. Therefore, DHEAS is analyzed in only a subset of the sample. Average baseline values were calculated for salivary cortisol ( $N = 19$ ), DHEAS ( $N = 12$ ), and the DHEAS-cortisol ratio ( $N = 12$ ) [(Day 1 + Day 2)/2] at 0900 and 1930, respectively [i.e., free-living condition (FL)]. Subsequently, during the captivity phase of survival training [i.e., stressful captivity (SC)], salivary samples were obtained approximately at the corresponding time points (0900 and 1930). DHEAS-cortisol ratios [DHEAS (ng/mL)/cortisol (nmol/L)] were calculated at both time points, during both conditions (FL and SC).

#### *Clinician-Administered Dissociative States Scale (CADSS)*

The 19 self-report items from the CADSS (5) were used to assess the frequency and intensity of state symptoms of dissociation. Although the CADSS includes additional items used for clinical observation of the participant, the 19 self-report items have been shown to comprise a valid, reliable, and independent indicator of dissociative state symptoms (20). The scale was administered to participants immediately after a high-intensity, captivity-related challenge during SC. This scale is designed to assess how perceptually connected or disconnected an individual is relative to the individual's environment. Examples of items include: "Did you feel as if you were watching the situation as an observer or spectator?"; "Did you space out or in some way lose track of what is going on?"; and "Did you feel as if you were looking at things outside of your body?". The self-report scale is composed of 19 items, rated on a Likert scale of 0 (not at all) to 4 (extremely), with a possible total score of 76. Participants were asked to respond to the questions relative to the high-intensity captivity-related challenge. Cronbach's alpha reliability for CADSS in the present study was 0.83, and the mean CADSS score was 28.5 (SD = 10.7).

#### *Military Performance*

During SC, students were graded on several observed survival target skills during both high- and low-intensity captivity-related challenges. As reported elsewhere, these skills enhance the likelihood of survival (18). Scores reported here reflect the sum of the target skills that students are expected to demonstrate during the captivity-related challenge. Additionally, because of the focus of the current research on identifying individual differences in stress resilience, an individual "resilience" score is also reported. Overall performance scores and resilience scores are reported for both a low- (OP-Low) and high-intensity captivity-related challenge (OP-High). These performance scores were developed by military experts, independent of this research. Higher scores are indicative of better performance.

#### *Impact of Events Scale-Revised (IES-R)*

The IES-R (32) is a self-report measure designed to assess current subjective distress for any specific life event.



It has 22 items, comprising 3 subscales corresponding to DSM-IV-specified PTSD symptoms: avoidance (IES-Avoid; mean of 8 items measuring the extent to which the respondent avoids situations that remind him or her of the stressful or traumatic event), intrusion (IES-Intrusion; mean of 8 items assessing the extent to which one experiences intrusive thoughts), and hyperarousal (IES-Arousal; mean of 6 items measuring anger, irritability, heightened startle response, and hypervigilance). The total impact of events score (IES-Total) is composed of the sum of the three subscales. In the present study, at the conclusion of survival training, respondents were shown a list of difficulties people sometimes have after stressful life events, and were asked to indicate how distressing each difficulty has been with respect to the high-intensity situation encountered during captivity on a scale of 0 (not at all) to 4 (extremely). Adequate reliability and predictive validity have been shown for this scale (6,29) and Cronbach's alpha reliabilities in the present sample were 0.75, 0.81, and 0.79 for IES-Arousal, IES-Avoidance, and IES-Intrusion, respectively. Cronbach's alpha reliability for IES-Total was 0.91.

