Conference paper

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Special Forces Selection Involving Neuroendocrine Stress Markers: Future Directions in Human Reliability Analyses

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Abstract

Special Forces (SF) selection applications include diverse forms of human reliability analyses. The current paper reports from a field experiment during an extremely strenuous prisoner of war (POW) exercise within the Belgian SF selection procedure. Twenty-seven SF candidates (M = 27.4 years, SD = 5.1) were randomly assigned to a no-stress control group (n = 14) or to a high-intensity stress group (n = 13). Immediately after stress or control treatment, candidates' coping capabilities were assessed through standardized cognitive (digit span test and Rey-Osterrieth complex figure). Concurrently, stress levels were assessed subjectively (NASA task load index) and objectively by obtaining salivary cortisol assays as neuroendocrine stress markers. As expected, exposure to POW stress led to significant differences in subjectively perceived stress, robust increases of cortisol concentrations, and substantially deteriorated cognitive performance. Interestingly, in the stress group, cognitive performance outcomes correlated negatively with cortisol reactivity. Furthermore, distinct differences between high and low cortisol responders were observed with respect to the stress reaction. Incited by the latter bottom-up approach, the authors discuss potential future directions in naturalistic stress research that involve endocrinological stress markers to detect individual differences in the response to stressors. Potential promising fields of application in the military appear to be the assessment of training aimed at stress reduction, cognitive reliability analyses, and – in a later stadium – improved predictive validity of the selection process of high-reliability professionals such as SF operators.

Keywords: *Cognitive performance, Digit span test, High-intensity stress, NASA TLX, Glucocorticoids, Human reliability analyses, Rey-Osterrieth complex figure*

Registration and testing protocols for the empirical study were submitted to and approved by the standing ethics committee of the Open University, the Netherlands.

Introduction

Following an early 2005 meeting at the International Long Range Reconnaissance Patrol School at Pfullendorf, Germany (currently the International Special Training Centre, I-Wing), a thorough revision of the Belgian Special Forces (SF) selection procedure was started up. During that meeting, SF selection officers from diverse NATO members met to discuss solutions for several critical issues such as the decreased influx of SF candidates and the (extremely) high attrition during training. A broad range of potential options – which paralleled both the number of participants, and their respective national interests and specificities – emerged from the meeting. The Belgian plan to resolve the critical shortfalls in SF recruitment and, more generally, the unit's incomplete effectives encompassed a combination of short, mid, and long-term measures. One of the mid-term options was a substantial review of the selection procedure.

The new SF selection procedure, besides the traditional medical and psychological tests, culminated in a strenuous five-days 'Selection Week'. The selection week was conceived as an assessment centre application, based upon some of the best available practices in selection, and that focused on candidates' intrinsic stress resistance and their coping abilities under adversity. More specifically, the program has been developed in close cooperation with a SF officer and was composed of highly demanding physical, mental, and cognitive SF job samples. Some of the main principles were that (1) the program was unknown to the candidates – who were regularly hoodwinked with regard to the actual purpose of an activity, (2) participants were assessed anonymously (based upon a chest number), and (3) feedback was only provided formally at the end of the procedure. One of the activities throughout the selection week was a combined exercise (CombEx).

Although an extensive elaboration on CombEx and its method of stress exposure exceeds the scope of this paper (some parts of the exercise are confidential), a brief description seems warranted to fully appreciate its findings. CombEx starts with a brusque capture that unexpectedly interrupted a bogus façade exercise. The exercise further contains the main ingredients of a relatively brief, albeit intense SF mission, of which the core simulates a mock POW situation. Here candidates are exposed to a concise, albeit extremely strenuous prisoner of war (POW) treatment. As such, CombEx has conceptual similarities with the U.S. 'Survival, Evasion, Resistance, and Escape' (SERE, 1985) program. Irrespective of the similarities, however, CombEx had been developed to exploit absolute unexpectedness and uncontrollability to assess candidates' shock resistance, resilience, and subsequent capacity for reengagement (e.g. the physical, mental, and cognitive ability to start a new mission under extremely stressful circumstances). Accordingly, the CombEx set-up provided an ideal opportunity to perform human reliability analyses under extreme stress.

Throughout three subsequent selection applications (to different candidates), CombEx proved to be fully satisfactory with respect to its primary objectives – stress induction and subsequent assessment of candidates' shock resistance. However, in a continuous effort to improve the entire selection procedure, it was decided to submit CombEx to a thorough test, which included in-depth stress assessments with cortisol as biomarker and a refinement of the applied cognitive performance measures.

Cognitive reliability assessment

Cognitive reliability analysis is an emerging branch in the broader field of human factors research. In so-called "high-reliability occupations" (Flin 2002, p. 255), stress management capabilities and appropriate cognitive functioning under dangerous, non-routine circumstances are key issues. High-reliability professionals, such as SF operators, are characterized by the ability to function under conditions of high-demands with fatal outcomes in case of failure. In effect, the ability to effectively cope with stress and act with calmness in crisis are commonly required performance characteristics. This requires the best knowledge available to warrant their appropriate cognitive functioning during stressful events (Bartone et al. 2008; Delahaij et al. 2011). Empirical work, however, in this domain is very limited, particularly when it involves in-depth stress analyses with endocrinological markers (e.g. cortisol secretion; Dickerson & Kemeny, 2004) and cognitive outcome measures in operational settings (Harris et al. 2008).

Exposure to stress is known to trigger a number of psychophysiological reactions, of which many are related to the stress-responsive hypothalamic-pituitary-adrenal (HPA) axis. Although its exact mechanisms are not yet entirely clear, the HPA axis seems to respond to stress with the secretion of glucocorticoids according to a dose-response relationship (Joëls et al. 2006; Kudielka et al. 2009). Glucocorticoid regulation (primarily cortisol in humans) is a protective HPA reaction that mobilizes energy for coping with the stressor, but also shuts down the initial fight or flight response of the sympathetic nervous and the immune systems to prevent them from overshooting and damaging vital bodily functions (Munck 2000).

Besides, ample research has demonstrated that the secretion of cortisol modulates learning and memory. Although the precise direction of impact is still somewhat ill-understood, there are indications that cortisol secretion during acute stressful events may have facilitating as well as disruptive effects on cognitive performance (Het et al. 2005; Smeets et al. 2008; Wolf 2009). These dual effects have led to suggestions of an inverted U-curve to characterize the relationship between learning and cortisol secretion (e.g. Abercrombie et al. 2003; Andreano & Cahill 2006). Animal research, primarily in rodents, attributes this relationship to divergent corticosteroid affinities in the brain of mineralocorticoid (MR; with a high affinity for cortisol) and glucocorticoid receptors (GR; with a significantly lower affinity for cortisol) (McEwen & Sapolsky 1995). While memory facilitation seems to occur when MRs are fully and GRs only partially occupied; it is only when GRs become fully saturated that a decline in cognitive performance is observed (Abercrombie et al. 2003).

