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Effects of Threat and Sleep Deprivation on Action Tendencies and Response Inhibition

Jacobien M. van Peer[1, a], Thomas E. Gladwin[2], & Arne Nieuwenhuys[1,3, a]

Author Note

[1] Behavioural Science Institute, Radboud University, Nijmegen, the Netherlands

[2] Department of Psychology and Counselling, University of Chichester, Chichester, United Kingdom

[3] Department of Exercise Sciences, The University of Auckland, Auckland, New Zealand

[a] These authors equally contributed to the paper

Correspondence concerning this article should be addressed to Jacobien van Peer, Behavioural Science Institute, Radboud University, Nijmegen, Montessorilaan 3, 6525 HR Nijmegen, The Netherlands. Tel: (+31) 24 3611593, E-mail: j.vanpeer@psych.ru.nl or to Arne Nieuwenhuys, Department of Exercise Sciences, The University of Auckland, Private Bag 92012, Auckland 1142, New Zealand. Tel: (+64) 9 923 7974, E-mail: a.nieuwenhuys@auckland.ac.nz

Abstract

The ability to control action is crucial for adaptive responding, but may be compromised in situations involving strong emotions (e.g., threat) or when people are deprived of resources (e.g., sleep). As compromised action control can have large consequences in threatening situations, for example when police officers face a potentially armed suspect, we experimentally investigated how acute threat and partial sleep deprivation affect the ability to control impulsive responses, in 52 healthy young adults performing a simulated shooting task. The results showed that acute threat increased the tendency to act quickly (i.e., reduced response times; Coef = 9.46, *95% CI* [3.49, 15.29], $p = .001$) and impaired response inhibition (i.e., increased stop signal reaction times; Coef = -4.91, *95% CI* [-9.47, -0.44], $p = .035$). In addition, three nights of partial sleep deprivation (five hours [$n = 28$] vs. eight hours [$n = 24$] of sleep), led to a significant decrease in overall response accuracy (Coef = -0.22, *95% CI* [-0.40, -0.05], $p = .025$). Contrary to expectations, our results did not show increased threat sensitivity in sleep-deprived individuals (all $p > .13$). Nevertheless, they may have important implications for professionals who are required to maintain behavioral control under high levels of threat and who experience disturbed sleep due to e.g. shift work, as both factors negatively affected performance.

Keywords: Threat, sleep deprivation, action, response inhibition

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The ability to control our impulses is crucial for adaptive responding in everyday life. For instance, healthy eating behavior (e.g., Bartholdy, Dalton, O'Daly, Campbell, & Schmidt, 2016), effective conflict management in social situations (DeWall, Baumeister, Stillman, & Gailliot, 2007), and safe behavior in traffic (e.g., Hatfield, Williamson, Kehoe, & Prabhakharan, 2017) all require the control of impulsive responses. Under normal circumstances, most people are well able to achieve this. However, there is reason to believe that in situations that involve strong emotions, or when people are deprived of resources (e.g., due to a lack of sleep), maintaining effective control over actions can become quite difficult (e.g., Walker & van der Helm, 2009). Deficiencies in action control can have large consequences, for example in the work of police officers and soldiers, who are required to maintain effective control under high levels of acute threat (e.g., as lives may be at stake). Although these professionals also often experience disturbed sleep (Dru et al., 2007; Fekedulegn et al., 2017; Foster et al., 2016; Neylan et al., 2002; Peterson, Goodie, Satterfield, & Brim, 2008), intricate understanding about how sleep deprivation and threat together influence behavior and control is currently lacking.

Independent of sleep, neurobiological models of threat and cognitive functioning indicate that acute threat triggers a cascade of responses that rapidly increase attentional vigilance and promote fast stimulus-driven responding at the cost of maintaining cognitive control (see e.g., Hermans, Henckens, Joëls, & Fernández, 2014 for an overview). For example, in humans threat has been shown to increase perceptual sensitivity to fast temporal and coarse spatial visual information (see e.g., Bocanegra & Zeelenberg, 2011; Lojowska, Gladwin, Hermans, & Roelofs, 2015), lower the excitation threshold in the cortico-spinal tract (Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009; Hajcak et al., 2007; Oliveri et al., 2003; Schutter, Hofman, & Van Honk, 2008), and increase activity of the neurocognitive salience network, while the executive control network is suppressed (Bishop, 2008; Hermans et al., 2014), in order to facilitate quick processing of threat-relevant stimulus information and fast motor responses. Although such automatic defensive responses are generally considered to be adaptive (Blanchard, Hynd, Minke, Minemoto, & Blanchard, 2001), performance may be negatively affected on tasks that rely heavily on cognitive control functions (see e.g., Eysenck, Derakshan, Santos, & Calvo, 2007; Nieuwenhuys & Oudejans, 2017, 2012).

In line with this account, studies employing the Go/NoGo paradigm, in which participants respond to one type of stimulus (Go) while withholding responses to other stimuli (NoGo), show that experimental manipulations of threat are typically associated with faster responding and decreased response accuracy, specifically an increase in false alarms (De Houwer & Tibboel, 2010; Nieuwenhuys, Savelsbergh, & Oudejans, 2012, 2015; D. Patton, 2014; Wilson, de Joux, Finkbeiner, Russell, & Helton, 2016; but cf. Gladwin, Hashemi, van Ast, & Roelof, 2016). This includes studies using a shoot-don’t shoot task in which police officers responded to suspects with (Go) or without (NoGo) a firearm (Nieuwenhuys et al., 2012, 2015). These findings suggest that threat indeed creates a tendency to act quickly, and leads to more impulsive responding.

In addition to an increased action tendency, a second factor that may explain how threat causes faster and less accurate responses is an impaired response inhibition. Response inhibition can be defined as the ability to withhold or withdraw actions (before or during execution, see e.g., Dillon & Pizzagalli, 2007), and is considered to be an important aspect of cognitive control. Yet, despite the fact that threat has been shown to impair cognitive control functions (Hermans et al., 2014) and increase erroneous Go responses (i.e., false alarms in the Go/NoGo paradigm described above), studies employing a more pure test of response inhibition (see e.g., Aron, 2011; Dillon & Pizzagalli, 2007), the stop-signal task, indicate that it is rather inconsistently affected by threat. In this task participants are required to respond to certain stimuli (as in the Go trials described above), but these trials are occasionally interrupted by a stop-signal that indicates that the ongoing response should be cancelled. This paradigm allows calculation of the stop-signal reaction time (see e.g., Logan, 1994), which is a direct measure of the latency of the inhibition process (i.e., inhibition efficiency). Although most studies using this paradigm indicate that threat impairs stop-signal response inhibition (e.g., Herbert & Sütterlin, 2011; Kalanthroff, Cohen, & Henik, 2013; Pessoa, Padmala, Kenzer, & Bauer, 2012 experiment 2; Rebetez, Rochat, Billieux, Gay, & Van der Linden, 2015; Verbruggen & De Houwer, 2007; Yu et al., 2012), others report no effect (Sagaspe, Schwartz, & Vuilleumier, 2011), or indicate that it improves response inhibition (e.g., Pawliczek et al., 2013; Pessoa et al., 2012 experiment 1; Senderecka, 2016; Weinbach, Kalanthroff, Avnit, & Henik, 2015). As such, whether threat indeed impairs the ability to inhibit activated responses and in this way contributes to observed increases in erroneous responding (e.g., as in Nieuwenhuys et al., 2012, 2015), remains unknown. To address this question, the first aim of the current study was to investigate action tendencies and response inhibition under conditions of low and high threat, using a simulated shooting task that included Go/NoGo as well as stop-signal trials.

