Sustained Military Operations and Cognitive Performance

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INTRODUCTION: Cognitive performance is crucial during military operations. It is suggested that impaired cognitive performance accounts for most of the accidents during training courses and actual battle. There is a need to define when soldiers' operational readiness becomes impaired. The objective of this systematic review was to investigate the effects of sustained military operations (SUSOPS) on vigilance, reaction time, working memory, and reasoning in order to select good indicators for performance impairment.

METHODS: A systematic literature search was performed using publicly accessible databases (IngentaConnect, PubMed, Science Direct, and Defense Technical Information Center online) that were screened until July 2015. Keywords were military, sustained operations, (cognitive) performance, soldier, and training.

RESULTS: Only 7 out of 589 studies met the inclusion criteria. Selected studies were difficult to compare due to different methodologies, cognitive tasks, and military courses. Vigilance, reaction time, and working memory were affected after only a few hours, showing severe impairment. They are linearly related to military stress up to 80 h of SUSOPS. These three indicators needed little recovery time to return to baseline levels. After more than 80 h of SUSOPS, no significant impairments of those indicators were observed. Reasoning becomes impaired after high stress levels of relatively short duration and can remain affected after more than 80 h of SUSOPS.

DISCUSSION: Vigilance, reaction time, and working memory are affected after only a few hours while little recovery time is needed. For reasoning to return to baseline values, longer recovery is needed than the time available during SUSOPS.

KEYWORDS: sustainability, vigilance, reaction time, working memory, reasoning.

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Sustained military operations expose soldiers to extremely demanding situations and possibly severe environmental conditions without having the ability to fully recover until their task is finished.[6,31,59] During combat, high levels of physical and cognitive stress, arousal, danger, sleep deprivation, and stressful incidents[18,20] can be experienced. In addition, long periods of inactivity can also occur in between demanding and dangerous situations,[19,20] which makes it difficult to remain alert. The experienced stress level can approach the limits of human capabilities.[26]

Military sustained operations (SUSOPS) in this paper are defined as carrying out military work with no or limited rest/sleep (less than 3 h uninterrupted sleep and not scheduled in advance) for a minimum of 36 h to a maximum of a soldier's capabilities. As soon as rest and sleep are scheduled and a system shift occurs, soldiers are not participating in military SUSOPS but in military continuous operations (CONOPS). Training courses teach soldiers what it feels like to encounter high stress levels during combat. In addition, soldiers are trained and familiarized with adequate coping strategies to mitigate the impact of sustained operations on performance,[32] since it affects operational effectiveness.[11,20,51]

Cognitive performance is a multidimensional construct since it cannot be captured by solely measuring memory or vigilance, as it consists of multiple modalities. Therefore, it is difficult to determine when cognition, as a whole, is affected. It

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is even harder to determine the magnitude of the degradation for the various cognitive modalities due to the different effects of stress on cognitive performance and the complexity by which the cognitive modalities are tested.[21] Furthermore, there are multiple factors that affect soldiers' operational readiness. It has been shown that total sleep time,[48] energy balance,[33,41,48] hydration status,[1] climate,[12] and physical[48] and mental stress[30] are influencing factors. The effects of decreased cognitive performance should not be underestimated. Thomas and Russo[51] reported that 80–85% of military accidents are due to decreased cognitive performance. In order to diminish accidents and to preserve cognitive functioning, research has been conducted to try to optimize soldiers' cognitive performance during military operations.[6,17,46,51]

Cognitive performance was found to be affected in several ways during combat and training courses. Slower reaction times or reduced accuracy of the reactions given, poor logical reasoning, lack of concentration, poor memory, reduced confidence, and even hallucinations were described as the result of prolonged operational stress.[7,30] In order to attempt to mitigate these deleterious effects, several pharmacological interventions have been tested to counteract the deteriorating effects of fatigue on cognition.[8,13] In addition, SUSOPS and hormonal responses have been investigated in laboratory environments.[36,46] Despite these attempts to manage cognitive performance, it remains difficult to improve this performance when the underlying processes are not clearly defined. The threshold that can be used to determine performance decrements in soldiers based on their cognitive performance is unknown.