Cortisol effects have been frequently linked to declarative memory, involving the amygdala, the hippocampus, and associated brain regions (Joëls et al. 2006; Shin et al 2006; Wolf 2009). Recent findings, however, demonstrate that stress not only affects declarative memory, but also influences working memory (WM; Oei et al. 2006; Schoofs et al. 2009, 2008). Known brain areas involved in WM functioning are in general prefrontal and parietal brain structures (Lezak et al. 2004; Müller & Knight 2006). A meta-analysis on brain imaging studies by Cabeza and Nyberg (2000) revealed that WM is almost always associated with increased activity in the prefrontal cortex (PFC). More specifically, the left dorsolateral PFC is activated for during verbal WM tests and the right during spatial WM tasks. Recent functional magnetic resonance imaging (fMRI) research confirmed these findings, as acute stress, elicited by viewing extremely violent movie clips, reduced the WM-related right-hand side dorsolateral PFC activity and reallocated neural resources away from executive function networks (Qin et al. 2009).

The influences of moderate stress levels on cognitive functioning have been extensively researched under lab conditions (for reviews, see: Chida & Hamer 2008; Dickerson & Kemeny 2004). However, a meta-analysis by Dickerson and Kemeny (2004 p. 359) found that the endogenously evoked right-hand side of the inverted U-curve, including the effects of realistic high-intensity stress on memory performance, “[…] has been remarkably scarcely investigated in empirical research.” An exception is the work by Morgan and colleagues. In a decade of research examining the impact of intense stress in special military populations, Morgan et al. (2000) found strong (serum and salivary) cortisol increases during stressful military exercises. Follow-up studies, under similar circumstances, extended these findings and found potent hormonal increases (plasma cortisol, catecholamines, and neuropeptide Y), as well as evidence of dissociation and of relationships with diminished (military) performance (Morgan et al. 2004, 2002, 2001). Morgan et al. (2006) examined the effects of acute stress during SERE (1985) training. Interestingly, the authors included the Rey-Osterrieth complex figure (ROCF; Knight & Kaplan 2003), a renowned test for WM and visuo-spatial abilities, and showed that SERE training yielded significant deficits in cognitive performance. However, they did not focus upon neuroendocrine alterations.

The current study

Cognitive ability is generally assessed through tasks that require participants to store and process increasing amounts of information until the point at which recall errors are made (Alloway 2006; Lezak et al. 2004). For the current study, standardization and predictive validity were the most important test prerequisites. The ease of administration and univocal instructions to promote uniformity and experimental control in field conditions were other important requirements. Finally, the sensitive SF environment obliged the research team to introduce tests with high face validity, of a short duration, and that could be visually administered to avoid linguistic biases, given the Belgian bilingualism. The Digit Span test (DS; in which numbers represent map coordinates or radio frequencies) for WM (Lezak et al. 2004; Wechsler 1987) and the ROCF (simulating memorization and reporting of an unknown target) as a test for visuo-spatial capacity within declarative memory (Knight & Kaplan 2003; Shin et al. 2006), were chosen because they all satisfied the constraints mentioned above.

Consistent with the dose-response theorem of cortisol regulation and the inverted U-curved relationship between cortisol secretion and learning (Joëls et al., 2006; Kudielka et al., 2009), the following effects were hypothesized:

1. Robust increases in cortisol levels for the high-intensity stress group (vs. no-stress control) – exceeding 200%, the commonly observed maximal increase under lab stressor exposure.
2. Endogenous cortisol regulation would fully saturate the GRs (Abercrombie et al., 2003), leading to a significant decline in cognitive performance (as measured with the DS test and the ROCF) for the high-intensity group (vs. no-stress control).

3. Subjective and objective (salivary free cortisol responses) stress measurements would be significantly correlated (vs. no-stress control)
4. In the stress group, the cortisol increase would be significantly and inversely correlated with the cognitive performance indicators (the DS test and the ROCF).

Method

Participants

Participants were 27 healthy, physically fit males with normal body mass indexes. Ages ranged from 21 to 37 years (M = 27.4, SD = 5.1). All were active duty Belgian Armed Forces that volunteered as SF candidates. Participants were preliminarily medically tested (e.g. for cardiovascular deficiencies), and on location controlled for endocrine disorders and the use of medication. Because of the reported use of medication by one participant, these data were excluded from further analyses.

Measures and Materials

Saliva sampling and cortisol analyses. Salivary cortisol samples were collected by cotton roll devices (Salivette®; Sarstedt, Etten-Leur, the Netherlands) and stored at -20°C immediately after collection. Subsequently, the samples were thawed, numbered, and centrifuged at 3000 rpm, 4°C for 5 min at the Dresdner Technical University LabServices. Salivary free cortisol was analyzed using a commercial chemiluminescence immunoassay (IBL Hamburg, Germany). Samples from same subjects were analyzed in a single run to reduce error variance. Inter- and intra-assay coefficients of variation were below 10%.

NASA Task Load Index. Subjective allostatic task (over)load was measured as a proxy of stress by the NASA Task Load Index (TLX) (Hart & Staveland 1988). The TLX is a multi-dimensional rating scale, designed to obtain estimates from participants while performing a task or shortly afterwards. TLX combines information about the magnitude of six task load-related subscales; mental demands, physical demands, time demands, own performance, effort, and frustration. The scale has been extensively applied in research and is considered a highly sensitive assessment technique (Rubio et al. 2004). Total scores were obtained by summing raw scores of the six subscales, presented as Likert scales ranging from 0 to 20. High scores represented high stress levels.

Digit Span Test. The DS paradigm has been linked to performance on intelligence tests and problem solving (Sternberg 2003), and is often used as a free-standing performance measure in WM research (Axelrod et al. 2006). A computerized version of the standard DS test was used as a measure of WM (Wechsler 1987). Testing procedures followed the digits forward (DF) and digits backward (DB) paradigm. Participants were presented four to nine digits for immediate recall (one by one, at a rate of one per second). As prescribed for healthy participants (Lezak et al. 2004), total scores were obtained by combining forward and backward component scores.

Rey-Osterrieth complex figure. The Rey-Osterrieth complex figure (ROCF) is one of the most widely used neuropsychological tests for the evaluation of non-verbal learning, planning, and WM. In the immediate recall paradigm, the figure permits the assessment of visuo-spatial abilities within declarative memory (for a review see Knight & Kaplan 2003; Shin et al. 2006). A computerized version of the ROCF (Figure 1) was presented in black-on-white for 45 seconds and with a size-on-screen of 12x8 cm, according to the intentional, single trial, immediate recall protocol (Knight 2003b). Considering that low variability of the ROCF copy scores has been reported in healthy subjects (Shin et al. 2006), the copy phase was excluded to avoid ceiling effects. Participants subsequently had 3 min for immediate recall. The ROCF was scored double-blind with the Denman Scoring System (DnSS; Knight 2003a).