Besides high threat, another potential cause of diminished cognitive functioning is a lack of sufficient sleep (see e.g., Alhola & Polo-Kantola, 2007 for a review), which has been associated with decreased activity in brain regions that play a key role in cognitive control (prefrontal cortex (PFC), see e.g., Chuah, Venkatraman, Dinges, & Chee, 2006; Drummond et al., 1999). On a behavioral level, Van Dongen et al. (2003) showed that chronic partial sleep deprivation (i.e., 14 days of four or six hours of sleep per night) led to marked reductions in psychomotor vigilance (see also Chuah et al., 2006). In addition, several studies showed that both complete and partial sleep deprivation lead to lower accuracy (e.g., Chuah et al., 2006;

Drummond, Paulus, & Tapert, 2006), and in some cases a specific increase in false alarms (e.g., Demos et al., 2016; Drummond et al., 2006), indicating impaired response inhibition, on the Go/NoGo task. Building on these findings, the second aim of the current study was to test whether sleep deprivation also impairs stop signal reaction times.

Beyond its direct effects on cognitive functioning, some findings suggest that a lack of sleep is also associated with increased negative emotionality (see Walker & van der Helm, 2009 for a review). That is, sleep deprived individuals showed increased amygdala reactivity and decreased PFC-amygdala connectivity when viewing negative emotional pictures, suggesting an amplified response to aversive stimuli and a failure of top-down control of the emotional response (Yoo, Gujar, Hu, Jolesz, & Walker, 2007). In addition, sleep deprived individuals have been reported to be quicker in perceiving a situation as stressful (e.g., Minkel et al., 2012). Despite these observations, effects of sleep deprivation on behavioral responses to threat have rarely been studied. A noteworthy exception is a recent study by Anderson and Platten (2011) who showed that 36 hours of sleep deprivation resulted in more (and faster) false alarms, specifically in response to negative stimuli, in an emotional Go/NoGo task. Although these findings suggest that sleep deprivation may decrease response inhibition, especially under negative emotional circumstances, to our knowledge a direct assessment of how sleep deprivation influences response inhibition under *threat* is currently not available. The third aim of the current study was therefore to test whether effects of threat on response inhibition (false alarms and stop signal reaction times) are more pronounced after sleep deprivation.

To address the above-mentioned questions, the present study employed an adapted version of Gladwin et al.'s (2016) simulated Go/NoGo shooting task, with integrated stop-signal trials to directly measure inhibition of activated responses. During the task, threat was manipulated within-subjects by a cue that predicted the presentation of a quiet (low threat) or loud (high threat) white noise stimulus (see e.g., Sperl, Panitz, Hermann, & Mueller, 2016) whenever participants made a response error. In addition, sleep was manipulated between-subjects by means of a three-day partial sleep-deprivation protocol (i.e., five hours sleep vs. eight hours sleep per night; cf. Belenky et al., 2003). Regarding the effect of threat, we predicted an increased tendency to act, resulting in faster and more go responses, and impaired response inhibition, resulting in more false alarms and longer stop-signal reaction times in the high compared to the low threat condition (e.g., Herbert & Sütterlin, 2011; Kalanthroff et al., 2013; Pessoa et al., 2012 experiment 2; Rebetez et al., 2015; Verbruggen & De Houwer, 2007; Yu et al., 2012). Regarding the effect of sleep deprivation, we predicted decreased vigilance, resulting in slower responses, and impaired response inhibition, resulting in more false alarms and longer stop signal reaction times, in the five hour as compared to the eight hour sleep condition (Chuah et al., 2006; Demos et al., 2016; Drummond et al., 2006; Van Dongen et al., 2003). Finally, we anticipated an interaction between these two factors, resulting in stronger effects of threat after sleep deprivation (Anderson & Platten, 2011; Minkel et al., 2012; Yoo et al., 2007).

Method

Participants

We aimed to include 25 participants in each group based on an a priori power analysis (see Supplemental Material). Sixty-nine students at the Radboud University Nijmegen were screened for participation in the study. Exclusion criteria were current depression (measured with the screening questions of the Major Depression Questionnaire, Van der Does, Barnhofer, & Williams, 2003) and sleep problems (indicated by a total score > 5 on the Pittsburgh Sleep Quality Index [PSQI], Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989; or a total score > 2.02 on the Holland Sleep Disorders Questionnaire [HSDQ], Kerkhof et al., 2013). Five persons were excluded based on these criteria and nine (all from the five hour sleep group) dropped out prior to (*n* = 8) or during (*n* = 1) the experimental session. Of the remaining participants, three (all from the eight hour sleep group) were excluded due to insufficient adherence to the sleep protocol, as indicated by their sleep diary and Actiwatch data (see procedure below). The cut-off criterion for sleep protocol adherence was > 90 min deviation (daily average) from target sleeping time (i.e., five hours or eight hours), to avoid overlap between conditions. As a result, 52 participants were left for the analyses (*n* = 28 in the five hour sleep [5hr] deprivation condition and *n* = 24 in the eight hour sleep [8hr] control condition). See Table 1 for participant characteristics and protocol adherence. All participants provided written informed consent and received course credit or financial compensation (30 euro). The study was approved by the ethical committee of the Faculty of Social Sciences of Radboud University Nijmegen and was in accordance with the Declaration of Helsinki.

Procedure

Participants visited the lab individually at the start of the week (Monday or Tuesday) to fill in the screening questionnaires and, if they fulfilled the criteria for participation, were randomly (block method, odd-even numbers) assigned by the experimenter to the 5hr or the 8hr sleep condition. Participants in the 5hr group were instructed to sleep five hours in the three nights prior to the experimental session. They were advised to stay up late, rather than get up very early, and to keep bedtimes as stable as possible. Participants in the 8hr group were instructed to sleep eight hours in the three nights prior to the experimental session. Finally, participants filled in some questionnaires that measured possible confounding trait variables (Aggression Questionnaire: Buss & Perry, 1992; Dutch version Meesters, Muris, Bosma, Schouten, & Beuving, 1996; Barratt Impulsiveness Scale: J. H. Patton, Stanford, & Barratt, 1995; Dutch version Lijffijt & Barratt, 2005; Attentional Control Scale: Derryberry & Reed, 2002; Dutch version Verwoerd, Cieraad, & de Jong, 2007).