#### Data Analysis

Data were analyzed using SPSS software, version 15 (SPSS, Inc., Chicago, IL). Analyses included descriptive statistics, analysis of variance (ANOVA) with repeated measures, and bivariate correlations. Descriptive statistics were used to summarize the physical and demographic characteristics of the sample. A  $2$  (0900 vs. 1930)  $\times$   $2$  (FL vs. SC) repeated-measures ANOVA with follow-up *t*-tests examined differences in cortisol between FL and SC conditions. Percent change scores from FL to SC  $[(SC - FL)/FL]$  were also calculated for each participant at each time point (0900 and 1930, respectively). These analyses were repeated with DHEAS and DHEAS-cortisol ratios as the dependent variables. Pearson product-moment correlations were performed to examine relationships among endocrine responses, objectively measured performance, peritraumatic dissociative symptoms, and subsequent impact of events. All hypothesis tests were two-sided and the probability of committing a type I error was set at 0.05.

## RESULTS

Mean age, body mass index, and years of military service for this sample were 21.5 yr (SD = 1.7),  $24.2 \text{ kg} \cdot \text{m}^{-2}$  (SD = 1.6), and 1.5 yr (SD = 0.9), respectively. Of the 19 subjects, 14 subjects (73.7%) had received a high school education and 5 (26.3%) were college educated. All subjects were Caucasian. Regarding military occupational specialties, 14 subjects (73.7%) were students under instruction to become Aviation Warfare Specialists/Rescue Swimmers, while the remaining 5 (26.3%) were students under instruction to become Special Warfare/SEAL Officers. Specifically, the Aviation Warfare members had completed the majority of their coursework to receive their warfare designation and were awaiting graduation and subsequent assignment to SERE training. Similarly,

the Special Warfare members had graduated from Basic Underwater Demolition/SEAL training and were awaiting enrollment in SERE school as a component of SEAL Qualifying Training – a 6-mo series of advanced training experiences prior to receiving their warfare designation.

Mean cortisol values during FL were  $9.2 \text{ nmol} \cdot \text{L}^{-1}$  (SD = 3.4) at 0900 and  $3.5 \text{ nmol} \cdot \text{L}^{-1}$  (SD = 3.0) at 1930, while mean cortisol values during SC were 18.4 (SD = 10.5) at 0900 and  $27.7 \text{ nmol} \cdot \text{L}^{-1}$  (SD = 10.9) at 1930. A repeated-measures ANOVA yielded a significant interaction [ $F(1,18) = 42.9$ ,  $P < 0.001$ , observed power = 1.0], such that cortisol concentrations were higher in the morning than in the evening during FL (indicative of the normal diurnal pattern), but increased substantially from morning to evening during SC. Mean cortisol values increased significantly in response to SC at both time points [0900:  $t = 4.1$ ,  $P < 0.001$ , mean percent  $\Delta = +113\%$  (SD = 120); 1930:  $t = 10.2$ ,  $P < 0.001$ , mean percent  $\Delta = +1388\%$  (SD = 1335)] (Fig. 1A).

Mean DHEAS values during FL were  $1.7 \text{ ng} \cdot \text{mL}^{-1}$  (SD = 1.3) at 0900 and  $1.5 \text{ ng} \cdot \text{mL}^{-1}$  (SD = 0.8) at 1930; during SC, DHEAS values were  $6.7 \text{ ng} \cdot \text{mL}^{-1}$  (SD = 3.5) at 0900 and  $4.5 \text{ ng} \cdot \text{mL}^{-1}$  (SD = 3.0) at 1930. A repeated-measures ANOVA revealed a significant overall effect of SC on DHEAS concentrations [ $F(1,11) = 18.3$ ,  $P < 0.001$ ; observed power = 0.97]. As shown in Fig. 1B, mean DHEAS values increased significantly in response to SC at both time points [0900:  $t = 5.4$ ,  $P < 0.001$ , mean percent  $\Delta = +381\%$  (SD = 284); 1930:  $t = 4.1$ ,  $P < 0.01$ , mean percent  $\Delta = +207\%$  (SD = 138)]. DHEAS values were significantly higher in the morning compared with evening hours during SC, but this downward shift was not evident during the FL condition.