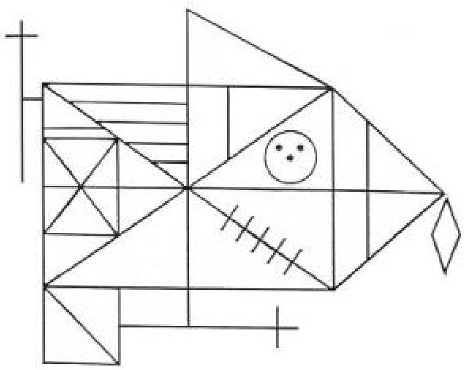


Figure 1. The Rey-Osterrieth complex figure as presented during the experiment.

Control Measures. In the CombEx situation two control measures for individual differences were thought to be of interest: (1) the impact of formerly experienced traumatic stress was tapped with the Impact of Event Scale-Revised (IES-R) (Creamer et al. 2003; Weiss & Marmar 1997). The 22 items of the IES-R are divided over three subscales (intrusions, hyperarousal, and avoidance) that parallel the DSM-IV criteria for PTSD. Participants were instructed to complete the scale while recalling the most impactful event in their lives. Answering possibilities ranged from 0 (not at all) to 4 (extremely); and (2) Personality Hardiness (PH) was assessed by the revised 15-item Dispositional Resilience Scale (DRS15-R). PH is characterized by (self)perceptions on three sub-dimensions: commitment, control, and challenge (Maddi et al. 2006). Higher levels of PH have been shown to provide a natural advantage and are associated with increased outcome performance in both civilian and military stress research, notably with SF candidates (Bartone 2007; Bartone et al. 2008; Eid & Morgan 2006). Answering possibilities ranged from 0 (not at all true) to 4 (completely true).

Procedure

Screening and preparation. Participants voluntarily engaged in the official SF selection process. Approximately one month prior to the selection phase, all went through a thorough medical screening that required the most stringent medical profile within the Belgian Armed Forces. Next, candidates passed a psychological test battery that included the NEO Personality Inventory-Revised (Costa & McCrae 1992) and the Generalized Cognitive Test Battery (GCTB), the standard Belgian Armed Forces cognitive ability test (Irvine 2006). The remaining candidates were invited into the SF selection week and signed a written informed consent at entry. Next, the candidates were instructed to remove all external identification marks (rank, brevets, and identity tags) and received a chest number to maximize selection objectivity. Candidates then enrolled into the assessment centre phase. In the course of day one, they collectively completed the IES-R and DRS15-R scales, and orally reconfirmed their informed consent during a semi-structured intake interview.

Experimental procedure. Participants were randomly assigned to the no-stress control group (n = 14) or the stress group (n = 13) for a between-subjects field experiment. Participants were tested individually and, to control for circadian cortisol rhythms, all tests fell between 19.00 and 22.00 hours. Participants were deprived of food, drinks, smoking, and did not perform heavy physical exercises at least 90 min prior to the cortisol measurements. They were not deprived of sleep the night before and all performed exactly the same daytime activities.

Participants were intentionally kept unaware of the program. Shortly after the cortisol baseline (C_0) measurement, those assigned to the no-stress control condition ran a 60 min non-intensive filler task (completing administration and a non-stressful weapon handling task), while the stress group was exposed to 60 min POW treatment. Behind the façade of a bogus non-stressful activity, the latter were brusquely captured and physically constrained (Phase I: 10 min, transportation included), confined (Phase II: 30 min), and subjected to a concise mock POW interrogation (Phase III: 15 min). Transportation towards the cognitive performance test area and test instructions for DS and ROCF took about 5 min. Individual timings were meticulously registered and all fell within a 60 ± 5 min interval.

Computer-administered testing procedures were identical for both conditions. Two cortisol samples were collected during the WM tests, one at onset (C_1 at T) and one 15 min later (C_2 at T+15). The time point for the start of the WM tests and, concurrently, the first cortisol measurement, 60 min after the start and about 15 min after termination of CombEx, was based on previous findings that indicated that these periods coincide with robust increases of stress hormones (Dickerson & Kemeny 2004; Joëls et al. 2006; Morgan et al. 2006). After CombEx, participants were instructed to reflect on their respective stress phases and to complete the TLX. Finally, all passed an obligatory clinical debriefing. Figure 2 shows the experimental set-up for both test conditions.

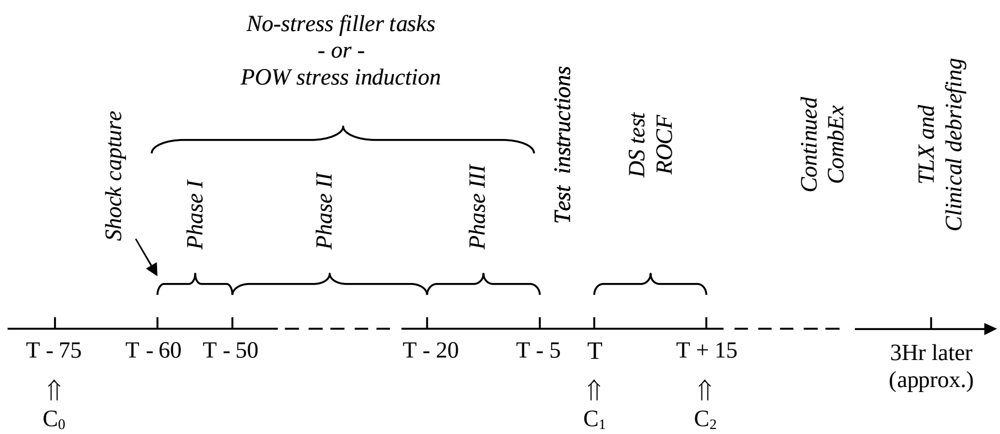


Figure 2. Experimental timeframe (minutes) for both groups (no-stress vs. stress), including: Baseline saliva sampling (C_0 at T-75), filler tasks or POW stress induction (Phases I, II, and III), test instructions, performance tests [Digit Span (DS) test and Rey-Osterrieth complex figure (ROCF)], cortisol saliva sampling (C_1 at T and C_2 at T+15), completion of NASA Task Load Index (TLX), and clinical debriefing.