During the three-day sleep protocol, all participants engaged in normal daily activity but were asked to abstain from excessive use of alcohol and from the use of psychoactive substances that could influence their alertness or induce health risks. Furthermore, participants were asked not to use alcohol in the 24 hours preceding the experimental session, and not to consume caffeine-containing drinks in the morning of the experimental session. Protocol adherence was checked by means of continuous Actiwatch recording (Actiwatch 2, Philips Respironics, Murrysville, USA) and an extended version of the Consensus Sleep Diary (Carney et al., 2012), which was filled in each morning immediately after waking up. To monitor subjective responses to the sleep protocol, the sleep diary not only assessed sleep quantity and protocol adherence, but also asked for self-reported sleep quality, sleepiness, fatigue, fitness, feeling well-rested, alertness, positive and negative mood, and performance ability (10-point Likert scales: 1 = not at all, 10 = very much).

After the third night of the sleep protocol, participants revisited the lab individually in the morning or early afternoon (i.e., on Thursday or Friday between 09:30 and 13:30) for the experimental session, in which they performed the shooting task, followed by a questionnaire to measure their subjective responses to the task.

Shooting Task

The shooting task consisted of an adapted (stop-signal) version of the Go/NoGo shooting task designed by Gladwin et al. (2016). It contained an introduction, training, and measurement phase. In each trial, the screen showed a view of a parking garage with an opponent character in the center of the screen, an armed police officer in the background, and a view of the participant’s own “in-task” hands, holding a gun. To manipulate threat, there were two different opponents, who could be easily distinguished by their face and clothing. Both opponents behaved identically, but when participants made an incorrect response they received a loud (97 dB, 40 ms) white noise sound via headphones for one of the opponents (high threat [HT] condition, see e.g., Sperl et al., 2016) and a quiet sound (same sound at 50 dB) for the other opponent (low threat [LT] condition). The opponent-threat mapping was randomized across participants.

Trials began with the appearance of one of the opponents (the cue). After a variable interval (cue-stimulus interval, 0.5 to 4.5s), the opponent took one of two actions: He would draw a gun (the Go stimulus, 85% of trials) or a mobile phone (the NoGo stimulus, 15% of trials). When the opponent drew a gun, he would subsequently shoot (76% of gun trials, i.e., 65% of total trials) or he would put his gun down again (Stop signal, 24% of gun trials, i.e., 20% of total trials) after a brief delay (Stop Signal Delay, SSD). Participants were instructed to shoot the opponent, by pressing the space bar on the keyboard as fast as possible when he drew a gun, but to inhibit this response if he put his gun down again or when he drew a phone. When participants shot the opponent in time (800 ms response window) on gun trials, they would see their own gun flash and the opponent drop down on his knees. When they responded too late, the opponent would shoot them. If participants shot before stimulus onset, after the Stop signal, or in response to a phone, the police officer in the background would shoot the participant, in order to avoid strategic false-positive responding. When the opponent or the police officer shot the participants, participants would see a gun-flash and hear the loud (HT) or quiet (LT) sound. On 10% of Go trials the response window was reduced to 250 ms, so that participants would be too late and experience negative feedback (HT sound), thereby exposing them to the cue-threat contingencies even when they performed relatively quickly and accurately. Trials were separated by a variable inter-trial interval (0.6 to 0.9 s), during which the parking garage was shown without the opponents or police officer.

In the introduction phase (12 trials), participants were exposed to all possible trial types (twice with each opponent) and instructed what to do in each case. Next, participants performed a training block (100 trials, 50% LT and HT) in which all scenarios were presented in randomized order. The SSD was set at 250 ms at the start of the training, and was subsequently adjusted after each Stop signal trial as a function of participants' performance (staircase procedure, separately for LT and HT). That is, the SSD increased by 50 ms after successful stopping and decreased by 50 ms after unsuccessful stopping. The final measurement phase consisted of six blocks of 60 randomized trials each.

After completing the shooting task, participants filled in a questionnaire about their subjective responses to the task. To assess awareness of the threat contingencies, participants were asked which of the two opponents was associated with which sound, and how certain they were about that. Subsequently, they rated the unpleasantness of the two sounds at the beginning and end of the task, and their motivation to shoot each opponent. All of these ratings were done on nine point Likert-scales (1 = not at all, 9 = very much). Finally, they rated their subjective responses to each opponent on nine point non-verbal pictorial scales (Self-Assessment Manikins, see Bradley & Lang, 1994. Valence: 1 = pleasant, 9 = unpleasant; arousal: 1 = excited, 9 = calm, and dominance: 1 = controlled, 9 = in control).

Data Preparation

Trials with very short response windows (10% of Go trials) and trials with responses before stimulus onset (1.2% of all trials) were excluded from the behavioral analyses. Responses after the response deadline (too late, 0.9% of all trials) were coded as incorrect and were excluded from the response time analyses. Response time (RT, in ms) was calculated as the time between stimulus onset and participants' shooting responses on gun trials (correct Go response) or phone trials (false alarm response). Response accuracy was calculated as the proportion of correct responses on gun trials (correct Go responses) and phone trials (correct NoGo responses), relative to the total number of gun and phone trials, respectively. Stop Signal Reaction Time (SSRT) was calculated, per participant and threat condition, with the integration method (Verbruggen, Chambers, & Logan, 2013) in Matlab. First, all RT's on gun and phone trials combined (including too late and false positive responses) were rank ordered. Then the RT value corresponding to the achieved Stop-response probability was chosen (e.g., 55th percentile RT in case of unsuccessful stopping on 55% of stop trials). Finally, the SSRT was calculated by subtracting the mean SSD from this RT value. Longer SSRTs indicate decreased response inhibition.

The processed data of this study are available via https://doi.org/10.17026/dans-2cx-x5th.

Statistical Analyses

All statistical analyses were performed in R (R Core Team, 2016). Details of the statistical procedures and models are reported in the Supplemental Material.

To check for group differences in possible confounding variables[1], gender was analyzed with a Chi square test, and age, scores on sleep questionnaires (HSDQ and PSQI), trait variables (aggression, impulsivity, and attentional control), Time of Testing (i.e., start time of shooting task) and Time Awake at the moment of testing (i.e., Time of Testing minus time of awakening on the day of testing; in minutes) were analyzed with two-sided unpaired *t*-tests.

All other (repeated measures) variables were analyzed with a linear mixed effects models approach (for details see Supplemental Material). To test the effects of the sleep manipulation, all sleep diary and Actiwatch data were analyzed (in separate models) with the factors Sleep (5hr, 8hr) x Night (1, 2, 3). To test the subjective effects of the threat manipulation in the shooting task, all ratings of the opponents were analyzed (in separate models) with the factors Sleep (5hr, 8hr) x Threat (LT, HT). The model for the unpleasantness ratings of the sounds additionally included the factor Time (Beginning, End of task). Response accuracy and RT in the shooting task were analyzed in separate models with the factors Sleep (5hr, 8hr) x Threat (LT, HT) x Stimulus (Go, NoGo). The model for SSRT only included the factors Sleep (5hr, 8hr) x Threat (LT, HT). Coef represents the unstandardized regression coefficients (i.e., slopes), with standard errors in brackets. All *p*-values were determined with parametric bootstrapped Likelihood Ratio Tests (X^2). Significant interactions were followed by tests of least-squares means. For details see Supplemental Material. The analyses reported below excluded three participants that did not adhere to the sleep protocol and – for the SSRT – two participants that did not adhere to stop instructions. To verify the impact of these exclusion criteria, and the robustness of our main results, we re-analyzed our behavioral data (response accuracy, RT, and SSRT) without making these exclusions. The results of these analyses are reported in detail in the Supplemental Material (Robustness Checks).