Only a few field studies have been conducted using measures of cognitive performance. Methodological and practical issues make it difficult to measure in the field[15,29,38] and to compare the gathered data. In addition, ecological validity is a major issue when conducting field trials. Cognitive tasks used in the laboratory measure one specific cognitive process, while in the field all these separate modalities interact with each other. Simply summarizing test results of separate cognitive dimensions will not reflect real-world performance and might actually be an underestimation of operational performance.[44] Thus, the paucity of available data warrants a better understanding of the influence of SUSOPS on cognitive performance.

The aim of this article is to systematically review the results of (simulated) field studies that investigated the effects of SUSOPS on different cognitive modalities. The review will give insight in the time courses by which the cognitive modalities are affected, together with the severity of the decrement. This, in turn, will indicate which modalities are good indicators of performance degradation and should be focused on to manage task planning. It is hypothesized that the selected modalities deteriorate over time. The magnitude of the deterioration is expected to increase with exposure time. Whether the available data allow determination of the relationship of this increase (either linear, exponential, or cyclic) or the time constant remains to be determined.

METHODS

Selection Criteria

A systematic literature review for relevant publications was performed using the following publicly accessible databases: IngentaConnect, PubMed, Science Direct, and Defense Technical Information Center (DTIC) online. The databases were screened until July 2015. The following keywords, as well as a combination of these terms, were used during the search: military, sustained operations, (cognitive) performance, soldier, and training. Inclusion criteria had to meet our definition of SUSOPS, so they had to be military sustained operations, field trials, or simulated field trials, include male soldiers, the operation had to last for at least 36 h, and cognitive performance had to be investigated.

Studies were excluded when they did not meet the inclusion criteria, when the time needed for testing was more than 2 h/d (because the actual combat program will be affected too much), and when stress was limited to either physical or mental stress instead of the combination of both. Also, studies were excluded when soldiers received scheduled sleep for more than 3 uninterrupted hours per mission or when a shift system was present; CONOPS were not included in this review. Studies that looked at soldier performance in protective clothing (influence on results), simulated laboratory trials trying to reproduce field trial test results (controlled studies are not similar to field studies), studies investigating solely female soldiers or (helicopter) pilots, and studies lacking statistical analysis were excluded as well. After the screening on the aforementioned inclusion criteria, 7 articles out of the 589 identified records were selected. It has to be noted that the two selected articles by Lieberman[34,35] both described the same 53-h military training course. In addition, Lieberman et al.[35] also described the 73 h of Hell Week from the Navy SEALs.

RESULTS

Table I summarizes methodological information about the selected studies, showing similarities, but particularly the many methodological differences. All selected studies measured the effects of sustained operations on cognitive performance, but due to the multidimensional construct of cognition, many different aspects of cognition have been analyzed.

A summary and short explanation of the used cognitive tasks is presented in **Table II**. Cognitive aspects are divided into four different modalities: vigilance, reaction time, working memory, and reasoning. Three of these modalities (reaction time, working memory, and reasoning) were selected from the six cognitive constructs used by Casler and Cook.[9] Vigilance was added since it is highly relevant to remain alert during military tasks. In addition, vigilance is intuitively likely to be affected during SUSOPS, including the fact that vigilance will be a confounding variable in results from other modalities if the test duration exceeds 30 min.[37] Besides the fact that we ranked the outcomes of the selected studies per cognitive modality, study

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Table I. Description of the Selected Studies.