Statistical analyses

The effect of high-intensity stress vs. no stress (TLX) was analyzed by an independent samples *t*-test (two tailed) and cortisol levels were analyzed with a mixed model analysis of variance (ANOVA) with Time (C_0, C_1, C_2) as repeated measure factor and Group (no-stress control vs. stress) as between group factor. Greenhouse-Geisser corrected *p*-values are reported when appropriate. Next, for each participant individual peak cortisol responses (ΔC) were computed. ΔC was defined as: $\Delta C = C_{Peak} - C_0$, and analyzed by two-tailed independent samples *t*-tests. For two participants in the no-stress control group, ΔC could not be calculated due to missing data. An additional Area Under Curve (AUC) computation, with respect to cortisol increase (AUC_{I_Cort}; Pruessner et al. 2003) was performed as a single measure of the total cortisol response. Potential differences in AUC_{I_Cort} were investigated using a two-tailed independent *t*-test. Memory performance on both the DS and the ROCF tests were analyzed by separate two-tailed independent samples *t*-tests (no-stress control vs. stress). As an indication of the DnSS's inter-rater reliability, a *post-hoc* Pearson correlation of 0.97 was found between the immediate (for selection purposes) and the experimental double-blind ROCF scores. IES-R and PH were analyzed by separate two-tailed independent samples *t*-tests. For all tests alpha was set at 0.05.

Results

There was no between-groups difference for the IES-R [($M_{no\text{-}stress} = 9.79$, SE = 2.52); ($M_{stress}$ = 12.38, SE = 1.72); [$t(25) = -0.84$; $p = 0.41$] and for PH [($M_{no\text{-}stress} = 36.21$, SE = 0.80); ($M_{stress}$ = 35.30, SE = 0.73); [$t(25) = 0.83$; $p = 0.41$]. Although there were no maximum scores observed on the PH measure, all participants scored above the 85^{th} percentile. Cortisol data were log-transformed (Ln) due to excessive skewness. Unless explicitly indicated, all further cortisol-related analyses were conducted with log-transformed data. Salivary cortisol pre-stress levels (C_0) did not differ between no-stress control (M = 1.34, SE = 0.22) and stress (M = 1.25, SE = 0.12) groups [$t(25) = 0.36$; $p = 0.72$].

After stress induction, the *t*-test on TLX scores yielded a significant difference between the no-stress control (M = 9.86, SE = 1.28) and stress group (M = 58.62, SE = 2.59) [$t(17.6) = -16.9$; $p < 0.001$]. It is noteworthy that a *t*-test between the physical load and time demands subscales were non-significant, thus signaling the exclusive mental-psychological nature of the stress exposure. The 2 (Group; no-stress, stress) x 3 (Time; C_0, C_1, C_2) mixed model

ANOVA also yielded a significant Group x Time interaction effect [Wilks' $\lambda = 0.28$, $F(2,24) = 30.99$; $p < 0.001$, partial $\eta^2 = 0.72$], a significant main effect of Time [Wilks' $\lambda = 0.43$, $F(2,24) = 15.82$; $p < 0.001$, partial $\eta^2 = 0.57$], and a significant main effect of Group [$F(2,24) = 50.32$; $p < 0.001$, partial $\eta^2 = 0.69$]. *Post-hoc* tests revealed no differences between the cortisol levels for the no-stress control group over time. In the stress group, however, salivary cortisol levels showed significant differences between C_0 and both C_1 ($M_{Difference} = -21.16$, SE = 2.70, $p < 0.001$) and C_2 ($M_{Difference} = -24.74$, SE = 3.16, $p < 0.001$), while C_1 and C_2 did not differ significantly ($p = 0.07$). The results of these analyses are shown in Figure 3. For information purposes only, Figure 3 represents differences in mean salivary cortisol increment in the stress group for high vs. low cortisol responders (cut-off by median split, after Smeets et al., 2006). Due to the restricted number of participants in the stress group, differences between high vs. low cortisol responders were not included in further analyses.

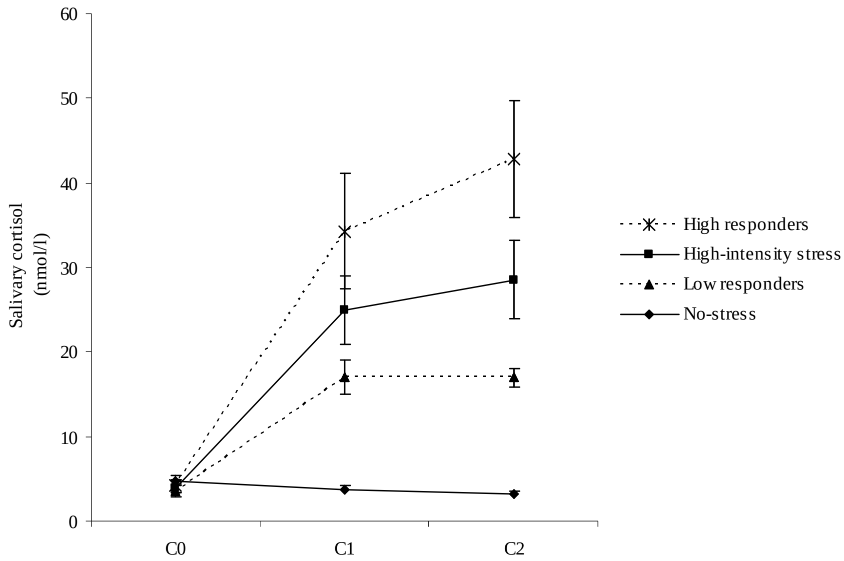


Figure 3. Salivary cortisol measures (means ± SEM) for the no-stress control (n = 14) vs. the stress group (n = 13) (C0 at T-75 min, C1 at T, and C2 at T+ 15 min). Exclusively for information purposes the figure includes differences in mean salivary cortisol increment for high (n = 6) vs. low cortisol responders (n = 7) in the stress group (cut-off by median split).

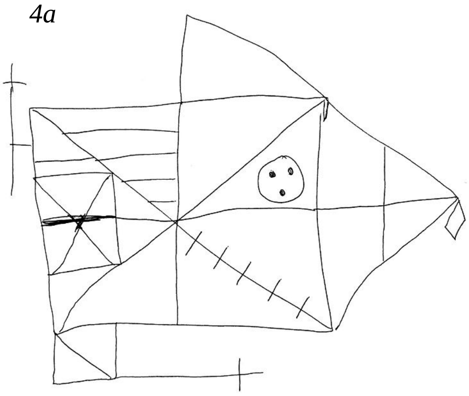
The Pearson correlation between subjective (TLX) and objective (ΔC) stress indicators was statistically significant, $r(25) = 0.89$, $p < 0.01$. Increases in salivary cortisol concentrations (ΔC) also differed significantly between groups in the independent samples *t*-test [$t(25) = -10.17$; $p < 0.001$], with untransformed means of -0.81 nmol/l (SE = 0.59) for the no-stress and

27.01 nmol/l (SE = 4.39) for the stress group. For the stress group, mean salivary cortisol response increases of over 600% were observed. As expected, individual differences in cortisol response were high, with a maximum increase of over 1,100%. Similarly, the no-stress control and the stress group differed significantly in terms of AUC_{I_Cort} [$t(25) = -9.96$; $p < 0.001$].