Results

<<< TABLE 1 ABOUT HERE (participant characteristics) >>>

<<< TABLE 2 ABOUT HERE (post-experimental questionnaire) >>>

Manipulation Checks

Sleep manipulation. As can be seen in Table 1, the 5hr and 8hr group did not differ with respect to age, gender, trait variables (aggression, impulsivity, and attentional control), scores on the PSQI and HSDQ, and Time of Testing. Importantly, regarding adherence to the three-day sleep restriction protocol, Actiwatch recordings (*n* = 7 missing data due to technical problems or wrong use) and sleep diary reports (*n* = 1 missing data on night 2) confirmed that the 5hr and 8hr groups indeed slept approximately five hours (300 min) and eight hours (480 min) per night, respectively, resulting in a highly significant difference in total sleep time between both groups. In line with this difference, in the morning after the third night of the protocol (i.e., on the day of the experimental session), the 5hr group felt significantly more sleepy and fatigued, and less fit, well-rested, alert, positive and able to perform than the 8hr group (see Table 1). For self-rated sleep quality and negative mood, differences between the

5hr and 8hr group did not reach significance. Overall, these results indicate that our protocol reliably induced sleep deprivation in the 5hr group. No important adverse events or side effects were reported. See Supplemental Material for the remaining results of the sleep diary (including night 1 and 2).

Threat manipulation. Results of the post-experimental questionnaire are presented in Table 2. All except two participants (one from each group) correctly reported which opponent was the LT cue (associated with the soft sound) and which one was the HT cue (associated with the loud sound). Certainty about these contingencies was high and did not differ significantly between the two conditions (see Table 2). The ratings of the unpleasantness of the sounds showed significant main effects of Threat (Coef = -2.47 (0.13), *95% CI* [-2.74, -2.23]; $X^2(1) = 112.50$, $p = .001$), and Time (Coef = 0.43 (0.07), *95% CI* [0.29, 0.56]; $X^2(1) = 30.92$, $p = .001$), and a significant interaction of Threat by Time (Coef = -0.21 (0.06), *95% CI* [-0.33, -0.09]; $X^2(1) = 11.84$, $p = .001$). Post hoc tests showed that the unpleasantness ratings of both sounds decreased from the beginning to the end of the task (soft: begin $M = 1.8$, $SD = 1.3$, end $M = 1.4$, $SD = 0.7$, $t(112.84) = 2.31$, $p = .023$; loud: begin $M = 7.2$, $SD = 1.5$, end $M = 5.9$, $SD = 2.0$, $t(112.84) = 6.92$, $p < .0001$), but participants rated the loud sound as significantly more unpleasant than the soft sound at both time points (begin: $t(86.82) = -19.16$, $p < .0001$; end: $t(86.82) = -16.12$, $p < .0001$). Finally, the threat manipulation was also effective in terms of subjective responses to the opponents (see Table 2). Participants reported a significantly increased motivation to shoot, increased negative valence, and increased arousal in response to the HT versus the LT opponent. The dominance ratings did not differ significantly between the opponents. None of the ratings showed a significant main or interaction effect of Sleep (all $p > .18$, see Supplemental Material for detailed results). The threat manipulation did not result in adverse events or side effects.

Behavioral Results

<<<TABLE 3 ABOUT HERE (dependent variables shooting task)>>>

Response accuracy. The generalized linear mixed effects model showed significant main effects of Sleep (Coef = -0.22 (0.09), *95% CI* [-0.40, -0.05]; $X^2(1) = 5.66$, $p = .025$) and Stimulus (Coef = 0.81 (0.12), *95% CI* [0.58, 1.05]; $X^2(1) = 33.06$, $p = .001$). As shown in Table 3, response accuracy was significantly lower for participants in the 5hr compared to the 8hr group. In addition, across both groups and both threat conditions, response accuracy was significantly higher when the opponent pulled a gun (Go trials) than when he pulled a phone (NoGo trials). No other effects reached significance (Threat: Coef = 0.07 (0.05), *95% CI* [-0.03, 0.17]; $X^2(1) = 1.99$, $p = 0.20$; Sleep x Threat: Coef = 0.05 (0.04), *95% CI* [-0.03, 0.14]; $X^2(1) = 1.67$, $p = .20$; Sleep x Stimulus: Coef = -0.002 (0.12), *95% CI* [-0.24, 0.23]; $X^2(1) = 0.00$, $p = .99$; Threat x Stimulus: Coef = -0.05 (0.05), *95% CI* [-0.15, 0.06]; $X^2(1) = 0.88$, $p = .37$; Sleep x Threat x Stimulus: Coef = 0.01 (0.04), *95% CI* [-0.07, 0.10]; $X^2(1) = 0.08$, $p = 0.79$).

To better characterize the effects on response accuracy, we performed additional exploratory analyses of signal detection measures, which allow differentiation between decision accuracy (sensitivity *d*') and response bias (criterion β). We calculated these measures following the formulas from Stanislaw and Todorov (1999), whereby "hits" were defined as correct responses on gun (Go) trials, and "false alarms" as incorrect responses on phone (NoGo) trials. Means and standard deviations are presented in Table 3. β values were significantly positively skewed and therefore normalized with a natural log transform before analysis (Field, Miles, & Field, 2012). The two measures were analyzed in separate linear mixed effects models with Sleep, Threat, and their interaction as fixed effects. All other settings were as described in the statistical analysis section. The analyses showed a significant effect of Sleep on *d*’ (Coef = -0.21 (0.09), *95% CI* [-0.39, -0.03]; $X^2(1) = 5.43$, $p = .020$), reflecting more accurate decisions (higher *d*’) in the 8hr compared to the 5hr group. The results also showed a tendency towards a higher *d*’ on LT compared to HT trials, but this effect did not reach statistical significance (Coef = 0.07 (0.04), *95% CI* [-0.001, 0.15]; $X^2(1) = 3.57$, $p = .059$). There was no significant interaction effect between Sleep and Threat (Coef = 0.01 (0.04), *95% CI* [-0.07, 0.09]; $X^2(1) = 0.14$, $p = .71$). The analysis of the response criterion (β) showed no significant effects (Sleep: Coef = 0.05 (0.15), *95% CI* [-0.25,0.37]; $X^2(1) = 0.12$, $p = .74$; Threat: Coef = 0.04 (0.06), *95% CI* [-0.09, 0.15]; $X^2(1) = 0.37$, $p =.55$; Sleep x Threat: Coef = -0.09 (0.06), *95% CI* [-0.21,0.02]; $X^2(1) = 2.30$, $p = .14$) suggesting that the effect of partial sleep deprivation on response accuracy, reported above, was more likely the result of a decrease in decision accuracy than of a change in response bias. It is also worth noting that the mean (untransformed) β values were all < 1, which indicates that overall participants used a liberal decision criterion (Stanislaw & Todorov, 1999), suggesting a general Go (shoot) bias.