To further explore DHEAS responses in relation to cortisol responses, a repeated-measures ANOVA was also used to determine whether the DHEAS-cortisol ratio differed significantly from FL to SC. A significant interaction was observed [ $F(1,11) = 18.1$ ,  $P < 0.001$ , observed power = 0.97]. Mean DHEAS-cortisol ratios increased significantly from FL to SC at 0900 [ $t = -3.0$ ,  $P < 0.01$ , mean percent  $\Delta = +130$  (SD = 159)]; conversely, DHEAS-cortisol ratio scores decreased significantly from FL to SC at 1930 [ $t = 3.2$ ,  $P < 0.01$ , mean percent  $\Delta = -69$  (SD = 20)] (Fig. 1C).

A nonsignificant inverse trend was observed between overall performance during a high-intensity, captivity-related challenge (OP-High) and DHEAS at 0900 during SC ( $r = -0.51$ ,  $P = 0.10$ ). Inverse relationships emerged between OP-High and the DHEAS-cortisol ratio ( $r = -0.60$ ,  $P < 0.05$ ) at the 0900 time point during SC ( $N = 12$ ). Also, inverse relationships were also observed between OP-High and percent change (FL to SC) in DHEAS ( $r = -0.65$ ,  $P < 0.05$ ) and DHEAS-cortisol ratio ( $r = -0.61$ ,  $P < 0.05$ ) measured at the 1930 time point ( $N = 12$ ). An objectively measured score of resilience during the same challenge was positively associated with cortisol concentrations ( $r = 0.56$ ,  $P < 0.01$ ) and inversely related to DHEAS-cortisol ratios at 0900 during SC ( $r = -0.70$ ,  $P < 0.01$ ) ( $N = 12$ ). Overall performance during