STUDY DURATION	WHEN COGNITIVE TESTING	TEST TIMES	EXERCISES DURING STUDY	WATER AVAILABILITY	FOOD AVAILABILITY	AMOUNT OF SLEEP	SOURCE
53 h	Prefield/field/postfield	6 PM/12 PM/5 AM	Continuously active, exercises simulate combat, traveling small boats, off-road hiking with heavy load carriage	Ad libitum	Limited to 1250 kcal during whole study	Unknown	Lieberman et al.[34]
73 h	Prefield/postfield	5-6 PM/10:30 PM & 5 AM	Extremely demanding continuous activities on beach, in boats, or in surf. Severe cold stress. >50% subjects dropped out	Unknown	Unknown	1 h	Lieberman et al.[35]
84 h laboratory-based	Prefield/50 h/postfield	6-11 AM	49 h military relevant field exercises (e.g., battle drills, road marches, land navigation courses)	Ad libitum	1650 kcal/d (energy expenditure 4500 kcal/d)	5 × 1 h and 1 × 2 h	Castellani et al.[10]
5 d	7× in 24 h (every 4 h)	1st at 8 AM	Continuously physically active. (Intensity level ± 35% maximal oxygen uptake)	Ad libitum	1195 kcal/d (energy expenditure 9560 kcal/d)	Estimated 1-3 h	Opstad[42]
3× a 5-d training course; the first and second test week are reported	Monday, Wednesday, and Friday morning, Wednesday and Friday afternoon	Not reported	Continuously physically active with military field exercises (e.g., speed marches, obstacle courses, battle drills).	Ad libitum	Unknown	Estimated 5-7 h (the third week >3 h uninterrupted sleep was reported, not meeting the inclusion criteria)	Vrijkotte et al.[57]
7 d	Prefield/postfield	4 PM or morning before start/4 PM	Survival training with many elements of military operations	Unknown	Unknown	Unknown (>3 h uninterrupted sleep unlikely)	Harris et al.[20]
9 d	Days 4 to 9	Days 4 to 8, 5-7 PM/Day 9, 8 AM	Except for being inside 12× 50 min during first 4 d, subjects were outside conducting survival exercises in the cold	Melting snow	Days 7 and 8 limited food (total of 450 kcal)	Unknown (>3 h uninterrupted sleep might have occurred)	Marrao et al.[39]

results are also ranked from shortest duration of the operation to the longest SUSOPS. This particular order was chosen to allow us to identify a possible time constant of the performance decrement.

Vigilance was measured in five studies (**Table III**). Moreover, Harris et al.[20] compared start task performance with end task performance, which also quantifies vigilance. Therefore, these outcomes were also included as vigilance performance. Vigilance decreased in four of the selected studies.

In the studies of Lieberman et al.,[34,35] the amount of errors made during the four choice reaction time task (FCRT task) was found to increase by 200% (from 12.5 at the start to 39.8 after the course[34]) and 700% (no exact values were presented[35]) comparing start and end task results, with reaction

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Table II. Overview of the Investigated Cognitive Performance Attributes, Outcome Variables, and Grouping of the Attributes.