Response times. The linear mixed effects model showed significant main effects of Threat (Coef = 9.46 (2.90), *95% CI* [3.49, 15.29]; $X^2(1) = 8.69$, $p = .001$) and Stimulus (Coef = -23.23 (3.78), *95% CI* [-30.54, -16.19]; $X^2(1) = 30.16$, $p = .001$). As shown in Table 3, response times were significantly shorter in response to HT versus LT opponents. In addition, shooting responses on phone trials (false alarms) were significantly faster than on gun trials (correct Go responses). In contrast to our hypotheses, we did not find significant main or interaction effects of Sleep on response times (Sleep: Coef = 11.68 (7.32), *95% CI* [-3.72, 25.25]; $X^2(1) = 2.56$, $p = .10$; Sleep x Threat: Coef = 2.59 (2.90), *95% CI* [-3.63, 8.52]; $X^2(1)= 0.75$, $p = .37$). No other effects reached significance (Sleep x Stimulus: Coef = 2.82 (3.78), *95% CI* [-4.86, 10.28]; $X^2(1) = 0.55$, $p = .48$; Threat x Stimulus: Coef = 3.03 (2.70), *95% CI* [-

2.24, 8.34]; $X^2(1) = 1.08$, $p = .29$; Sleep x Threat x Stimulus: Coef = 2.97 (2.70), *95% CI* [-2.65, 8.19]; $X^2(1) = 1.15$, $p = .23$).

Stop signal reaction times. The stop-response probability of two of the participants deviated strongly (> 0.2) from the target probability of 0.5, suggesting non-adherence to task instructions. Inspection of their SSD tracking results (staircase) revealed that these participants responded on almost all stop trials, as a result of which the SSD continuously decreased and reached the minimum value (25 ms) shortly after the beginning of the task (< 15 stop trials). As the SSD could not be adjusted further downwards, the tracking procedure was not effective in these cases and the SSRT could not be reliable estimated (see e.g., Verbruggen & Logan, 2009). The data of these participants were therefore excluded from the SSRT analysis[2]. The linear mixed effects model of the remaining data showed a significant main effect of Threat (Coef = -4.91 (2.31), *95% CI* [-9.47, -0.44]; $X^2(1) = 4.51$, $p = .035$). As shown in Table 3, SSRTs were significantly longer in HT versus LT trials, reflecting a decreased response inhibition under threat. The results also showed a tendency towards longer SSRTs in the 5hr compared to the 8hr group, but this effect did not reach statistical significance (Coef = 9.97 (5.28), *95% CI* [-0.36, 19.94]; $X^2(1) = 3.58$, $p = .068$). We did not find a significant interaction between Sleep and Threat (Coef = 0.30 (2.31), *95% CI* [-4.38, 4.58], $X^2(1) = 0.02$, $p = .91$).

Correlation between response accuracy and SSRT. As both false alarm responses on phone (NoGo) trials and SSRT are measures of response inhibition, we computed Spearman correlations (in R, with the rcorr function of the Hmisc package, Harrell Jr, Dupont, & others, 2016) to explore whether these two measures were correlated across participants. The results of these analyses showed that, in both threat conditions, SSRT was negatively correlated with response accuracy on phone (NoGo) trials (LT: *rho*(50) = -0.37, $p = .01$, HT: *rho*(50) = -0.29, $p = .04$), suggesting that increased SSRT (slower inhibition of activated responses) is indeed associated with more false alarm responses (see Figure 1). SSRT was not correlated with response accuracy on gun (Go) trials (LT: *rho*(50) = 0.08, *p* = .59, HT: *rho*(50) = 0.06, *p* = .67), suggesting that the relation is specific for inhibition errors, and does not reflect a general performance effect.

Discussion

The current study investigated the effects of acute threat and (partial) sleep deprivation on action tendencies and response inhibition in a simulated shooting task. We predicted that threat would increase the tendency to act and decrease response inhibition, that sleep deprivation would decrease vigilance and response inhibition, and that sleep deprivation would increase the effects of threat. Our findings partially confirm the anticipated main effects of threat and sleep deprivation, but provide no indication of larger threat effects in sleep-deprived individuals. These findings will be discussed in detail below.

Effects of Threat on Shooting Decisions and Response Inhibition

Subjective reports confirmed that the threat manipulation was effective, as participants perceived the loud sounds as (highly) unpleasant, were accurate and certain in identifying the opponents associated with each sound, and experienced an increased negative valence, arousal and motivation to shoot the HT vs. the LT opponent. More importantly, in line with our predictions (see e.g., Nieuwenhuys et al., 2012, 2015; Weinbach et al., 2015), participants showed faster shooting (i.e., Go) responses on HT than LT trials, suggesting an increased tendency to act quickly under threat. Furthermore, the SSRT results revealed that threat impaired the ability to inhibit activated responses (see e.g., Herbert & Sütterlin, 2011; Kalanthroff et al., 2013; Pessoa et al., 2012 experiment 2; Rebetez et al., 2015; Verbruggen & De Houwer, 2007; Yu et al., 2012 for comparable findings). Although this effect is not always observed in behavioral experiments (see e.g., Pawliczek et al., 2013; Pessoa et al., 2012 experiment 1; Sagaspe et al., 2011; Senderecka, 2016; Weinbach et al., 2015), it is in line with neurobiological models suggesting that acute threat causes a decrease in prefrontal cognitive control functions (see e.g., Bishop, 2008; Hermans et al., 2014). The fact that we did find impaired stop-signal response inhibition under threat while others did not, may be due to the intensity of our threat manipulation. Pessoa et al. (2012) showed that high intensity threat (i.e., shock conditioned stimuli) led to *impaired* stop-signal response inhibition, while low intensity threat (i.e., fearful face stimuli) led to *improved* stop-signal response inhibition. Our threat manipulation (98 dB white noise bursts) is comparable to the high intensity threat of shock stimuli (see Sperl et al., 2016).

In contrast to our expectations based on previous findings with regular (De Houwer & Tibboel, 2010; Wilson et al., 2016) and shooting task (Nieuwenhuys et al., 2012, 2015; D. Patton, 2014) versions of the Go/NoGo paradigm, threat did not increase the percentage of false alarms. In our study, threat did not significantly affect response accuracy (although we did find a trend towards a decrease in decision accuracy *d*'). This discrepancy with previous findings may be due to methodological differences. Our task involved a task-relevant, performance-contingent, threat manipulation in which negative feedback (LT/HT) followed erroneous (i.e., false positive and false negative) responses. Hence, participants could avoid the loud noise bursts by increasing performance (except in the short latency Go trials and stop trials). This was not the case in most previous studies, where threat was either task-irrelevant (De Houwer & Tibboel, 2010; Wilson et al., 2016) or unrelated to performance (Nieuwenhuys et al., 2012, 2015; but cf. D. Patton, 2014).

