The impact of total sleep deprivation upon cognitive functioning in firefighters

Introduction: Firefighters as a profession are required to maintain high levels of attention for prolonged periods. However, total sleep deprivation (TSD) could influence negatively upon performance, particularly when the task is prolonged and repetitive.

Purpose: The aim of this study is to examine the influence of TSD on cognitive functioning in a group of firefighters.

Subjects and methods: Sixty volunteers who were active male fire brigade officers were examined with a computerized battery test that consisted of simple reaction time (SRT) (repeated three times), choice reaction time, visual attention test, and delayed matching to sample. Six series of measurements were undertaken over a period of TSD.

Results: Performance in the second attempt in SRT test was significantly worse in terms of increased number of errors and, consequently, decreased number of correct responses during TSD. In contrast, the choice reaction time number of correct responses as well as the visual attention test reaction time for all and correct responses significantly improved compared to initial time points.

Conclusion: The study has confirmed that subjects committed significantly more errors and, consequently, noted a smaller number of correct responses in the second attempt of SRT test. However, the remaining results showed reversed direction of TSD influence. TSD potentially leads to worse performance in a relatively easy task in a group of firefighters. Errors during repetitive tasks in firefighting routines could potentially translate into catastrophic consequences.

Keywords: constant routine protocol, simple reaction time, choice reaction time, visual attention test, delayed matching to sample mental functioning

Introduction
Research performed over the last 100 years has shown paradoxical results: studies suggest that it is harder to maintain prolonged attention while the ambient environment is monotonous and requires lower levels of cognitive resources than in interesting and demanding environments.1–4 Additionally, total sleep deprivation (TSD) can lead to neurocognitive decline in attention, working memory, and executive function.5,6

Firefighters require the ability to maintain high levels of attention for prolonged periods; even the smallest mistake while performing procedures can lead to failure on a huge level. However, TSD could negatively influence the quality of performance, especially when cognitive function tests are not exciting and prolonged in time. Several studies confirm that the ability to maintain attention is susceptible to sleep deprivation.7–10

Moreover, results of meta-analyses have shown that the combined effect size of TSD has an influence upon simple attention and vigilance tasks and is the largest of all cognitive domains studied.11 It has been noted that there is not a large cognitive decline...
in complex cognitive tests after TSD, probably due to the
effects of a phenomenon known as compensation: partici-
pants self-drive and motivation increases during cognitive
tests after TSD, therefore, the difference between pre- and
posttest is minimal. Increasing task difficulty facilitates
the cerebral compensatory response to TSD. For example,
meta-analysis average effect sizes for complex attention and
working memory tests have been shown to be moderate. Moreover,
results of several studies have shown somewhat
similar pattern of TSD effects upon cognitive domains. However,
in the case of simple attention and vigilance
tasks, the compensation effect has its least potency during
TSD. Furthermore, the meta-analysis average effect sizes
of the accuracy measures for tests of processing speed were
not statistically significant, which has been confirmed by
the results of more recent intervention-based studies. This
could be explained by introducing a trade-off model: when
TSD diminishes the ability of subjects to perform processing
speed tests, subjects have the ability to “choose” how to best
manage with such inconvenience. On the one hand, subjects
can try to respond faster; however, this would lead to an
increase in the number of committed errors or false alarms
in simple reaction time tests. On the other hand, taking
effort to minimize the level of errors could lead to slower
reaction times.

Most studies show the negative effects of TSD upon
cognitive functioning, especially when the task is long
and repetitive. However, there are few data related to the
effects of TSD on healthy experts in maintaining high-level
attention for prolonged time periods during stressful situa-
tions. Studies were conducted on professional drivers, house officers, or military troops. The visual, auditory,
olfactory, and tactile systems of firefighters ought to be highly
effective in order to perform their jobs well. Recent advances in
neuroimaging methods have allowed researchers to study
brain activity while executing various tasks. Interestingly,
neuroimaging data suggest that the pattern of activity while
undertaking attention tests differs after sleep deprivation
compared to after “normal” sleep; increased activity was
observed in the anterior cingulate and right prefrontal cortex
dering attention-switching tests after TSD. State Instability
Hypothesis was proposed to explain variability in results
of sustained attention tasks during TSD. It proposes that
homeostatic drive for sleep, endogenous cues for wakeful-
ness promotion, and the compensatory effort undertaken by
the subject to perform affect greater variability in attention
level dynamics.