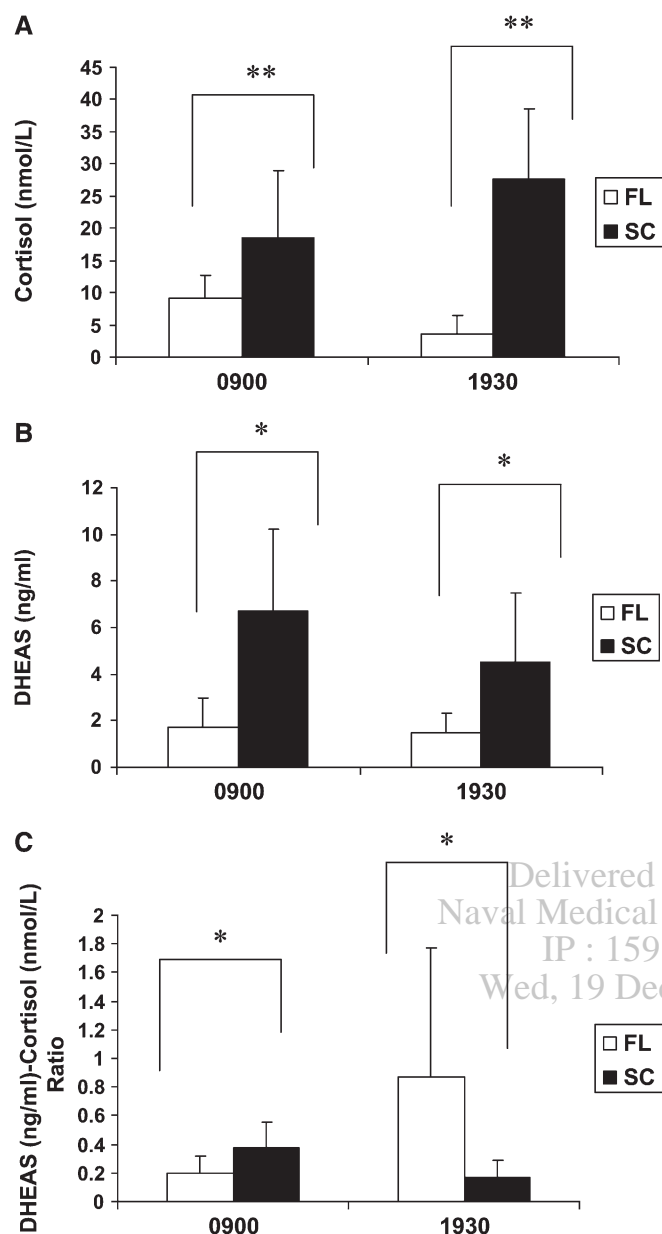


Fig. 1. FL vs. SC comparisons for: A) cortisol; B) DHEAS; and C) DHEAS-Cortisol ratio. All values are mean  $\pm$  SD.  $P$ -values are provided for post hoc comparisons across conditions at each time point: \*  $P < 0.01$ ; \*\*  $P < 0.001$ .

a low-intensity, captivity-related challenge (OP-Low) was positively associated with DHEAS during SC at the 0900 time point ( $r = 0.59$ ,  $P < 0.05$ ) and a significant trend emerged between OP-Low and the DHEAS-cortisol ratio at the same time point ( $r = 0.55$ ,  $P = 0.06$ ) ( $N = 12$ ).

Dissociative symptoms (as measured by the CADSS) during the high-intensity captivity-related challenge did not relate to any of the endocrine indices during SC or percent change of the endocrine indices from FL to SC. There was also no relationship between dissociative symptoms and OP-High. IES-Avoid was positively associated with cortisol concentrations during SC at 0900 ( $r = 0.55$ ,  $P < 0.05$ ) as well as percent change in cortisol (FL to SC) at 0900 ( $r = 0.52$ ,  $P < 0.05$ ). Similarly, IES-

Intrusion was associated with cortisol concentrations during SC at 0900 ( $r = 0.58$ ,  $P < 0.05$ ) as well as percent change in cortisol at this same time point ( $r = 0.52$ ,  $P < 0.05$ ). IES-Arousal was inversely associated with the percent change in DHEAS-cortisol ratio at the 0900 time point ( $r = -0.71$ ,  $P < 0.05$ ) and the 1930 time point ( $r = -0.74$ ,  $P < 0.05$ ). Finally, IES-Total demonstrated inverse associations with percent change in DHEAS at the 1930 time point ( $r = -0.69$ ,  $P < 0.05$ ).

Dissociative symptoms measured immediately after the high-intensity, captivity-related challenge predicted the subsequent impact of events. Specifically, positive associations were observed between dissociative symptoms and IES-Avoid ( $r = 0.57$ ,  $P < 0.01$ ), IES-Intrusion ( $r = 0.48$ ,  $P = 0.06$ ), and IES-Total ( $r = 0.53$ ,  $P < 0.05$ ).

## DISCUSSION

The present study was initiated to extend our understanding of cortisol and DHEAS responses to the stress of military survival training, and to evaluate the relationships to human performance as well as key symptoms of PTSD. We demonstrated robust increases in both cortisol and DHEAS in response to the stress of survival training. Additionally, we noted possible intensity-dependent relationships between endocrine indices and performance during the high-intensity challenge, but both were positively associated with performance during the low-intensity challenge. Finally, as hypothesized, cortisol reactivity to SC tended to exacerbate, and DHEAS tended to ameliorate, the subsequent impact of stressful, captivity-related events.

As expected, we observed robust increases in both cortisol and DHEAS in response to SC, evidenced by 1.1- to 13.8-fold increases in cortisol and 2.1- to 3.8-fold increases in DHEAS. These results are in general agreement with prior findings (20–22). Specifically, Morgan and colleagues examined cortisol reactivity to survival training in 72 Army personnel (21,22), and showed that cortisol increased substantially during captivity, and peaked directly after stressful, captivity-related challenges. These findings were subsequently replicated in a sample of 25 Navy personnel at a separate survival training facility (19). Similarly, these same researchers showed that DHEAS levels increased substantially in the Navy personnel during the captivity phase of survival training (20).