Together, these findings indicate that threat increased the tendency to act quickly (i.e., accelerated Go responses) and impaired the ability to inhibit activated responses (inhibition efficiency, i.e., slowed SSRT), but did not impair the ability to withhold erroneous responses (i.e., did not increase false alarms).

Effects of Sleep Deprivation on Shooting Decisions and Response Inhibition

Our results regarding the effect of partial sleep deprivation are in line with earlier work suggesting that three consecutive nights with five (compared to eight) hours of sleep lead to significantly increased feelings of fatigue, and decreased alertness and positive mood (e.g., Belenky et al., 2003; Van Dongen et al., 2003). Importantly, performance significantly declined, as was reflected by a general decrease in response accuracy (for Go and NoGo stimuli) and a reduction in decision accuracy (*d*') in the sleep-deprived compared to the non-deprived participants (e.g., Chuah et al., 2006; see Alhola & Polo-Kantola, 2007 for a review). In contrast to our expectations, however, our results showed no evidence of a general slowing of responses (decreased vigilance, e.g., Van Dongen et al., 2003) after sleep deprivation. This finding could be due to the generally motivating and arousing nature of our shooting task (see Table 2), which may have masked or compensated a negative effect of sleep deprivation on response times[3]. Furthermore, we did not find a deficit in withholding Go responses (i.e., a specific increase in false alarms or response bias, e.g., Demos et al., 2016; Drummond et al., 2006), and although sleep deprived individuals did show slightly slower SSRTs (see Table 3), suggesting an impaired ability to inhibit activated responses, this group difference did not reach statistical significance. A possible explanation for the absence of significant effects of sleep deprivation on these inhibition measures may be the fact that with only three consecutive nights of partial sleep deprivation, effects on cognitive control functions might be relatively small (i.e., as compared to prolonged or more severe sleep deprivation, see e.g., Belenky et al., 2003; Van Dongen et al., 2003). Alternatively, the non-significant effect of Sleep on SSRT may have been due to insufficient statistical power, as suggested by the wide confidence interval (see Supplemental Material Figure S1, panel a) and the finding that when (self-reported) Sleep was included as a continuous variable, accounting for individual differences, the effect of Sleep was significant (see Supplemental Material).

In sum, our findings indicate that three nights of partial sleep deprivation negatively affected response accuracy, but we did not find robust evidence that it impaired response times or response inhibition. Further research, with more statistical power, is necessary to provide more definite evidence for the effects of partial sleep deprivation on RT and SSRT.

Combined Effects of Threat and Sleep Deprivation

Previous studies showed that sleep deprived individuals show increased amygdala activity and reduced functional PFC-amygdala connectivity in response to negative emotional pictures, suggesting an amplified subcortical response to aversive stimuli and a failure of top-down control of this response (see e.g., Walker & van der Helm, 2009; Yoo et al., 2007). Furthermore, sleep deprivation increased subjective perceptions of threat (Minkel et al., 2012), and increased impulsive behavior in response to negative emotional stimuli (Anderson & Platten, 2011). Based on these findings we expected that effects of threat would be stronger in individuals suffering from sleep deprivation, but we found no support for this hypothesis. A possible explanation for the absence of this interaction effect is that our participants underwent only three nights of partial sleep deprivation, whereas previous studies (Anderson & Platten, 2011; Minkel et al., 2012; Yoo et al., 2007) used complete sleep deprivation. Furthermore, data of Minkel et al. (2012) suggest that sleep deprivation increases stress in mildly, but not highly, stressful situations. As our threat manipulation was relatively intense (Pessoa et al., 2012; Sperl et al., 2016), this may have prevented a moderation effect of sleep deprivation on the effect of threat. Future work is necessary to find out whether different amounts of sleep deprivation and threat intensity do show (dose-dependent) interaction effects on performance. Considering the relatively small size (and narrow confidence intervals) of the estimated interaction effects observed in the current study (see Figure S1 in the Supplemental Material), future studies may need to be designed with more power to detect small effects.

Limitations

It should be noted that the fact that we found significant effects of threat, but only marginal effects of sleep deprivation, on stop-signal response times may be due to a difference in statistical power, as threat was manipulated within-subjects and sleep between-subjects. In addition, although participants were explicitly instructed not to consume caffeine on the day of testing, we cannot exclude the possibility that some did, as a strategy to counteract the effects of sleep restriction. Furthermore, it is important to bear in mind that our task context was specific in that participants provided ‘shooting’ responses in reaction to a gun stimulus (see also Gladwin et al., 2016), which may be perceived as inherently threatening (Benjamin & Bushman, 2018) and trigger automatic defensive responses (Blanchard et al., 2001). Although our results clearly show significant effects of our threat manipulation over and above a potential effect of the gun stimulus, it is important to establish whether our findings of the effects of task-manipulated threat generalize to responses that are not inherently defensive. In addition, future work may determine whether observed effects are due to the arousing nature of threat, or due to its negative valence (see e.g., Pessoa et al., 2012; Verbruggen & De Houwer, 2007).

Conclusion

To conclude, the current study showed that acute threat increased action tendencies and impaired stop-signal response inhibition, but did not affect response accuracy. In addition, three nights of partial sleep deprivation led to a significant decrease in response accuracy, marginally decreased stop-signal response inhibition, and did not affect action tendencies. Against our hypothesis, no evidence was observed to indicate that sleep-deprived individuals are more strongly affected by threat. Perhaps the most straightforward explanation for this observation is that the extent to which sleep deprivation affects response inhibition or increases threat sensitivity is dose dependent. However, given that the main effects of threat and sleep were concentrated on different performance measures, an alternative explanation may be that, on a behavioral level, effects of threat and sleep are relatively independent. Of interest with respect to these findings are review studies suggesting that action control is not a unitary concept but depends on different underlying processes. For example, Verbruggen, McLaren, and Chambers (2014) suggested that three different cognitive processes (i.e., signal detection or attention, action selection, and action execution) play an important role in the control of actions (see also Nieuwenhuys & Oudejans, 2017, 2012), and Eagle et al. (2008) showed that different neuropharmacological processes (noradrenaline and serotonin) are involved in action control in stop-signal compared to Go/NoGo tasks. These underlying processes might be differentially affected by threat and sleep deprivation.

While from a theoretical perspective our results thus urge further investigation of the interaction between threat and sleep as well as the underlying mechanisms of their respective effects, it is important to note that also the separate negative effects of these factors may bear important practical implications for professions in which performance strongly depends on cognitive control under high levels of threat (e.g., emergency healthcare, military, law enforcement) and individuals are often deprived of a good night of sleep. Based on the current findings, interventions aiming to improve action control under threat and optimize sleep may prove fruitful avenues for future research.