Sleep is considered as crucial in learning processes. However, the entire function of sleep is yet to be fully
understood. Therefore, it is important to examine cognitive
functioning in a group of participants whose usual role is
to undertake tasks that require high levels of attention and
short response times to environmental cues while maintaining
high quality and as low as possible a number of committed
errors. Moreover, in the case of firefighter, these actions are
performed under TSD condition as their shifts usually last
24 hours. Therefore, the aim of this study was to examine the
influence of sleep deprivation upon cognitive functioning in
a group of firefighters.

Subjects and methods
Study group
The study included 60 volunteers – all of them were active
male fire brigade officers working in fire brigade units in
the Kujawsko-Pomorskie Voivodeship. Their age ranged
from 23 to 50 years (Table 1). Interestingly, all participants
had to pass fitness test to become professional firefighters,
which is repeated annually. The study was approved by the
Ethics Committee, Ludwik Rydygier Memorial Collegium
Medicum in Bydgoszcz, Nicolaus Copernicus University,
Torun, Poland. Written informed consent was obtained
from all participants. Due to technical reasons, some data
(n=5) were missing; therefore, data on 55 participants were
analyzed in this study.

The subjects met the following criteria for enrollment
into the study group: 1) active service as a fire brigade
officer and 2) positively evaluated health status following a
standard comprehensive physical examination. In addition
to giving their voluntary consent to participate in the study,
the main enrollment criteria included sex (males only were
chosen to exclude potential role of menstrual cycle on the
outcome), absence of comorbidity, and absence of reported
sleep disorders (Pittsburgh Sleep Quality Index <5). The
exclusion criteria consisted of factors that could possibly
modify the response upon TSD: shift work, extreme morning/
evening chronotype, any caffeine or alcohol taken during the
study or within 12 hours before the test, drug dependence,

| Parameter                  | Study group (N=55), mean (range ± SD) |
|----------------------------|-----------------------------------|
| Age (years)                | 32.6 (23–50±6.8)                  |
| Body height (cm)           | 180 (160–195±6.5)                 |
| Body weight (kg)           | 80.5 (63–114±10.9)                |
| BMI (kg/m²)                | 24.6 (20–38±2.6)                  |
| sBP at rest (mmHg)         | 117.9 (94–152±7.3)                |
| dBP at rest (mmHg)         | 72.9 (61–101±6.5)                 |

Abbreviations: BMI, body mass index; dBP, diastolic blood pressure; sBP, systolic blood pressure.
participation in sports at a competitive level, receiving any
medication/supplements during the study, and potential
disorders of the cardiovascular system observed during the
test experiment. Pretest of the subjects’ health state assess-
ment included the basic neurologic, clinical examination
and evaluation of the autonomic nervous system using the
Autonomic Symptom Profile.30

Cognitive function measurement
To measure the cognitive function, the computerized
battery test – Test Sprawności Operacyjnej (software ver-

tion 4.6.0.44744, Speednet sp. z. o. o.,51 was used.51 The
following tests were included: simple reaction time (SRT),
choice reaction time (CRT), visual attention test (VAT);
visual version of match to sample), and delayed matching to
sample (DMS). SRT measures visual information processing
speed, CRT is a decision-making test, VAT measures visual
sustained attention, and DMS is a test of visual form of short-
term memory test. Too fast, too slow, or inadequate (wrong
or double-pressed key) responses are treated as an error in
this battery. At the beginning of every test, text instruction
is displayed until the participant confirms that he/she read it
fully by pressing a “space” key on the keyboard. The type
of the stimuli is randomly picked from one of five sets: geo-
metric shapes, plant and animal shapes, arrows, letters, or
numbers. Proper and distractor stimuli are randomly selected
by the software before each trial; all are presented on a white
background on 15.6” screen.

SRT measures the reaction time to stimuli which appear
20 times at random intervals in the same place (center of the
screen). “Space” button should be pressed as fast as possible
on the stimulus; otherwise, one should refrain from reaction
(go/no-go test). The test contains 75% of “go” stimuli rela-
tive to 25% of “no-go”; the stimuli are exposed in a random
order. The “no-go” stimuli come from the same set as the
desired (“go”) stimulus. The “go” stimulus is exposed before
the tests start, until the participant confirms that he/she is
ready to start to undertake the test by pressing a “space” key.
Each participant has 3 seconds to react; otherwise, prolonged
reaction is treated as an error.