TASK	CONTENT	OUTCOME VARIABLES (SOURCE)	COGNITIVE MODALITY
Code substitution	From the ANAM.[47] A digit-symbol pair has to be compared to a key-symbol pair. Subjects had to respond whether the shown digit-symbol pair matched a key-symbol pair or not.	Reaction time and number of correct responses.[3]	Working memory
Digit symbol substitution	Originated from the "Otis Army Beta Battery."[58] Symbols have to be associated with other symbols according to a predefined "code."	No outcome variables were defined.[42]	Working memory
Four-choice reaction time	A series of visual stimuli were presented at one of four different spatial locations on a computer screen.[14] Subjects had to indicate the correct spatial location of the stimuli by pressing one of four adjacent keys.	Number of correct and incorrect responses, reaction time, number of premature errors, and time-out errors.[10,34,35]	Reaction time
Grammatical reasoning	Sentences are claimed to describe the order of two letters (A and B). Subjects have to answer whether the description was true or false.[5]	Number of correct responses, number of incorrect responses, and reaction time.[34,35]	Reasoning
Grammatical transformation	Sentences are claimed to describe the order of two letters (A and B). Subjects have to answer whether the description was true or false.[5]	Number of correct responses normalized against baseline performance.[39]	Reasoning
"Higher mental processes"	Sentences are claimed to describe the order of two letters (A and B). Subjects have to answer whether the description is true or false.[5]	No outcome variables were defined.[42]	Reasoning
Logical reasoning	From the ANAM.[47] Subjects had to respond whether a given statement matched the displayed two symbols or not.	Reaction time and number of correct responses.[20]	Reasoning
Matching to sample	An 8 × 8 matrix of a red/green checkerboard was presented for 6 s followed by a variable delay interval. Then two matrices were presented: the original and one with the colors of the two squares reversed. Subjects had to select the original matrix.[49]	Number of correct responses and reaction time.[10,34,35]	Working memory
Memory task	A Sternberg memory task[50] with a two-item and a six-item memory set.	Reaction time and number of correct responses.[20]	Working memory
Memory task (continuous performance task)	From the ANAM—the continuous performance task.[47] A character is presented as the target character. Different characters are shown and the target character had to be detected.	Reaction time and number of correct responses.[20]	Working memory
N-back	A target is the character X (for 0-back) or the same character that was presented one or two stimuli previously (1-back and 2-back).[43]	Reaction time and percentage correct responses.[57]	Working memory
Planning	Plan the most efficient shopping routes using two carts to pick up highlighted items from a supermarket grid layout.[40]	Number of steps exceeding the perfect plan to complete the task.[39]	Reasoning
Repeated acquisition	A sequence of 12 keystrokes was learned by the subjects. A rectangle outline was presented and correct responses filled part of the rectangle. When the rectangle was filled, a new empty rectangle was presented.[3]	Number of incorrect responses and time to complete the trial.[10,34,35]	Working memory
Scanning visual vigilance	Subjects have to scan a computer screen to detect an infrequent, difficult-to-detect stimulus. The stimulus appears at random locations and intervals for 2 s. When a stimulus was detected, the keyboard space bar had to be pressed as rapidly as possible.[16]	Number of detected stimuli, reaction time, and number of incorrect responses.[34,35]	Vigilance
Simple reaction time	From the ANAM.[47] Each time the symbol '*' is presented on the screen, the subjects had to respond as quickly as possible.	Reaction time and number of correct responses.[20]	Reaction time
Silent wrist watch	Subjects had to respond to random vibrations of a silent wrist watch. A message accompanied the vibration and when the message "write" appeared, the time of the message had to be recorded.	Number of correct "write" responses.[43]	Vigilance
Spatial processing	From the ANAM.[47] A four-bar histogram was presented to memorize. Thereafter, a rotated four-bar histogram was presented and subjects had to respond whether the presented histogram was the same or not as the first histogram shown (except for the rotation).	Reaction time and number of correct responses.[39]	Working memory
Tower of Hanoi	Transform picture one into picture two by moving the disks in the presented amount of steps.	Completion time.[57]	Reasoning
VigTrack	Dual-task combining steering a disk to the red dot in the center of the screen with detecting the target figure presented within the red dot.[54]	Root mean square tracking error, percentage missed stimuli, reaction time.[57]	Vigilance
Visual vigilance	Subjects had to respond as fast as possible to a changing and difficult to detect stimulus that was presented at random intervals at different places on the computer screen for a total of 2 s. When a stimulus was detected, the keyboard space bar had to be pressed as rapidly as possible.	Number of detected stimuli, reaction time, number of incorrect responses.[10]	Vigilance

times becoming 15%[35] to 20%[34] slower. In addition, correct responses during the visual vigilance task decreased almost 25%, with 20% slower reaction times comparing prefield and postfield results.[34]

Castellani et al.[10] reported a performance decline around 60% for correct responses during the visual vigilance task, but no significance was found in false alarms nor reaction times. Also, a 10% decrease was observed for correct responses during

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Table III. Effects of Sustained Operations on Vigilance.