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Content Footnotes

[1] Groups differed significantly in Time Awake at the moment of testing (see Table 1). As this could be a confounding factor for the effects of Sleep (e.g., Thun, Bjorvatn, Flo, Harris, & Pallesen, 2015), we replicated the analyses of all behavioral measures with Time Awake included as a control factor (for details see Supplemental Material). The results of these analyses showed no significant main or interaction effects of Time Awake (all *p*s >.10), and including this factor did not change the results of any of the original analyses. Therefore, only the results without this factor are reported.

[2] The results of our robustness checks (see Supplemental Material) showed that including these participants changed the SSRT results: Both the effect of Threat and the effect of Sleep were not significant. We think this is due to biased SSRT estimates as a result of strategic behavior (i.e., not responding to stop-signals), and therefore exclusion of these participants is recommended (e.g., Leotti & Wager, 2010; Verbruggen & Logan, 2009). As non-adherence was specific to stop instructions, these two participants were not excluded from the accuracy and RT analyses reported above. However, our robustness checks showed that exclusion of these participants did not change those results.

[3] Prior to this study, we conducted a pilot study to assess the feasibility and effectiveness of our sleep protocols ($n = 8$, 5F/3M, age $M = 24.8$, $SD = 3.2$, within-subject design, protocols in counterbalanced order with four normal nights in between). The results of this pilot showed significant increases in response times on a custom-made 10-minute Psychomotor Vigilance Test (PVT; Dinges & Powell, 1985) after three nights of five hours compared to three nights of eight hours of sleep (5hr: $M = 263.15$ ms, $SD = 62.99$; 8hr: $M = 250.43$ ms, $SD = 40.94$; Coef = 6.19 (1.61), *95% CI* [2.80, 9.47]; $X^2(1) = 9.61$, $p = .004$). This suggests that partial

sleep deprivation with our protocol did lead to significant reductions in vigilance as assessed with a standard neutral task.

Table 1. Group Characteristics and Sleep Protocol Manipulation Check.

Dependent Variable	5hr	8hr		*p*	95% CI
N	28	24			
gender (male/female)	(8/20)	(6/18)	$X^2(1) = 0.08^1$	.77	[0.19, -3.38]
	M (SD)	*M (SD)*	*t(df)*		
age (years)	22.07 (3.13)	21.42 (3.41)	0.72 (47.19)	.48	[-1.18, 2.49]
AQ (29-145)	61.86 (11.31)	59.81 (16.17)	0.52 (40.29)	.61	[-5.89, 9.99]
BIS-11 (30-120)	60.21 (8.45)	57.46 (6.65)	1.32 (49.67)	.19	[-1.45, 6.97]
ACS (20-80)	49.50 (7.20)	46.66 (6.67)	1.47 (49.68)	.15	[-1.03, 6.70]
PSQI (0-21)	1.57 (1.20)	1.83 (1.40)	-0.72 (45.59)	.48	[-0.10, 0.47]
HSDQ (1-5)	1.51 (0.24)	1.48 (0.27)	0.39 (46.10)	.70	[-0.12, 0.17]
Time of testing	11:23 (0:56)	11:15 (1:05)	0.47 (45.68)	.64	[-0.02, 0.03]
Time awake	252.57 (69.10)	181.54 (66.65)	3.77 (49.27)	<.001	[33.14, 108.92]
TST actiwatch^2	282.82 (21.48)	447.52 (31.09)	-20.75 (39.21)	<.001	[-180.76, -148.65]
TST sleep diary	288.36 (23.30)	479.00 (31.20)	-24.62 (42.06)	<.001	[-206.27, -175.02]
Day 3 sleep diary					
Sleep quality	7.32 (1.89)	7.96 (1.04)	-1.53 (43.21)	.13	[-1.47, 0.20]
Sleepiness	7.29 (1.46)	3.71 (2.07)	7.08 (40.50)	<.001	[2.56, 4.60]
Fatigue	6.75 (1.32)	3.79 (2.00)	6.18 (38.84)	<.001	[1.99, 3.93]
Fitness	4.71 (1.38)	6.67 (1.55)	-4.75 (46.61)	<.001	[-2.78, -1.13]
Well-rested	4.79 (1.69)	7.21 (1.53)	-5.43 (49.81)	<.001	[-3.32, -1.53]
Alertness	4.86 (1.08)	6.54 (1.35)	-4.91 (43.86)	<.001	[-2.38, -0.99]
Positive mood	5.14 (1.69)	6.62 (1.50)	-3.35 (49.94)	.002	[-2.37, -0.59]
Negative mood	2.68 (1.85)	2.00 (1.67)	1.39 (49.85)	.17	[-0.30, 1.66]
Performance ability	4.93 (1.51)	6.08 (1.84)	-2.45 (44.64)	.02	[-2.11, -0.20]

Note. 5hr = partial sleep deprivation (five hour night -1); 8hr = no sleep deprivation (eight hour night -1); AQ = Aggression Questionnaire (total score); BIS-11 = Baratt Impulsiveness Scale (total score); ACS = Attentional Control Scale; PSQI = Pittsburgh Sleep Quality Index; HSDQ =

Holland Sleep Disorder Questionnaire; TST = Total Sleep Time (in minutes, averaged over three nights). Sleep diary self-report variables were measured on a 10-point Likert scale (1 = *not at all* to 10 = *very much*). Time of testing is the start time of the shooting task in hours and minutes on a 24 hour scale. Time awake is the Time of testing minus time of awakening on the testing day (in minutes). $t(df)$, p and *95% CI* indicate t-ratios (with degrees of freedom), p-values and 95% confidence intervals for the effect of Sleep (5hr, 8hr).[1] X^2 indicates Chi-square estimate (with degrees of freedom). [2] 5hr $n = 22$, 8hr $n = 23$ (7 missing values).

Table 2. Subjective Responses to Experimental Contingencies (Post-Experimental Questionnaire).

	5hr (*n* = 28)		8hr (*n* = 24)				
	LT	HT	LT	HT			
Dependent Variable	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	X^2 *(1)*	*p*	*95% CI*
Certainty	8.5 (1.3)	8.5 (1.1)	8.4 (1.0)	8.3 (1.1)	1.20	.29	[-0.06, 0.02]
Motivation	6.0 (1.8)	7.5 (1.4)	6.4 (1.6)	7.8 (1.1)	26.27	.001	[0.49,0.98]
Valence	4.9 (1.2)	6.8 (1.8)	4.6 (1.2)	6.7 (1.6)	39.54	.001	[0.72,1.31]
Arousal	5.6 (1.5)	4.0 (1.7)	6.4 (1.6)	4.0 (1.8)	32.94	.001	[-1.27,-0.65]
Dominance	6.0 (1.7)	5.5 (1.6)	6.0 (1.9)	5.4 (1.8)	2.83	.10	[-0.63, 0.03]

Note. 5hr = partial sleep deprivation (5 hour night $^{-1}$); 8hr = no sleep deprivation (8 hour night $^{-1}$); LT = Low Threat; HT = High Threat. Valence is scored on a bipolar scale (1 = *pleasant* to 9 = *unpleasant*). Arousal is inverse scored (1 = *excited* to 9 = *calm*). For the other measures a higher score represents a stronger response (1 = *not at all* to 9 = *very much*). X^2, *p* and 95% *CI* indicate Chi-square estimates (with degrees of freedom), *p*-values and 95% confidence intervals for the threat effect. None of the ratings showed a significant main or interaction effect of Sleep (5hr, 8hr).