CRT is very similar to SRT, except that CRT requires
two-choice reaction for 30 trials. The “m” key on the key-
board is used to react as fast as possible on proper stimulus.
Any other stimuli require pressing “z” as fast as possible.
A wide range of distractors is used: some of them have
only one distinctive feature compared to the actual target
(e.g., color or shape), while other distractors have more than
one distinctive feature. Fifty percent of the stimuli are distrac-
tors, which are exposed in a random order. Each participant
has 3 seconds to react; otherwise, prolonged reaction is
treated as an error.

The VAT, like the CRT, requires two-choice reaction (“m”
or “z” button). The stimuli are cards in the form of vertical
rectangles, with each containing two symbols on it which are
randomly selected from one of five sets. Participants have to
quickly compare the five cards placed on the upper part of the
screen with one card which appears at the center of the screen.
If the card at the center is the same as one of the upper five
cards, then the participant has to press “m” as fast as possible;
otherwise, “z” button should be pressed. The whole set of
upper cards on the screen is changed three times during each
trial (three sets of 20 stimuli each, every set contains stimuli
from a different category). Response longer than 3 seconds is
classified as an error. Fifty percent of the stimuli are distrac-
tors, which are exposed in a random order.

DMS is very similar to VAT with the only one exception
being the set of stimuli in the form of five cards on the upper
part of the screen is exposed for 10 seconds and disappears.
Then, at the center of the screen, one card appears at a time.
Participants have to remember if this card was in the set of five
cards on the upper part of the screen. If so, the correct response
is to press “m”, otherwise “z” should be pressed. Participants
have 3 seconds for the response; otherwise, lack of response is
treated as an error. The whole set of upper cards on the screen
is changed three times during each trial (three sets of 11 stimuli
each, every set contains stimuli from a different category).
There is 45.5% of distractors in overall 33 stimuli.

The whole battery test consists of subtests in the fol-

dowing order: SRT, CRT, SRT, VAT, DMS, and SRT. It is
worth noting that the SRT test is repeated three times during
the test. Overall, there is ~12 minutes interval between the
start of the whole battery test and the start of the last SRT
test. Moreover, there is ~2 minutes 20 seconds interval
between the start time of the first and the second SRT tests.
Therefore, the Test Sprawności Operacyjnej is a very elegant
tool to measure the influence of cognitive fatigue on SRT
performance through comparison of participants’ results
in three subsequent attempts to SRT test. On the basis of
meta-analysis,19 the results of simple visual task could be
potentially the most suitable for the effects of TSD examina-
tion. We will use SRT_1, SRT_2, and SRT_3 abbreviations
for simplicity.

Study protocol
The whole examination was performed in the chronobiology
laboratory while maintaining constant conditions (constant
routine; temperature 22°C, humidity 60%, light <10 lx).
As Table 2 shows, subjects arrived at the laboratory at
Table 2 Schedule of neuropsychological assessments taken into analysis

| Timeline of the intervention | Order of time points | Practice | Baseline | 12-hour TSD | 18-hour TSD | 22-hour TSD | 27-hour TSD | 31-hour TSD |
|-----------------------------|----------------------|----------|----------|-------------|-------------|-------------|-------------|-------------|
| Time interval               | 09:00 am             | 04:00 pm | 09:00 pm | 03:00 am    | 07:00 am    | 12:00 noon  | 04:00 pm    |

Note: Examination took place six times at 2–3-hour intervals (points) during TSD.

07:30 am after they had their typical sleep at home the previous night (sleep prescribed by the participants and monitored by actigraphy, total sleep time=421.2±68.2 minutes) and stayed awake until 06:00 pm on the next day (Day 2), that is, for 31 hours. After a normal night of sleep (the rested state), the subjects underwent training in test procedures. Following arrival in the laboratory at 07:30 am on Day 2 (Day 1=typical sleep), the volunteers began regular cognitive testing throughout the sleep deprivation period, during which eight measurements of cognitive functioning were undertaken. The first two neuropsychological test performances (between 09:00 am and 01:00 pm) were treated as a “practice” to minimize the “practice effect” and therefore were not taken into the analysis. The next six measurements started from 04:00 pm–06:00 pm to the last time point at 04:00 pm–06:00 pm on the next day (Day 2). Trained staff were present to make sure that subjects would stay awake during the whole period of TSD. In between cognitive assessments, subjects were allowed to undertake most of the regular daily life activities (reading, writing, talking, and playing games). Subjects ate the same meals at the same time of day (8:00 am, 12:00 noon, 03:00 pm, 07:30 pm). Water (100 mL) was administered at hourly intervals during the protocol. Additionally, the device Actigraph GT3X was used during the experiment to monitor subjects’ sleep deprivation and motor activity to exclude the potential effect of increased physical activity during TSD on the measured outcome.32,33