COURSE DURATION	PARTICIPANTS	TASK DURATION	EFFECT ON PERFORMANCE*	SOURCE
53 h	31 men	FCRT; 5 min. VV; 20 min.	↓ after 35 h: FCRT: incorrect responses $P < 0.01$& time-out errors $P < 0.05$ & reaction times P = NS VV: correct responses $P < 0.001$, false alarms $P < 0.01$, & reaction times $P < 0.01$ ↓ after 53 h: FCRT: incorrect responses $P < 0.001$, time-out errors $P < 0.01$, & reaction times $P < 0.001$ VV: correct responses $P < 0.001$, false alarms $P < 0.05$, & reaction times $P < 0.001$	Lieberman et al.[34]
73 h	16 men	FCRT; 5 min.	↓ after 73 h: FCRT; incorrect responses $P < 0.001$ & reaction times $P < 0.001$ No other vigilance outcome measures were presented	Lieberman et al.[35]
84 h	13 men	FCRT; 5 min. VV; 20 min.	↓/ – after 50 h: FCRT: correct responses $P < 0.05$, time-out errors $P < 0.05$, & reaction times P = NS VV: correct responses $P < 0.001$, false alarms P = NS, & reaction times P = NS ↓ / – after 75 h: FCRT: correct responses $P < 0.05$, time-out errors $P < 0.05$, & reaction times P = NS VV: correct responses $P < 0.001$, false alarms P = NS, & reaction times P = NS	Castellani et al.[10]
3× 5 d	9 men	VigTrack; 5 min.	↓ Week 1, after 4 d: VigTrack: RMS tracking error $P < 0.01$, reaction times $P < 0.01$, & percentage missed stimuli $P < 0.01$ ↓ Week 2, after 3 d: VigTrack: RMS tracking error $P < 0.01$, reaction times $P < 0.01$, & percentage missed stimuli $P < 0.01$	Vrijkotte et al.[57]
7 d	35 men	Not reported, but <20 min. in total since subsets of ANAM were used. ANAM takes 20 min.	↓ / – / ↑ within task performance: SRT: reaction time $P = 0.05$ CS: reaction time $P < 0.001$ & correct responses P = NS SP: reaction time P = NS & correct responses $P < 0.001$ LR1: reaction time $P < 0.01$& correct responses $P < 0.01$ Two-item MT: reaction time P = NS & correct responses $P = 0.05$ Six-item MT: reaction time P = NS & correct responses P = NS CPT: reaction time $P < 0.01$ & correct responses P = NS	Harris et al.[20]
9 d	28 men	SWW; 4 times 3 s	– over 4 test days (course days 5 to 8) SWW: correct responses P = NS	Marrao et al.[39]

*↓ Decrease in performance; – no change in performance; ↑ increase in performance.
FCRT = four-choice reaction time, VV = visual vigilance, MS = matching to sample, SRT = simple reaction time, CS = code substitution, SP = spatial processing, LR1 = logical reasoning, MT = memory task, CPT = continuous performance task, SWW = silent wrist watch, RMS = root mean square tracking error, NS = not significant.

the FCRT task and time-out errors significantly increased as well, but reaction times did not differ. Vrijkotte et al.[57] showed that the root mean square tracking error (the average distance of the disk compared to the target red dot) had doubled at day 5 in week 1. In the second test week, vigilance was affected at the third day already and remained affected during the rest of the week. This same pattern was observed for the percentage missed stimuli and reaction times during the second test week, although reaction times were affected less severely.

In six of the seven tasks investigated by Harris et al.,[20] performance (reaction time and/or correct responses) decreased. Within-task analysis revealed that accuracy during the spatial processing task decreased 5% after 7 d of military training. End task reaction times of the simple reaction time task, code substitution, logical reasoning, and continuous performance task decreased on average between 10 and 20% compared to start task performance. Accuracy of the two-item memory task improved by 2% while no differences were found for the six-item memory task performance. In Marrao et al.'s study,[39] no significant differences in vigilance were reported.

Simple reaction time was measured only in the study of Harris et al.[20] A 20-min subset of the ANAM was used, but exact task duration of the simple reaction time task was not reported. A significant 5% increase in reaction time during the simple reaction time task was observed, while the number of correct responses remained unaffected.

Five studies measured the effects of sustained operations on working memory (**Table IV**). After 73 h of Hell Week, completion of the repeated acquisition task took twice as much time compared to baseline performance, whereas reaction times during the matching-to-sample task increased by 25%.[34] Completion time on the same task after 53-h military training for Rangers increased by 40% and so did reaction times during the matching-to-sample task.[35] Castellani et al.[10] found no

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Table IV. Effects of Sustained Operations on Working Memory.