We also observed intensity-dependent relationships between endocrine indices and military performance during captivity-related problems. During a high-intensity challenge, overall performance scores were inversely associated with DHEAS as well as the DHEAS-cortisol ratio. During the low-intensity challenge, however, positive relationships were observed. Although not examining differences between high- and low-intensity challenges, previous research has shown positive relationships between percentage of free cortisol and military performance during captivity challenges (22) and, by

contrast, inverse relationships between salivary cortisol and performance (20). These researchers have also observed positive relationships between the DHEAS-cortisol ratio and performance (20). Comparison of the present findings with past research is complicated by the fact that different captivity-related challenges may have been examined, and different performance metrics may have been implemented, neither of which is publicly available. These findings may be considered in light of two well-known models of stress and performance: the inverted U (Yerkes-Dodson) hypothesis, which states that an optimal task-specific level of arousal is conducive to optimal performance (34) and the General Adaptation Syndrome, which states that one's capacity to mount a response in light of continued application of stress eventually erodes, leading to exhaustion (30). Studies with larger samples specifically designed to examine the endocrinological bases of the stress-performance relationship are needed to adequately test these relationships, which exceeds the scope of the present study.

In the present study, dissociative symptoms during the high-intensity, captivity-related challenge did not relate to any of the endocrine indices during SC or percent change from baseline to SC. In recent survival training research, Morgan et al. (20) noted positive relationships between dissociative symptoms reported after a captivity-related challenge and salivary cortisol, as well as inverse relationships with DHEAS values during SC. In that study, the dissociation measure was administered after the conclusion of survival training rather than directly after the stressful event, and participants were instructed to report dissociative symptoms with respect to the entire captivity experience. Another study by Morgan and colleagues (22) reported an inverse relationship between salivary cortisol and dissociative symptoms during a captivity-related challenge. In that study, participants completed the questionnaire after the captivity experience but were instructed to answer the questions specifically with respect to the captivity-related challenge. These subtle methodological differences may account for discrepancies across these studies.

We identified no relationship between dissociation and overall performance during the high-intensity challenge. In previous studies (10,20,22), dissociation has been linked with poor military performance during captivity-related challenges. As noted earlier, comparing present findings and past research is complicated by the fact that different captivity-related challenges and different performance metrics might have been implemented.

To our knowledge, the assessment of endocrine indices during acute military stress and subsequent assessment of impact of events is unprecedented. These preliminary findings support our hypothesis that both cortisol and DHEAS responses during SC may influence subsequent psychological impact, albeit in contrasting ways. Specifically, cortisol may play a more central role in exacerbating intrusive thoughts and avoidance of situations that trigger memories of the stressful event. By contrast, the DHEAS-cortisol ratio may buffer against

heightened physiological arousal (e.g., hypervigilance, increased startle reflexes) occurring subsequent to stressful or traumatic events. More research is needed to confirm and extend these findings.

Finally, we observed links between dissociative symptoms during SC and the subsequent impact of events, which may provide operationally relevant support for the relationship between peritraumatic dissociation and subsequent development of PTSD (2,7). Current literature across a variety of nonmilitary traumatic contexts suggests that participants reporting more peritraumatic dissociation are at greater risk for developing PTSD (29), although this notion has been challenged (7).