The device is routinely used in children and in young people; in patients with cardiovascular, neurologic, or orthopedic disorders; and for diagnosing and treating sleep disorders.34,35

Statistical methods

All statistical analyses were performed using statistical package (StatSoft, Inc. [2014], STATISTICA [data analysis software system], version 13.1. www.statsoft.com).32 Differences in the means of physical activity level between normal sleep and sleep deprivation were measured using dependent t-test for dependent samples. Data on the impact of sleep deprivation upon cognitive functioning were submitted to analysis of variance (ANOVA) with repeated measures and post hoc analysis using Bonferroni correction was applied. Mauchly’s test was used to check the assumption of sphericity, the Huynh–Feldt correction was applied, and the ε value and also the corrected value of degrees of freedom are reported where appropriate. Error bars on graphical representation of results indicate standard error. To calculate the overall effect size, the following equation for omega squared (ω²) was used.36 ω² = [\frac{k-1}{nk} (MS_m - MS_r)]\frac{MS_r + MS_m - MS_r}{k} + \frac{k-1}{nk} (MS_m - MS_r)

Results

All effects are reported as significant at p<0.05. Actigraph measurement revealed no significant differences in the physical activity of subjects between normal sleep and sleep deprivation: in the number of steps (384.8±240.0 vs 385.1±90.4, p>0.05), in the % of time spent on sitting (69.7±5.9 vs 69.7±3.0, p>0.05), in the % of slight activity (19.7±3.2 vs 21.1±2.1, p>0.05), in the % of moderate activity (7.2±3.1 vs 5.9±2.1), in the % of intensive activity (2.9±2.9 vs 3.5±1.1), and in the % of very intensive activity (0 vs 0.1±0.2, p>0.05).

Mean, min, max SD, and standard error values of every cognitive function subtests results (every attempt included) are provided in Table S1.

In the case of correct responses in SRT_2 test, Mauchly’s test indicated that the assumption of sphericity had been violated (χ²(14)=41.6, p<0.05); therefore, the degrees of freedom were corrected using Huynh–Feldt estimates of sphericity (ε=0.78). Repeated measures ANOVA confirmed that there was a significant effect of TSD on the number of correct responses in SRT_2 test (F[3,90, 210.64]=3.60, p=0.008, ω²=0.03). Bonferroni correction during post hoc
The impact of total sleep deprivation upon cognitive functioning analysis indicated significant difference in the number of correct responses between the first (04:00 pm) and the fifth (27th hour of TSD) time points in the second attempt of this test (Figure 1A). There were no statistically significant effects of TSD on errors committed in SRT_1 and SRT_3 tests ($p>0.05$). Moreover, the results showed that TSD significantly affected the number of errors committed in the SRT_2 test ($\varepsilon=0.80, F[3.99, 215.57]=3.61, p=0.007, \omega^2=0.03$). Bonferroni correction during post hoc analysis indicated significant difference in the number of correct responses between the baseline and 27th hour of TSD in the second attempt of this test (Figure 1B). There were no statistically significant effects of TSD on errors committed in SRT_1 and SRT_3 tests.

The reaction time in all (correct and incorrect) responses and the reaction time in correct responses in the SRT test were not significantly affected by the TSD ($p>0.05$; Figure 2A). Additionally, significant effect of TSD on the reaction time was observed in correct and all responses (Figure 2B) in the CRT test ($\varepsilon=0.91, F[4.53, 244.67]=2.54, p=0.03, \omega^2=0.008$ and $\varepsilon=0.89, F[4.43, 239.26]=2.64, p=0.03, \omega^2=0.008$, respectively).

![Figure 1](image1.png)  
**Figure 1** Number of correct responses and errors committed in SRT tests.  
**Notes:** (A) The X-axis indicates the time point of battery test execution. The Y-axis indicates the analyzed results of the test (number of correct responses in that case). Attempts in SRT test in which statistically significant effect of sleep deprivation on correct responses was observed using repeated measures ANOVA. Statistically significant differences in the number of correct responses between particular time points revealed by the post hoc Bonferroni correction are marked with double asterisks ($p<0.05$). Errors bars indicate SE. (B) Statistically significant differences in the number of errors committed between particular time points revealed by the post hoc Bonferroni correction are marked with double asterisks ($p<0.05$). Interestingly, differences in the number of committed errors among three attempts in SRT are the lowest in the last time point.  
**Abbreviations:** ANOVA, analysis of variance; SE, standard error; SRT, simple reaction time; TSD, total sleep deprivation.