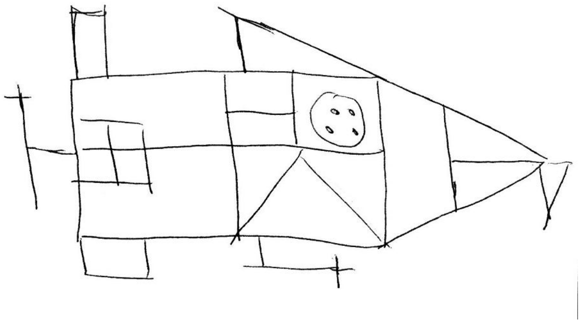
Mean DS scores of no-stress control (M = 11.36, SE = 1.09) and stress (M = 8.15, SE = 0.96) groups differed significantly [$t(25) = 2.20$; $p = 0.038$]. Specifically, mean performance scores for both groups in the DB paradigm (M = 5.64, SE = 0.51 vs. M = 4.08, SE = 0.45) also differed significantly [$t(25) = 2.30$; $p = 0.030$], while mean scores for the DF paradigm (M = 5.71, SE = 0.64 vs. M = 4.07, SE = 0.61) approached significance [$t(25) = 1.84$; $p = 0.078$]. Similarly, mean ROCF scores of no-stress control [(M = 53.36, SE = 1.94) and stress (M = 45.69, SE = 1.89); [$t(25) = 2.83$; $p = 0.009$] groups differed significantly. Within the stress group, correlation analyses addressed the relationship between ΔC, and DS and ROCF scores, respectively. ΔC and ROCF scores were found to be significantly correlated, $r(13) = -0.78$, $p \leq 0.01$, thus confirming the expected relationships, while ΔC and DS data confirmed this tendency [$r(13) = -0.48$, $p \leq 0.09$]. Follow-up analyses using distribution-free rank correlations confirmed these findings between ΔC and ROCF scores. Comparably, DS and ROCF performance correlated negatively with AUC_{I_Cort} within the stress group [$r(13) = -0.42$, $p \leq 0.15$ and $r(13) = -0.67$, $p \leq 0.01$, respectively]. Follow-up analyses using distribution-free rank correlations confirmed these findings for the relation between AUC_{I_Cort} and DS scores.

In order to qualitatively illustrate the differences in visuo-spatial declarative memory between both groups, Figures 4a and 4b show representative examples of ROCF performance for both groups. An original version of the ROCF is given in Figure 1. While all participants performed within the expected, standardized ranges for healthy persons (Knight, 2003b), the differences in performance under high-intensity stress seem clear.

4a



4b



Figures 4a and 4b. Representative examples of the Rey-Osterrieth complex figure (ROCF) for the no-stress control (4a) vs. the stress (4b) group.

Discussion

The current field experiment aimed to improve insight into the dynamics of endogenously instigated high level cortisol regulation, and to measure its effects on WM and visuo-spatial declarative memory performance. As expected, robust increases in salivary cortisol were observed in the stress group *(hypothesis 1 confirmed)*. The results further indicated that both groups performed within acceptable ranges for both performances tests (Knight 2003b; Sternberg 2003). In identical test conditions, however, exposure to high-intensity stress led to a significant decrease in both the DS test and ROCF *(hypothesis 2 confirmed)*. Whereas laboratory studies have generally shown low correlations between stress self-reports and cortisol measures (Dickerson & Kemeny 2004), exposure to high-intensity stress yielded significant correlations, first, between self-reported and salivary cortisol stress measures *(hypothesis 3 confirmed),* and, second, between cortisol increase and performance outcomes *(hypothesis 4 confirmed).*

As expected, high-intensity stress provoked robust cortisol increases, which largely exceeded those evoked by traditional lab stressors (Het et al. 2005). Mean cortisol rises of over 600%, with a maximum of over 1,100% were observed. These findings contribute to the HPA axis dose-response theorem in a realistic and unconventional process of stress induction. The current study has obvious contextual similarities with the work of Morgan and colleagues (2006, 2004, 2002, 2001, 2000). Conversion from *Système International* (SI) to conventional units revealed that the salivary cortisol concentrations were relatively well in line with hormonal data of Morgan et al. (2002, 2001, 2000). These studies measured cortisol – and other psychophysiological markers – in comparable circumstances, and registered similar or slightly more elevated mean cortisol increases, dependent upon the specific stressor and the envisaged population. Apart from the work of Morgan et al., there are, to the authors' knowledge, no other reports of comparable methods of stress induction.

Robust increases of salivary cortisol are also consistent with the notion that novelty, unexpectedness, and genuine uncontrollability create larger effects (Dickerson & Kemeny 2004). Moreover, the selection context and the omnipresent threat of negative evaluation (Dickerson et al. 2008) most likely added to the overall stress effect; failure to CombEx would substantially impede participants' progress to the personal goals they had singled out. On the other hand, a similar evaluation threat was present for both groups given that there was no attitudinal difference in approach by the evaluators. Hence, it can be reasonably expected that deviations in cortisol concentrations due to a different evaluative threat perception can be excluded.

Finally, objective (salivary cortisol increase) and subjective (TLX self-reports) stress measures correlated significantly. This finding is contradictory to results from laboratory studies that have generally shown low correlations between self-reports of experienced stress and cortisol measures (Dickerson & Kemeny 2004). It is, however, unsure whether this correlation can be explained by the shock effect, the realism, the uncontrollability (except under condition of jeopardizing the entire selection phase), or the salience of the situation for the participants. Yet another explanation might be that, in contrast to previous studies that used subjective stress measures that were more general in nature (e.g., overall mood questionnaires), the TLX is a more sensitive subjective measure for this particular high-intensity stress situation. Future research could unravel the respective roles of the different stressors and address the sensitivity of the TLX.

Exposure to high-intensity stress led to a significant decrease in both memory outcomes. These results are in line with other studies that applied the DS test as a performance measure for WM. There are, however, some controversies concerning the DS test, more specifically on the inclusion of the DF paradigm. Some researchers formulated *a priori* reservations in regard to the DF's sensitivity as a measure, particularly for healthy young adults (Banken 1985; Schoofs et al. 2008, 2009; Smeets et al. 2006; Unsworth & Engle 2007). Here, the standardized DS test (Wechsler 1987) proved to be sensitive enough to produce significant results for combined DF - DB scores. This result accords well with Lezak et al.'s (2004) recommendation to treat both paradigms as if they measure the same or very highly correlated behaviors in normal control subjects. However, it must be highlighted that – even under the current study's stress conditions, there are indications of a reduced sensitivity of the DF paradigm in healthy young adults (see Schoofs et al. 2009).