#### *Limitations and Future Research Directions*

There are several limitations of this study. To begin, this study has a relatively small sample size. Another limitation is that subjects self-collected the salivary samples during the free-living component of the study and were not subject to direct oversight from the research team. To address this, participants were given clear and concise directions regarding administration, and the importance of punctuality was expressed repeatedly by the research staff. A further limitation is that the survival-training curriculum is fluid, possibly limiting the extent to which participants are exposed to identical types and order of stressors. However, the operationally relevant testing environment of SERE dramatically enhances the generalizability of our findings and counterbalances this limitation to a certain extent. Finally, logistical requirements occasionally resulted in delayed salivary sampling (up to 90 min) during the captivity phase of survival training. Although cortisol concentrations would be sensitive to such a delay during FL conditions, during the SC condition diurnal patterns were overridden by the intensity of the survival training stressor. Finally, logistical limitations prevented the collection of more endocrine data points across the day, during both the FL and SC conditions.

Additional research is needed to clarify the relationships of endocrine indices to military performance during SERE training. Also, it would be of interest to build upon the current body of knowledge in this area by examining the usefulness of interventions to enhance resilience and performance during training. For example, nutritional and/or pharmacological supplementation may be explored. Additionally, it is likely that there is an optimal set of coping skills that can improve performance during training, particularly during the captivity-related challenges. These coping skills, once identified, could be taught during initial didactic phases of training so that students can apply them during the practical phase. Moreover, other psychophysiological and neuroscientific predictors of stress reactivity and performance during SERE training should be studied. Functional magnetic resonance imaging technology, for example, holds great promise for identifying brain regions that may have functional significance with respect to stress responses, performance, dissociation, impact of events,



and subsequent memory of events. Heart rate variability is another useful technology that has received some attention as a predictor of performance during SERE training (18). On a final note, the limited diurnal variation in DHEAS suggests that this ligand may be a better proxy of physiologic stress than cortisol; stress researchers may consider using it as an alternative marker of physiologic stress in operational research.

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## 14. ABSTRACT (maximum 200 words)

**Introduction:** Cortisol, the primary glucocorticoid, is the end product of hypothalamic-pituitary-adrenal activation and is responsible for stimulating blood glucose for energy and increasing blood pressure in support of the stress response. However, extreme and/or chronically high cortisol levels can have neurotoxic effects. By contrast, dehydroepiandrosterone sulfate (DHEAS), a precursor to the male sex hormone testosterone, is cosecreted with cortisol and is thought to confer neuroprotection during stress. Here we document the responsiveness of both cortisol and DHEAS to the stress of survival training in military men and evaluate relationships to performance and the subsequent impact of events that occurred during training. **Methods:** Baseline salivary cortisol samples were self-administered by 19 men (mean age = 21.5 years [SD = 1.7]) at 0900 and 1930 in a free-living environment and were averaged across 2 days to estimate the diurnal pattern. DHEAS samples were also collected in a subset of this sample (n = 12). Samples were subsequently taken at similar time points during a captivity phase of survival training. Repeated-measures analyses of variance with follow-up paired *t* tests examined differences across time and conditions. **Results:** Significant increases were observed at both time points (0900 and 1930) in response to acute stress in both cortisol (0900: mean  $\Delta$  = +113% [SD = 120],  $p$  < .001; 1930: mean  $\Delta$  = +1388% [SD = 1335],  $p$  < .001) and DHEAS (0900: mean  $\Delta$  = +381% [SD = 284]; 1930: mean  $\Delta$  = +207% [SD = 138],  $p$  < .01). Also, overall performance during a high-intensity captivity-related problem was inversely related to the DHEAS–cortisol ratio ( $r$  = -.61,  $p$  < .05); conversely, overall performance during a low-intensity captivity-related problem was positively related to DHEAS during captivity at the 0900 time point ( $r$  = .59,  $p$  < .05). Dissociation was unrelated to neuroendocrine indices measured during acute stress, while total impact of events was inversely related to percent change in DHEAS from free living to acute stress ( $r$  = -.69,  $p$  < .05). **Conclusions:** Cortisol and DHEAS increase in response to allostatic load, and may relate to human performance during acute stress as well as to key symptoms of posttraumatic stress disorder.

## 15. SUBJECT TERMS

stress resilience, coping strategies, cortisol

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