![Figure 2](image2.png)  
**Figure 2** Reaction time in SRT and CRT tests.  
**Notes:** (A) No statistically significant ($p>0.05$) effects of TSD on reaction time or on the correct reaction time (results not shown) in SRT test were observed. Interestingly, an opposite trend could be observed, that is, the reaction times tend to be lower (improved) in the following attempts. (B) Statistically significant effect of TSD on the reaction time in correct and all responses in CRT test was observed using repeated measures ANOVA ($p<0.05$). The greatest reaction time was obtained in the first time point of TSD.  
**Abbreviations:** ANOVA, analysis of variance; CRT, choice reaction time; SRT, simple reaction time; TSD, total sleep deprivation.
The effect of TSD on VAT reaction time and correct reaction time was observed ($F[5, 270]=10.59, p<0.001$, $\omega^2=0.04$; Figure 5 and $F[5, 270]=9.87, p<0.001, \omega^2=0.04$; data not shown, respectively). Bonferroni correction during post hoc analysis indicated significant differences in reaction time for all (Figure 5) and for correct responses (data not shown) between the baseline and the third, fourth, fifth, and the last time points, as well as between the second and the last two time points.

### Discussion

This study has shown significant overall differences between means of the number of errors and, consequently, the number correct responses in the second attempt of SRT (SRT_2) test during sleep deprivation. Worse results in terms of number of committed errors and correct responses, but not in the reaction time, are consistent with our assumptions that the effects of TSD will be manifest in the performance of the most repetitive test in terms of a trade-off model for speed or correctness of response.\(^9\) Interestingly, the number of errors increased noticeably after 12 hours of TSD and reached its peak at the 27th hour of TSD.

Moreover, our results showed an effect of TSD on the number of errors committed in DMS test. Interestingly, two “peaks” occurred in the number of errors during the study: late evening before deprived sleep (12th hour of TSD) and afternoon of the day after sleep deprivation (27th hour of TSD). This is in accordance with previous reports. In case of short-term memory tests which are based on recognition, statistically significant ($p<0.01$) combined effect size of TSD ($-0.378$) was reported.\(^37\) In contrast, moderate-range average effect sizes for complex attention and working memory tests were reported.\(^37\)

Our study confirmed a completely inverse relation of the influence of TSD on cognitive functioning in the remaining subtests, which could be considered as more complex. Using repeated measures ANOVA with adjustment for Bonferroni post hoc correction, we confirmed that the sample group obtained better results in terms of the greater number of correct responses in the CRT test as well as a shorter reaction time for all responses (correct and error) and correct reaction time in the VAT during TSD. Graphical presentation showed that these results were improved during following time points of TSD. This is in accordance with the results of a previous meta-analysis,\(^10\) which confirmed that TSD has relatively less impact upon cognitive tests characterized by greater complexity. Moreover, the State Instability Hypothesis assumes that compensatory effort exerted by participants to get the
best test results is one of the elements, which together with drive for sleep and endogenous circadian promotion of wakefulness affect cognitive lapses during TSD. The last element was controlled during the study by using constant routine protocol; however, increased patient motivation and greater control of drive for sleep due to adaptation to TSD because of the work pattern could potentially explain the observed results in group of firefighters. Our findings are consistent with the results of studies included in a previous systematic review.

Firstly, it was noted that studies exploring the influence of TSD upon cognitive functioning did not show a large decline, probably because of compensation effects. This observation could be explained by enhanced self-drive and motivation of participants while undertaking cognitive testing. In our studies, based upon a constant routine protocol, participants had a limited variety of activities during sleep deprivation. Therefore, participants could perceive a ~5-hour interval between consecutive cognitive tests as boring, in contrast to the time of testing, which could be considered to be more exciting and could, in turn, immediately increase participants’ alertness.