The stress-induced decrease in ROCF recall scores indicates a significant impairment of visuo-spatial declarative memory capacities (Shin et al. 2006). In relation to the overall ROCF immediate recall scores, this result is well in line with the quantitative results of Morgan et al. (2006) who measured ROCF performance in a SERE (1985) context. Interestingly, the differences in ROCF results found in the current study were by large of a quantitative nature, as all participants managed to incorporate the broad *gestalt* overview of the figure but failed to accurately process specific ROCF details (note that the results are not completely comparable, given that Morgan et al. included a copy phase in their ROCF application). Morgan et al. reported organizational deficits and piecemeal drawing strategies during the copy phase of their stress group, and found significant negative correlations between symptoms of dissociation and memory performance. A possible explanation for these deviating results could be that the population of the current study reported no or very little previously experienced trauma, while an important subset of the earlier study had encountered 'war zone experiences' or 'life-threatening events'. Previously experienced trauma is known to have a pervasive influence during subsequent stressful events on cortisol regulation, and cognitive performance (Kudielka et al. 2009; Yehuda et al. 2001). A second explanation could be that, given CombEx's much shorter timeframe (vs. SERE), no dissociations were evoked (three previous CombEx applications never signaled any sign of dissociations). Interestingly, observations during task completion and inquiries after the clinical debriefing revealed that nearly all participants performed some form of mental 'repetition' or 'seeing' of the running digits or ROCF, thus giving support to Baddely's (2002) suggested WM model, incorporating a *phonological loop* and *visuo-spatial sketch pad*.

The decline of memory performance on the right-hand side of the inverted U-curve has been attributed to divergent corticosteroid affinities of MRs (with a high affinity for cortisol) and GRs (with a significantly lower affinity for cortisol) in the brain (De Kloet et al. 1999; McEwen & Sapolsky 1995). Accordingly, it is assumed that the high-intensity stress fully saturated GRs, which led to the decrease in WM performance. This assumption is in line with observations that the PFC plays an important role in WM functioning (e.g. Cabeza & Nyberg, 2000), and that acute stress reallocates neural resources away from executive brain networks

(Qin et al. 2009). Evidence from animal and human research confirmed the presence of high concentrations of GRs in the PFC (Patel et al. 2008; Perlman et al. 2007), which could influence higher-order cognitive functions via elevated levels of cortisol (possibly combined with supra-optimal levels of catecholamines; Qin et al. 2009). In relation to the visuo-spatial declarative memory performance it is assumed that the amygdala, the hippocampus, and associated brain regions (Joëls et al. 2006; Shin et al 2006; Wolf 2009) were affected by excessive cortisol concentrations. The fact that participants scored well within the expected ranges can be explained by their overall hardy cognitive style – all scored above the 85^{th} percentile on the PH control measure, combined with the absence of past traumatic experiences. High scores on PH are known to improve individuals' capacity to cope with stressful events and enable them to perform better under stressful circumstances (Maddi 2007).

The current study has some limitations that need to be addressed. First, the conclusions are restricted to the right-hand side of the inverted U-curve between stress and memory, which makes comparisons with moderate stress levels (and with boredom) difficult. Next, it would be both desirable and informative to add performance tasks with repeated exposures of learning materials. In line with Lezak (2004 p. 465), it is thought that this would upgrade the study's findings to a more sophisticated level of cognition, "[…] permit emergence of a learning curve.", and transcend the level of memory functioning to effective learning. Also, replications on larger and more heterogeneous (e.g. gender diversification) samples are necessary. The restricted sample size, however, is thought to be inherent to the strenuousness of the application, which is mirrored by the limited influx of Belgian SF candidates (with, so far, no female candidates). Follow-up research should address these constraints, for example through application of counterbalanced within subjects designs, improved learning materials, and more balanced male-female samples.

Practical implications

In spite of its limitations, the current field experiment also has important strengths that are situated in the introduction of two standardized cognitive outcome measures in an inimitable – though well controlled – real-world setting. These design characteristics strengthen the study's ecological validity and the conclusions that can be drawn from it.

Therefore, the current findings may have practical implications for both SF applications and those that exceed the narrow scope of the SF environment:

1. *Assessment of current practices.* The findings provide straightforward support for the design of the current SF selection procedure. First, the cortisol measures and the subjective stress assessment during CombEx provide empirical evidence of the efficacy of the selection application. Moreover, given the continuous observation, evaluation, and the subsequent cognitive (and practical) ability tests, it can be reasonably assumed that participants' coping capacities and cognitive performances under pressure were assessed appropriately. CombEx also provides a realistic indication of the candidates' PH (Maddi 2007). Finally, candidates' overall satisfactory performances during the assessment centre phase also give some support to the appropriateness of the preliminary SF selection process (communication, auto-selection, and screening).
2. *Crossover.* Under specific conditions, the results may be extendable beyond the limited scope of the SF environment. Cognitive reliability and appropriate cognitive functioning under extreme, non-routine circumstances is also important in a variety of 'medium' and 'high risk professions' (Van Der Ploeg & Kleber 2003). Fire fighters, urgency medics, police officers, airplane pilots, and civilian disaster relief workers can be reasonably expected to encounter acute stress and/or life threatening situations that require accurate WM processing (e.g. Violanti et al. 2007).
3. *Operational expansion.* In relation to cognitive reliability analyses, the findings may be of interest to specialists tasked with the design of (1) Selection procedures that aim at the early identification of individuals with increased risk for cognitive decline, or who lack inherent coping abilities to reengage under stress – possibly via the distinction of high and low-cortisol responders; (2) Communication interfaces that enable operators to split attention when extreme levels of allostatic overload can be reasonably anticipated (Wickens et al. 2004; Yuan et al. 2006); (3) Inoculation training and/or *in vivo* habituation treatment to repeated and gradually increasing stress exposures (Meichenbaum 2007); and (4) Cognitive-behavioral interventions to improve coping abilities and to regulate cortisol modulation (Hammerfald et al. 2006).
4. *Neuroergonomics.* The current findings could also be of interest for the emerging field of neuroergonomics. Here scholars are interested in practical applications of current neuropsychological knowledge, such as pharmaceutical countermeasures to withstand

degradation of cognitive performance (NAS 2009; Parasuraman & Wilson 2008). As such, pharmacological agents that influence neurotransmitter receptors in specific brain areas could be expected to optimize cognitive functioning whenever extreme circumstances are likely to be encountered (Morgan et al. 2006; NAS 2009).

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References

Abercrombie HC, Kalin NH, Thurow ME, Rosenkranz MA, Davidson RJ. 2003. Cortisol variation in humans affects memory for emotionaly laden and neutral information. *Behav Neurosci* 117, 505-516.

Alloway TP. 2006. How does working memory work in the classroom? *Educational Research and Reviews* 1, 163-139.

Andreano JM, Cahill L. 2006. Glucocorticoid release and memory consolidation in men and women. *Psychol Sci* 17, 466-470.

Axelrod B, Fichtenberg N, Millis S, Wertheimer J. 2006. Detecting incomplete effort with digit span from the Wechsler Adult Intelligence Scale - Third Edition. *Clin Neuropsychol* 20, 513-523.