COURSE DURATION	PARTICIPANTS	TASK DURATION	EFFECT ON PERFORMANCE*	SOURCE
53 h	31 men	RA; 10 min. MS; 5 min.	↓ after 35 h: RA: incorrect responses $P < 0.01$& time to complete $P < 0.01$ MS: correct responses $P < 0.01$& time-out errors $P < 0.05$ & reaction times $P < 0.001$ ↓ after 53 h: RA: incorrect responses $P < 0.01$ & time to complete $P < 0.001$ MS: correct responses $P < 0.001$, time-out errors $P < 0.01$, & reaction times $P < 0.05$	Lieberman et al.[34]
73 h	16 men	RA; 10 min. MS; 5 min.	↓ after 73 h: RA: time to complete $P < 0.001$ MS: reaction times $P < 0.001$	Lieberman et al.[35]
84 h	13 men	RA; 10 min. MS; ± 7 min.	– after 50 h: RA: incorrect responses P = NS & time to complete P = NS; MS: correct responses P = NS, reaction times P = NS, & time-out errors $P < 0.05$ – after 75 h: RA: incorrect responses P = NS & time to complete P = NS; MS: correct responses P = NS, reaction times P = NS, & time-out errors $P < 0.05$	Castellani et al.[10]
5 d	18 men	HMS/DSS; not reported	↓ after the course: Mean HMS/DSS: performance $P < 0.001$	Opstad[42]
3× 5 d	9 men	N-back; 5 min.	↓ /– Week 1, after 4 d: 2-back: % correct responses $P < 0.01$ & reaction times P = NS ↓ Week 2, after 3 d: *2-back*; % correct responses $P < 0.01$ & reaction times $P < 0.05$	Vrijkotte et al.[57]
7 d	35 men	Not reported, but <20 min. in total since subsets of ANAM were used. ANAM takes 20 min.	↑/– post training: Two-item MT: correct responses P = NS Six-item MT: correct responses P = NS CPT: correct responses $P < 0.05$ CS: correct responses P = NS SP: correct responses $P < 0.05$	Harris et al.[20]

*↓ Decrease in performance; – no change in performance; ↑ increase in performance.
RA = repeated acquisition, MS = matching to sample, Mean HMS/DSS = mean higher mental processes/digit symbol substitution, MT = memory task, CPT = continuous performance task, CS = code substitution, SP = spatial processing, NS = not significant.

differences in working memory performance after 84 h of military work, with exception of the number of time-out errors during the matching to sample task, which was three times higher. Opstad[42] took the results of the working memory and reasoning tasks together and reported a 40% performance reduction.

Vrijkotte et al.[57] found a decrement of 25% in the percentage correct responses during the two-back task comparing the test results of the fifth day with test results earlier in week 1. Reaction times did not differ significantly. The second week, on the other hand, showed a more than 40% reduction of correct responses comparing day 1 with day 3 and a major reduction of 70% comparing day 1 to the final day of the week, although the afternoon sessions showed 20% recovery compared to day 1. Reaction times during week 3 became extremely fast (up to 375 ms) on the morning of the final day, which is beyond normal physiological response times. Performance on the two memory tasks and the code substitution task remained unaffected in the study of Harris et al.[20] Nevertheless, performance of the continuous performance task improved by 5% and the spatial processing task performance improved by 2% after 7 d of military training.

Reasoning was measured in four of the selected studies (**Table V**). After 35 h of military operations, Lieberman et al.[34] found a significant decrement of almost 7% in grammatical reasoning which continued to decline up to 15% after 53 h of SUSOPS, during which errors almost doubled from 4.2 to 7.8 errors. No differences were found for reaction time. In Opstad's study,[42] the results of the reasoning and pattern recognition tasks were taken together. Average performance decreased by 20% after 16 h of military training and up to 55% for between 72 and 96 h of SUSOPS compared to baseline. Vrijkotte et al.[57] found completion time for the Tower of Hanoi to be increased by 30% at day 5 in week 1. Again, performance in week 3 showed the most decrement, with reductions up to 130% on day 3 and even 260% on day 5. In Marrao et al.'s study,[39] grammatical transformation improved by 9% during the fifth test day, but no differences were found during the planning task.

DISCUSSION

It was expected that all cognitive modalities would deteriorate over time and that the magnitude of the deterioration would increase with the duration of the sustained operation, whether in a linear fashion or not, without reaching a steady state performance or a fatiguing point and despite the different goals for the selected training courses. This review showed that vigilance, reaction time, and working memory were affected during relatively short military operations (up to 80 h) with high exercise intensity, being sensitive for physical and mental stress without recovery time. Thereafter, a breaking point is observed with inconsistent performances (improvement, decrements, and stable performance). Reasoning seems to be sensible to different stress levels and related to a different time course

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Table V. Effects of Sustained Operations on Reasoning.