It is worth mentioning the “flow” concept, which is an interesting as yet unexplored phenomena. It is tempting to state that cognitive tasks which are subjectively highly challenging (but not too demanding) and perceived as interesting could be executed with higher motivation. These authors showed that the combined effect size of TSD’s influence on simple attention and vigilance tasks was the largest among all the categories studied, which compares favorably with the results of our study. The SRT test could be perceived as the “easiest” and the “most boring” test; therefore, motivation of participants could be the lowest in this particular subtest. Such potential factors were noted in the late 70s during a series of studies on the effects of TSD and have been consequently repeated over decades. In recent years, various network theories have described patterns of brain activity while performing tasks. In the case of functional analysis during attention tests, there are sparse data regarding how the tactile system as well as the olfactory system function. Results of a study on brain network functioning showed that subcortical and cerebellar network functioning in young TSD participants is similar to that in old patients under normal conditions. Authors conclude that TSD could serve as a model of cognitive aging in the above-mentioned networks. Moreover, TSD reduced selectivity in parahippocampal area and diminished firing of frontoparietal and ventral visual task-related areas could possibly lead to disturbances of selective and sustained attention, respectively.

Changes in the level of single neuron activity in the medial temporal lobe preceding cognitive lapses under conditions of TSD were observed. Interestingly, sporadic short-term

Figure 5 Reaction time in VAT.

Notes: Statistically significant differences in the reaction time between particular time points revealed by the post hoc Bonferroni correction are marked with double asterisks (p < 0.05). Interestingly, VAT reaction times for all responses tend to decrease in the second, third, and fourth time points in TSD, while the reaction time in the last three time points tend to be at a relatively constant level.

Abbreviations: TSD, total sleep deprivation; VAT, visual attention test.
TSD events are rather not related to long-term maladaptation at the nervous system level. However, in a systematic review on the influence of sleep loss on driving performance in young drivers, half of the analyzed studies showed detrimental effects. Additionally, in the examination of visual processing changes during TSD, an important role of features such as visual angle and duration of being awake was underlined. Interestingly, it has been shown that groups of single neurons could be “asleep” in sleep deprivation (SD) condition, affecting the cognitive functioning negatively. Moreover, two different dynamic patterns on the cortical level, one occurring during wake and rapid eye movement sleep and the second one occurring during non-rapid eye movement sleep, have been reported.

Practice effect was shown to be significant in tests without alternative version, while results of SRT test or CRT test tended to not differ in test–retest paradigm. Taking this into account, all of the subtests used in the above-mentioned studies should be relatively less vulnerable to the practice effect. Therefore, it can be assumed that two practice sessions that have been provided should be sufficient to minimize potential learning effect; however, its role could not be excluded.

**Conclusion**

To the knowledge of the authors, this study is the first one on the effects of TSD on cognitive functioning in a group of firefighters. Our results showed that not all of the examined cognitive domains were affected negatively by TSD; however, worse results in SRT test during TSD could translate into higher risk of committing a seemingly minor error during performing a firefighter routine and repetitive task, which in turn can result in substantial catastrophe. Therefore, further studies on firefighters should focus on development of methods which would be useful in prediction of cognitive lapse occurrence and in prevention. Moreover, the quantity of cognitive assessments and the time interval between them should be reconsidered in methodology of further studies on the effects of TSD. Probably, increasing number of assessments during acute SD could increase the chance that the observed changes in cognitive performance are caused by the effects of reinforced learning not by SD per se. In addition, the study protocol should allow to adjust obtained results by the effects of circadian rhythm.

**Disclosure**

The authors report no conflicts of interest in this work.