Baddeley AD. 2002. Is working memory still working? *European Psychologist* 7, 85-97.

Banken JA. 1985. Clinical utility of considering digits forward and digits backward as separate components of the Wechsler Adult Intelligence Scale-Revised. *J Clin Psychol* 41, 686-691.

Bartone P. 2007. Test-retest reliability of the dispositional resilience scale-15, a brief hardiness scale. *Psychol Rep* 101, 943-944.

Bartone P, Roland R, Picano J, Williams T. 2008. Psychological hardiness predicts success in US Army Special Forces candidates. *International Journal of Selection and Assessment* 16, 78-81.

Cabeza R, Nyberg L. 2000. Imaging cognition II: An empirical review of 275 PET and fMRI studies. *J Cogn Neurosci* 12, 1-47.

Chida Y, Hamer M. 2008. Chronic psychosocial factors and acute physiological responses to laboratory-induced stress in healthy populations: A quanitative review of 30 years of investigations. *Psychol Bull* 134, 829-885.

Costa PT, McCrae RR. 1992. *Revised NEO Personality Inventory (NEO-PI-R) and the Five Factor Inventory (NEO-FFI): Professional Manual*. Psychological Assessment Resources Inc, Odessa, FL.

Creamer M, Bell R, Failla S. 2003. Psychometric properties of the Impact of Event Scale-Revised. *Behav Res Ther* 41, 1489-1496.

De Kloet R, Oitzl M, Joëls M. 1999. Stress and cognition: Are corticosteroids good or bad guys? *Trends Neurosci* 22, 422-426.

Delahaij R, Van Dam K, Gaillard AWK, Soeters, JMML. 2011. Predicting coping under acute stress: The role of person characteristics. *Int J Stress Management*. No Pagination Specified. doi: 10.1037/a0020891

Dickerson SS, Kemeny ME. 2004. Acute stressors and cortisol responses: A theoretical integration and synthesis of laboratory research. *Psychol Bull* 130, 355-391.

Dickerson SS, Mycek, PJ, Zaldivar F. 2008. Negative social evaluation, but not mere social presence, elicits cortisol responses to a laboratory stressor task. *Health Psychol* 27, 116-121.

Eid J, Morgan III CA. 2006. Dissociation, hardiness, and performance in military cadets participating in survival training. *Mil Med* 171(5), 436-442.

Flin R. 2002. Selecting the right stuff: Personality and high-reliability occupations. In *Personality psychology in the workplace* (ed. B.W. Roberts and R. Hogan), pp. 253-276. American Psychology Association, Washington, DC.

Hammerfald K, Eberle C, Grau M, Kinsperger A, Zimmermann A, Ehlert U, Gaab J. 2006. Persistent effects of cognitive-behavioral stress management on cortisol responses to acute stress in healthy subjects: A randomized controlled trial. *Psychoneuroendocrinology* 31, 333-339.

Harris WC, Ross KG, Hancock PA. (2008). Changes in soldiers' information processing capacity under stress. In P.A. Hancock & J.L. Szalma (Eds.), *Performance under stress* (pp. 101-114). Hampshire: Ashgate Publishing Limited.

Hart SG., Staveland LE. 1988. Development of a multi-dimensional workload rating scale: Results of empirical and theoretical research. In *Human mental workload* (ed. P. A. Hancock and N. Meshkati), pp. 139-183. Elsevier Science Publishers, Amsterdam.

Het S, Ramlow G. Wolf OT. 2005. A meta-analytic review of the effects of acute cortisol administration on human memory. *Psychoneuroendocrinology* 30, 771-784.

Irvine S. 2006. The Irvine multiform series: A psychometric reference manual. Unpublished manual, Belgian Armed Forces Experimental Tests Services.

Joëls M, Pu Z, Wiegert O, Oitzl M, Krugers H. 2006. Learning under stress: How does it work? *Trends in Cognitive Sciences* 10, 152-158.

Knight J. 2003a. Administration procedures and scoring systems. In *The handbook of Rey-Osterrieth complex figure usage: Clinical and research applications* (ed. J. A. Knight and E. Kaplan), pp. 57-192. Psychological Assessment Resources, Inc., Lutz, FL.

Knight J. 2003b. ROFC psychometric characteristics and normative data. In *The handbook of Rey-Osterrieth complex figure usage: Clinical and research applications* (ed. J.A. Knight and E. Kaplan), pp. 193-254. Psychological Assessment Resources, Inc., Lutz, FL.

Knight J, Kaplan E. 2003. *The handbook of Rey-Osterrieth complex figure usage: Clinical and research applications*. Psychological Assessment Resources, Inc., Lutz, FL.

Kudielka BM, Hellhammer DH, Wüst S. 2009. Why do we respond so differently? Reviewing determinants of human salivary cortisol responses to challenge. *Psychoneuroendocrinology* 34, 2-18.

Levine S. 2005. Stress: An historical perspective. In *Handbook of Stress and the Brain* (ed. T. Steckler, N. H. Kalin and J. M. H. M. Reul), pp. 3-23. Elsevier Science Ltd, New York.

Lezak M, Howieson D, Loring D. 2004. *Neuropsychological assessment*, 4 edition. University Press, Oxford.

Maddi S. 2007. Relevance of hardiness assessment and training to the military context. *Mil Psychol* 19, 61-70.

Maddi S, Harvey R, Koshaba D, Lu J, Persico M, Brow M. 2006. The personality construct of hardiness, III: Relationships with repression, innovativeness, and performance. *J Pers* 74, 575-597.

Mauri M, Sinforiani E, Bono G, Vignati F, Berselli ME, Attanasio R, Nappi G. 1993. Memory impairment in Cushing's disease. *Acta Neurol Scand* 87, 52-55.

McEwen B, Sapolsky R. 1995. Stress and cognitive function. *Curr Opin Neurobiol* 5, 205-216.

McGauch JL, Roozendaal B 2002. Role of adrenal stress hormones in forming lasting memories in the brain. *Curr Opin Neurobiol* 12, 205-210.

Meichenbaum D. 2007. Stress inoculation training: A preventative and treatment approach. In *Principles and Practice of Stress Management* (ed. R.L.W.P.M. Lehrer, & W.S. Sime). Guilford Press, London.

Morgan III CA, Doran A, Steffian G., Hazlett, G., Southwick, M. 2006. Stress-induced deficits in working memory and visuo-constructive abilities in special operations soldiers. *Biol Psychiatry* 60, 722-729.

Morgan III CA, Southwick S, Hazlett G, Rasmusson A, Hoyt G, Zimolo Z, Charney D. 2004. Relationships among plasma dehydroepiandrosterone sulfate and cortisol levels, symptoms of dissociation, and objective performance in humans exposed to acute stress. *Arch Gen Psychiatry* 61(8), 819-825.