COURSE DURATION	PARTICIPANTS	TASK DURATION	EFFECT ON PERFORMANCE*	SOURCE
53 h	31 men	GR; 5 min.	↓ after 35 h: GR: correct responses $P < 0.05$, incorrect responses P = NS, no responses P = NS, & reaction times P = NS ↓ after 53 h: GR: correct responses $P < 0.001$, incorrect responses $P < 0.001$, no responses P = NS, & reaction times P = NS	Lieberman et al.[34]
5 d	18 men	HMS/DSS; none reported	↓ after the course: Mean HMS/DSS: performance $P < 0.001$	Opstad[42]
3× 5 d	9 men	Tower of Hanoi; 5 min.	↓ Week 1, after 4 d: 2-back: completion time $P < 0.01$ ↓ Week 2, mornings of days 3 and 5: 2-back: completion time $P < 0.01$	Vrijkotte et al.[57]
9 d	28 men	GT; 2 min. P; 5 min.	↑ test day 5: GT: correct responses $P < 0.05$ – over all test days: P: number of steps taken to complete task P = NS	Marrao et al.[39]

*↓ Decrease in performance; – no change in performance; ↑ increase in performance.
GR = grammatical reasoning, Mean HMS/DSS = mean higher mental processes/digit symbol substitution, LR1 = logical reasoning, GT = grammatical transformation, P = planning, NS = not significant.

compared to vigilance, reaction time, and working memory. Reasoning is affected during short and intensive training courses as well as after 7 d of military training.[20] Recovery of this modality is not as quick as the previously discussed cognitive modalities and it has to be kept in mind that complex cognitive task results might be influenced by motivation and effort. Harris et al.[20] showed that actual cognitive impairment can be masked due to the mobilization of resources (motivation and effort), which is absent in simple cognitive tasks.[10,20] In addition, Vrijkotte et al.[57] showed that reasoning performance can be restored to normal values within 12 h. This might be due to the changes in course intensity.

Quick recovery of vigilance, reaction time, and working memory is possible when short naps are taken or when soldiers are able to get some rest,[56] which confirms laboratory studies investigating the dose-response effect between sleep deprivation and cognitive performance, and the restorative effect of even short periods of sleep.[55] A total of 4 h/d of sleep for 6 d (thus 24 h of sleep in a period of 152 h) should be adequate to maintain cognitive performance[25] or to restore cognition after being awake for 90 h.[24] These results confirm the relationship between stress and the simpler constructs of cognitive performance.

A linear relationship might exist between high stress levels and an impaired vigilance, reaction time, and working memory, which is valid for training courses up to 80 h.[34,35] Belenky et al.[6] concluded that cognitive decline starts to show after 18 h of sustained work. Each 24 h, cognitive performance deteriorates by at least 25%, which results in a 75% deterioration of cognitive performance after 72 h sustained work, which is in line with our 80-h threshold. Despite the large performance drop after 72 h, Belenky et al.[6] stated that soldiers can remain operationally ready for 2 to 3 d without sleep. This is supported by Ainsworth and Bishop,[4] who found that tank crews showed little deterioration in performance after 48 h without sleep. On the contrary, Haslam[23] stated that soldiers lose their effectiveness after 48 to 72 h without sleep and one night in the field without sleep will already reduce cognitive performance. Again, these discrepancies, along with the small number of studies that actually met our inclusion criteria, warrants more thorough investigation of cognitive performance in operational settings to allow for the determination of an actual operational threshold. In our review we found inconsistent results in simple cognitive performance during SUSOPS lasting longer than 80 h. This finding might be true, but the amount of sleep, caloric consumption,[24,41,48] and differences in military tasks that were performed and environmental circumstances might account for dissimilar findings in different studies.

Incidents that occur during combat and training courses are likely to be the result of affected cognitive performance,[35] arising all of a sudden.[19,35] This abrupt strike can have devastating consequences which should be prevented. There is no model or equation to predict the level of cognitive decrement as a function of stress. Apart from the obvious caveat of interindividual differences, which are a common denominator in all human performance research, the development of such a model would be very complex due to two key elements that need to be included in this formula: time and intensity. Soldiers' sustainability is not just the simple product of time and intensity, it is a process during which time and intensity continuously affect each other. This interaction, in turn, affects the recovery or impairment of cognitive modalities. Therefore, determining whether a soldier is still operationally "ready" is very complex and an issue researchers are trying to clarify. Our reviewed studies show that the amount of cognitive decline is very dependent on the circumstances and the stress experienced by the soldier. Therefore, adjustments need to be made according to the circumstances and it needs to be questioned whether a cognitive decline of around 75%, as reported by Belenky et al.,[6] is acceptable for operational readiness.