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## Supplementary material

### Table S1 Mean, min, max, SD, and SE values

| Variable | Mean | Min | Max | SD  | SE  |
|----------|------|-----|-----|-----|-----|
| _01CRT_correct_answers_ | 28.73 | 25 | 30 | 1.14 | 0.15 |
| _01CRT_correct_reaction_time_ | 494.95 | 356 716 | 73.80 | 9.61 |
| _01CRT_errorscommitted_ | 1.41 | 0 | 6 | 1.31 | 0.17 |
| _01CRT_reaction_time_ | 494.14 | 354 716 | 74.10 | 9.65 |
| _01DMs_correct_answers_ | 23.83 | 16 | 33 | 3.98 | 0.52 |
| _01DMs_correct_reaction_time_ | 1,296.69 | 727 2077 | 329.76 | 42.93 |
| _01DMs_errorscommitted_ | 9.20 | 0 | 18 | 4.04 | 0.53 |
| _01DMs_reaction_time_ | 1,269.58 | 628 1,916 | 322.56 | 41.99 |
| _01SRT_1_correct_answers_ | 0.76 | 0 | 3 | 0.88 | 0.11 |
| _01SRT_1_correct_reaction_time_ | 19.25 | 17 | 20 | 0.86 | 0.11 |
| _01SRT_1_reaction_time_all_ | 422.97 | 288 844 | 87.23 | 11.35 |
| _01SRT_2_correct_answers_ | 0.36 | 0 | 3 | 0.69 | 0.09 |
| _01SRT_2_correct_reaction_time_all_ | 19.68 | 17 | 20 | 0.69 | 0.09 |
| _01SRT_2_reaction_time_ | 416.14 | 312 783 | 77.76 | 10.12 |
| _01SRT_3_correct_answers_ | 0.47 | 0 | 2 | 0.63 | 0.08 |
| _01SRT_3_correct_reaction_time_ | 19.53 | 18 | 20 | 0.63 | 0.08 |
| _01SRT_3_reaction_time_all_ | 420.27 | 299 718 | 88.16 | 11.48 |
| _01SRT_3_reaction_time_ | 419.17 | 299 718 | 86.53 | 11.27 |
| _01VAT_correct_answers_ | 55.15 | 46 | 60 | 3.20 | 0.42 |
| _01VAT_correctReaction_time_ | 1,243.58 | 822 1,650 | 195.16 | 25.41 |
| _01VAT_errorscommitted_ | 4.93 | 0 | 14 | 3.22 | 0.42 |
| _01VAT_reaction_time_ | 1,257.68 | 820 1,747 | 206.24 | 26.85 |
| _02CRT_correct_answers_ | 29.20 | 26 | 30 | 0.88 | 0.12 |
| _02CRT_correct_reaction_time_ | 488.82 | 360 847 | 87.08 | 11.64 |
| _02CRT_errorscommitted_ | 0.82 | 0 | 4 | 0.90 | 0.12 |
| _02CRT_reaction_time_ | 487.48 | 361 847 | 86.33 | 11.54 |
| _02DMs_correct_answers_ | 23.05 | 13 | 28 | 3.77 | 0.50 |
| _02DMs_correct_reaction_time_ | 1,284.09 | 491 2,049 | 336.69 | 44.99 |
| _02DMs_errorscommitted_ | 10.07 | 5 | 20 | 3.79 | 0.51 |
| _02DMs_reaction_time_ | 1,237.27 | 462 1,822 | 301.01 | 40.22 |
| _02SRT_1_correct_answers_ | 0.46 | 0 | 3 | 0.69 | 0.09 |
| _02SRT_1_correct_reaction_time_ | 19.57 | 18 | 20 | 0.63 | 0.08 |
| _02SRT_1_reaction_time_all_ | 412.04 | 308 638 | 68.98 | 9.22 |
| _02SRT_1_reaction_time_ | 411.86 | 309 638 | 69.43 | 9.28 |
| _02SRT_2_correct_answers_ | 0.27 | 0 | 2 | 0.56 | 0.07 |
| _02SRT_2_correct_reaction_time_ | 19.73 | 18 | 20 | 0.56 | 0.07 |
| _02SRT_2_reaction_time_ | 405.86 | 283 563 | 62.82 | 8.39 |
| _02SRT_2_reactiontime_all_ | 405.86 | 283 563 | 63.06 | 8.43 |
| _02SRT_3_correct_answers_ | 0.59 | 0 | 4 | 0.89 | 0.12 |
| _02SRT_3_correct_reaction_time_ | 19.43 | 16 | 20 | 0.89 | 0.12 |
| _02SRT_3_reaction_time_all_ | 398.98 | 287 556 | 71.75 | 9.59 |
| _02SRT_3_reactiontime_ | 398.91 | 287 554 | 71.80 | 9.59 |
| _02VAT_correct_answers_ | 55.38 | 46 | 59 | 3.36 | 0.45 |
| _02VAT_correctReaction_time_ | 1,198.20 | 715 1,705 | 201.19 | 26.89 |
| _02VAT_errorscommitted_ | 4.71 | 1 | 15 | 3.40 | 0.45 |
| _02VAT_reaction_time_ | 1,208.73 | 730 1,767 | 212.56 | 28.40 |
| _03CRT_correct_answers_ | 29.07 | 26 | 30 | 1.10 | 0.15 |
| _03CRT_correct_reaction_time_ | 482.89 | 370 697 | 73.97 | 9.97 |
| _03CRT_errorscommitted_ | 0.96 | 0 | 4 | 1.17 | 0.16 |
| _03CRT_reaction_time_ | 484.75 | 361 697 | 77.30 | 10.42 |
| _03DMs_correct_answers_ | 24.13 | 17 | 31 | 3.43 | 0.46 |