Morgan III CA, Rasmusson A, Wang S, Hoyt G., Hauger RL, Hazlett, G. 2002. Neuropeptide-Y, cortisol, and subjective distress in humans exposed to acute stress: Replication and extension of previous report. *Biol Psychiatry* 52, 136-142.

Morgan III CA, Wang S, Mason J, Southwick SM, Fox P, Hazlett G, Charney DS, Greenfield G. 2000. Hormone profiles in humans experiencing military survival training. *Biol Psychiatry* 47, 891-901.

Morgan III CA, Wang S, Rasmusson A, Hazlett, G, Anderson, G., Charney DS. 2001. Relationship among plasma cortisol, catecholamines, neuropeptide Y, and human performance during exposure to uncontrollable stress. *Psychosom Med* 63, 412-422.

Müller NG., Knight RT. 2006. The functional neuroanatomy of working memory: Contributions of human brain lesion studies. *Neuroscience* 139, 51-58.

Munck A. 2000. Corticosteroids and stress. In *Encyclopedia of Stress*, vol. 1 (ed. G. Finck), pp. 570-577. Academic Press, New York.

NAS. (2009). *Opportunities in neuroscience for future army applications (http://www.nap.edu/catalog/12500.html)*: National Academy of Sciences.

Oei NY, Everaerd WT, Elzinga BM, Van Well S, Bermond B. 2006. Psychosocial stress impairs working memory at high loads: An association with cortisol levels and memory retrieval. *Stress* 9, 133-141.

Parasuraman R, Wilson GF (2008). Putting the brain to work: Neuroergonomics past, present, and future. *Human Factors, 50,* 468-474.

Patel PD, Katz M, Karssen AM, Lyons DM. 2008. Stress-induced changes in corticosteroid receptor expression in primate hippocampus and prefrontal cortex. *Psychoneuroendocrinology* 33, 360-367.

Perlman WR, Webster MJ, Herman MM, Kleinman JE, Weickert CS. 2007. Age-related differences in glucocorticoid receptor mRNA levels in the human brain. *Neurobiol Aging* 28, 447-458.

Pruessner JC, Kirschbaum C, Meinlschmid G, & Helhammer DH. (2003). Two formulas for computation of the computation of the area under the curve represent measures of total hormone concentration versus time-dependent change. *Psychoneuroendocrinology, 28*, 916-931.

Qin S, Hermans EJ, Van Marle H, Luo J, Fernández G. 2009. Acute psychological stress reduces working memory-related activity in the dorsolateral prefrontal cortex. *Biol Psychiatry*, 66, 25-32.

Roozendaal B, Hui G.K, Hui IR, Berlau DJ, McGaugh JL, Weinberger NM. 2006. Basolateral amygdala noradrenergic activity mediates corticosterone-induced enhancement of auditory fear conditioning. *Neurobiol Learn Mem* 86, 249-255.

Rubio S, Díaz E, Martín J, Puente JM. 2004. Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. *J Appl Psychol* 53, 61-86.

Schmidt FL, Greenthal AL, Hunter JE, Berner JB, Seaton F W. 2006. Job sample vs. paper-and-pencil trades and technical tests: Adverse impact and examinee attitudes. *Pers Psychol* 30, 187-197.

Schoofs D, Preuβ D, Wolf OT. 2008. Psychosocial stress induces working memory imairments in an *n*-back paradigm. *Psychoneuroendocrinology* 33, 643-653.

Schoofs D, Wolf OT, Smeets T. 2009. Cold pressor stress impairs performance in working memory tasks requiring executive functions in healthy young men. *Behav Neurosci*, 123, 1066-1075.

SERE. 1985. *Code of Conduct, Survival, Evasion, Resistance, and Escape (SERE) Training*. Retrieved June 15, 2009 from http://www.fas.org/irp/doddir/army/ar350-30.pdf.

Shin M, Park S, Park S, Seol S, Kwon J, Park, S, Seol S, Kwon J. 2006. Clinical and empirical applications of the Rey-Osterrieth Complex Figure test. *Nature Protocols* 1, 892-899.

Smeets T, Jelicic M, Merkelbach H, Peters M, Fett A, Taverniers J, Henquet C., Dautzenberg J. 2006a. Enhanced memory performance on an internal-internal source monitoring test following acute psychosocial stress. *Behav Neurosci* 120, 1204-1210.

Smeets T, Otgaar H, Candel I, Wolf OT. 2008. True or false? Memory is differentially affected by stress-induced cortisol elevations and sympathetic activity at consolidation and retrieval. *Psychoneuroendocrinology 33*, 1378-1386.

Starkman M, Giordani B, Berent S, Schork A, Schteingart D. 2001. Elevated cortisol levels in Cushing's disease are associated with cognitive decrements. *Psychosom Med* 63, 985-993.

Sternberg R. 2003. *Cognitive psychology*, 3rd edition. Wadsworth/Thomson Learning, Belmont.

Touma C, Bunck M, Glasl L, Nussbaumer M, Palme R, Stein H, Wolferstätter M, Zeh R, Zimbelmann M, Holsboer F, Landgraf R. 2008. Mice selected for high versus low stress reactivity: A new animal model for affective disorders. *Psychoneuroendocrinology* 33, 839-862.

Unsworth N, Engle RW. 2007. On the division of short-term and working memory: An examination of simple and complex span and their relation to higher order abilities. *Psychol Bull* 133, 1038-1066.

Van Der Ploeg E, Kleber RJ. (2003). Acute and chronic job stressors among ambulance personnel: Predictors of health symptoms. *Occ Env Med, 60*(supplement 1), i40-i46.

Violanti, J. M., Andrew, M., Burchfiel, C. M., Hartley, T. A., Charles, L. E., & Miller, D. B. (2007). Post-traumatic stress symptoms and cortisol patterns among police officers. *Policing: An Int J Police Strategies & Management, 30*(2), 189-2002.

Wechsler D. 1987. *WMS-R Manual: Wechsler Memory Scale-Revised*. Harcourt Brace Jovanovich, Inc., The Psychological Corporation, New York.

Weiss D, Marmar C. 1997. The Impact of Event Scale -Revised. In *Assessing psychological trauma and PTSD* (ed. J. Wilson and T. Keane). Guildford, New York.

Wickens CD, Lee J, Liu Y, Becker SG. 2004. Stress and workload. In *An Introduction to Human Factors Engineering*, pp. 324-350. Pearson Education, Inc, Upper Sadle River.

Wolf OT. 2009. Stress and memory in humans: Twelve years of progress? *Brain Res* 1293, 142-154.

Yehuda R, Halligan S, Grossman R. 2001. Childhood trauma and risk for PTSD: Relationship to intergenerational effects of trauma, parental PTSD and cortisol excretion. *Dev Psychopathol* 13, 733-753.

Yuan K, Steedle J, Shavelson R, Alonzo A, Oppezzo M. 2006. Working memory, fluid intelligence, and science learning. *Educational Res Rev* 1, 83-98.