There appears to be an inconsistency in the use of the taxonomy of cognitive aspects. Due to the multiple variable outcomes of tasks, many inconsistencies in the denomination of cognitive modalities were found. This was summarized in Table II. For example, several studies mentioned measuring pattern recognition while they were actually investigating working memory[20,23,42] or reasoning.[39] More specifically, Opstad[42] called the 'digit symbol substitution task' a pattern recognition task, whereas this task is known to tap into working memory because working memory is used to keep the "code" of symbol pairs available and to create the right substitution according to these pairs. In addition, many tasks measure

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additional cognitive aspects besides the main aspect which the task was designed to evaluate, but it appears that authors find it difficult to separate different outcome measures, probably because cognition works in an integrated fashion as a whole. For example, the reaction times measured during memory, reasoning, or recognition tasks are presented as part of the main task, while in fact reaction time is a different cognitive construct,[20] which, if not investigated separately to ensure it is not affected, may confound results from these modalities. The same applies to vigilance, as we discussed earlier with the comparison of performance at the beginning and at the end of a task. The problem of the interpretation of the task results is closely related. There are authors who report the outcome variables separately, while Opstad[42] reports multiple performance variables or tasks. Combined task results need different interpretation compared to single outcome variables.

When attempting to measure performance, there is always the tradeoff between ecological validity and standardization. The more standardized the training courses, the better results can be compared with other studies. However, more standardization will negatively affect the replication of the real battlefield. Soldiers are more likely to experience higher stress levels during real field operations compared to simulated operations.[34,35] Although military teachers strive to expose their pupils to situations as realistic as possible, training sessions will always be limited. In addition, every course has its own program and purpose, influencing the duration and the physical and mental stress of training courses.[27,52,53] Since physiological stress is probably related to cognitive performance on various tasks, we advise collecting physiological data in order to quantify and relate physiological data with cognitive parameters.

For each cognitive modality, multiple tests have been developed and there is no consensus about the tasks being used. In 1989, a NATO RTO workgroup developed the AGARD test battery.[2] Unfortunately, researchers did not collectively adopt and use the test battery, but continued to use their own set of tasks and tests. This holds true for the use of questionnaires, diaries, and other measurements as well. Due to the lack of gold standard measurements in the field of cognition, outcome variables are still slightly different, even when stemming from tests aimed at investigating the same constructs. Furthermore, with regard to protocol, test times are not consistent, which makes circadian and ultradian rhythms confounding variables in the data.[28,56] Limited duration of cognitive tasks might cover up differences in cognitive performance when solely comparing average task scores. It is recommended to test for within-task performance deteriorations. Also, test frequency varies, with too many test sessions leading to learning effects. In addition, the number of participants in the selected studies is low, leading to limited statistical power.[10]

Uncontrollable factors also influence task results. Leadership style, group cohesion, and other psychological issues are of importance for cognitive performance.[22,23,45] Haslam[23] reported that platoon commanders were responsible for 52% of the soldiers who completed the course due to their enthusiasm and spirit. In addition, experienced soldiers were found to have lower anxiety scores and better cognitive performance.[35] According to Haslam,[23] experienced soldiers might better pace the course, but it remains unclear whether this is the case in the real battlefield.

From the few studies that met our stringent inclusion and exclusion criteria, we can conclude that cognitive performance is severely affected during SUSOPS. The modalities that were investigated can be divided into two groups with their own time constraints of decrement and recovery. Results of the selected studies indicate that vigilance, reaction time, and working memory are affected most during episodes of relatively short duration and high intensity exercise. Deteriorations of these modalities during courses longer than 80 h were limited; therefore, it is likely that these cognitive constructs recover quickly when stress is reduced. On the contrary, logical reasoning is affected during short durations of high intensity exercise, but remains affected during prolonged military operations. These findings lead us to believe that reasoning is a cognitive construct that needs a relatively long recovery time to restore to baseline functions. Considering the implications for decision making in the battlefield, the means to counteract this decrement would warrant further investigation.

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