(Continued)
Table S1 (Continued)

| Variable                        | Mean   | Min   | Max   | SD    | SE    |
|---------------------------------|--------|-------|-------|-------|-------|
| _05SRT_2 correct reaction time  | 400.29 | 262   | 633   | 70.95 | 9.32  |
| _05SRT_2 reaction time all      | 400.00 | 268   | 633   | 71.92 | 9.44  |
| _05SRT_3 errors committed      | 0.79   | 0     | 2     | 0.72  | 0.09  |
| _05SRT_3 correct answers        | 19.22  | 18    | 20    | 0.70  | 0.09  |
| _05SRT_3 correct reaction time  | 406.71 | 284   | 653   | 75.69 | 9.94  |
| _05SRT_3 reaction time all      | 404.74 | 282   | 631   | 74.14 | 9.74  |
| _05SRT_correct_answers          | 56.10  | 43    | 60    | 3.00  | 0.39  |
| _05VAT_correct_reaction_time    | 1,143.33 | 742 | 1,643 | 199.09 | 26.14 |
| _05VAT_errors committed         | 4.97   | 0     | 9     | 7.83  | 1.03  |
| _05VAT_reaction_time            | 1,150.55 | 745  | 1,709 | 209.28 | 27.48 |
| _06CRT_correct_answers          | 29.25  | 26    | 30    | 0.96  | 0.12  |
| _06CRT_correct_reaction_time    | 473.02 | 363   | 654   | 63.33 | 8.25  |
| _06CRT_errors committed         | 0.76   | 0     | 4     | 0.97  | 0.13  |
| _06CRT_reaction_time            | 471.80 | 363   | 654   | 63.69 | 8.29  |
| _06DMS_correct_answers          | 24.61  | 16    | 32    | 4.09  | 0.53  |
| _06DMS_correct_reaction_time    | 1,274.97 | 794  | 1,922 | 265.80 | 34.60 |
| _06DMS_errors committed         | 8.42   | 1     | 17    | 4.12  | 0.54  |
| _06DMS_reaction_time            | 1,203.98 | 741  | 1,736 | 220.32 | 28.68 |
| _06SRT_L errors committed       | 0.64   | 0     | 3     | 0.78  | 0.10  |
| _06SRT_L correct answers        | 19.36  | 17    | 20    | 0.78  | 0.10  |
| _06SRT_L correct reaction time  | 400.24 | 270   | 550   | 68.71 | 8.95  |
| _06SRT_L reaction time all      | 398.00 | 271   | 550   | 66.37 | 8.64  |
| _06SRT_2 errors committed       | 0.64   | 0     | 4     | 0.85  | 0.11  |
| _06SRT_2 correct answers        | 19.39  | 17    | 20    | 0.79  | 0.10  |
| _06SRT_2 correct reaction time  | 400.51 | 279   | 726   | 75.48 | 9.83  |
| _06SRT_2 reaction time all      | 397.71 | 276   | 678   | 71.72 | 9.34  |
| _06SRT_3 errors committed       | 0.75   | 0     | 5     | 0.99  | 0.13  |
| _06SRT_3 correct answers        | 19.34  | 17    | 20    | 0.82  | 0.11  |
| _06SRT_3 correct reaction time  | 401.59 | 294   | 681   | 69.23 | 9.01  |
| _06SRT_3 reaction time all      | 406.39 | 294   | 758   | 83.12 | 10.82 |
| _06VAT_correct_answers          | 55.92  | 45    | 60    | 3.27  | 0.43  |
| _06VAT_correct_reaction_time    | 1,131.12 | 807  | 1,517 | 173.25 | 22.56 |
| _06VAT_errors committed         | 4.34   | 0     | 16    | 3.43  | 0.43  |
| _06VAT_reaction_time            | 1,134.00 | 790  | 1,558 | 180.70 | 23.52 |

Notes: Following number of prefixes concerns the following time points of measurement during TSD: _01 prefix concerns measurement from the first (baseline) time point, _02 prefix concerns values from the second time point (12-hour TSD), _03 concerns values from the third time point (18-hour TSD), _04 _03 concerns values from the fourth time point (22-hour TSD), _05 _03 concerns values from the fifth time point (27-hour TSD), and _06 _03 concerns values from the sixth time point (31-hour TSD).

Abbreviations: CRT, choice reaction time; DMS, delayed matching to sample; SE, standard error; SRT, simple reaction time; TSD, total sleep deprivation; VAT, visual attention test.