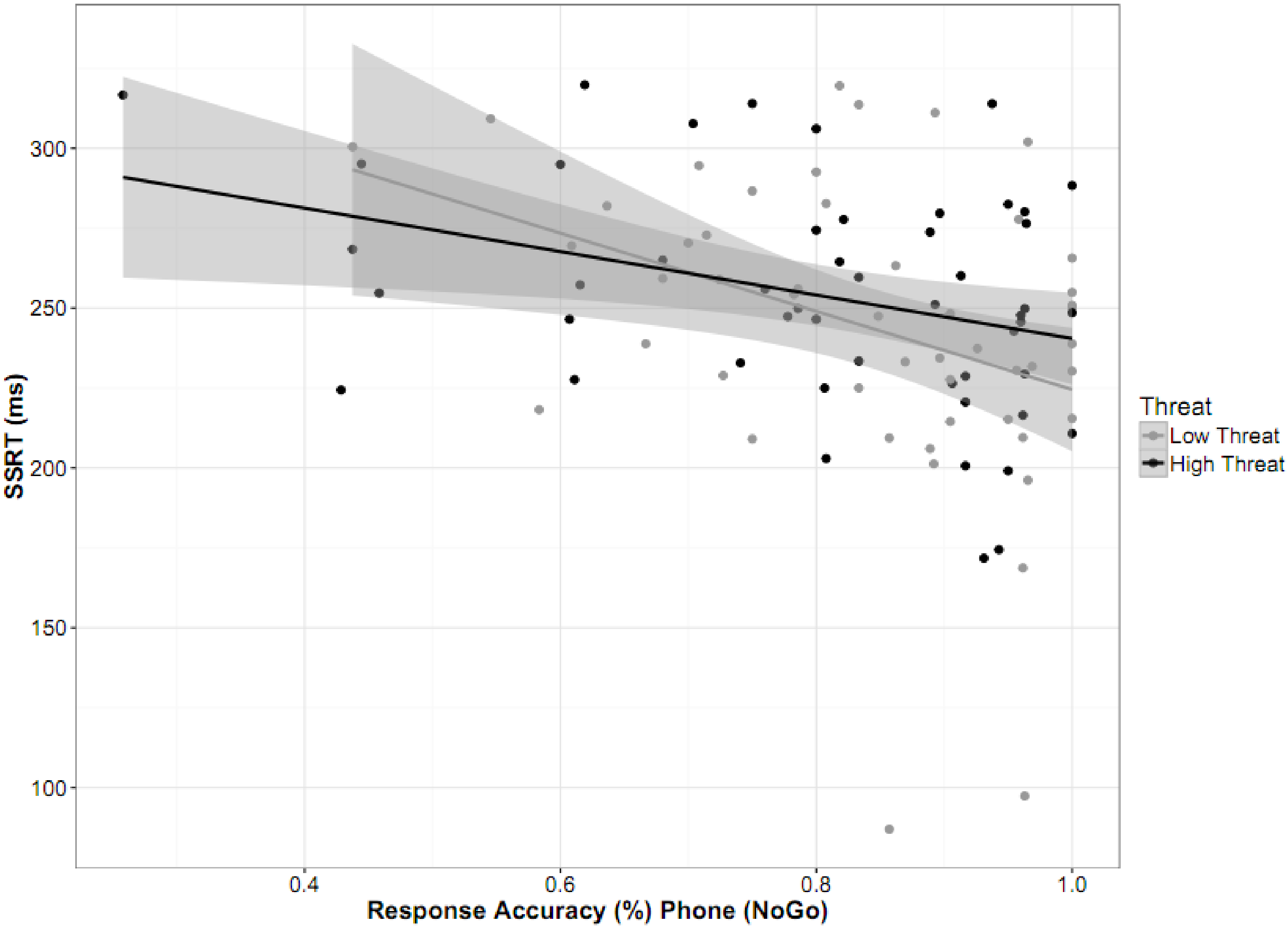
Table 3

Table 3. Means (*M*) and Standard Deviations (*SD*) of Response Accuracy and Response Times in the Shooting Task.

	5hr (*n* = 28)		8hr (*n* = 24)	
	LT	HT	LT	HT
Dependent Variable	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Response Accuracy (% correct)				
Gun (Go)	0.95 (0.05)	0.94 (0.05)	0.96 (0.03)	0.97 (0.03)
Phone (NoGo)	0.81 (0.13)	0.76 (0.21)	0.86 (0.15)	0.84 (0.13)
Signal Detection measures				
d' (sensitivity)	2.8 (0.7)	2.6 (0.8)	3.2 (0.7)	3.1 (0.6)
β (decision criterion)	0.7 (0.9)	0.7 (1.0)	0.7 (0.7)	0.4 (0.4)
Response Times (ms)				
Gun (Go)	405 (121)	391 (115)	386 (105)	373 (100)
Phone (NoGo, FA)	354 (124)	327 (97)	322 (106)	317 (82)
Stop Signal Response Time (SSRT, ms)	253 (31)	263 (33)	233 (59)	243 (36)

Note. 5hr = partial sleep deprivation (five hour night $^{-1}$); 8hr = no sleep deprivation (eight hour night $^{-1}$); LT = Low Threat; HT = High Threat; FA = False Alarm.

Figure 1. Spearman Correlations between SSRT and Response Accuracy on NoGo trials (5hr and 8hr data combined).



Supplemental Material

Justification of Sample Size

An a priori power analysis computed in G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that we needed 25 participants in each group to detect a small to medium effect (*f* = 0.20) with 80% power and alpha 0.05 using analysis of variance (ANOVA) with a repeated measures 2 x 2 within-between design. For practical reasons we included a few more participants (*n* = 28 and *n* = 27, after substitution of subjects that dropped out). To account for the binomial nature of the accuracy data and to analyze accuracy and RT data at the unaggregated trial level, we used a linear mixed effects models approach instead of ANOVA. Power analyses for these models are not readily available, but require simulations based on existing (e.g., pilot) data (see e.g., Brysbaert & Stevens, 2018), which we did not have. However, we expected these linear models to be at least as powerful as the ANOVA, and perhaps even more, as they include individual variations (random effects) at the stimulus level in the model and thereby lead to more accurate estimates of effect sizes and standard errors (see e.g., Brysbaert & Stevens, 2018; Dixon, 2008; Judd, Westfall, & Kenny, 2017).

Statistical Analyses

The statistical analyses reported in the main text are described in more detail below. All statistical analyses were performed in R (R Core Team, 2016). In order to check for group differences in possible confounding variables, gender was analyzed with a Chi square test with the gmodels package (Warnes et al., 2015). Age, scores on sleep questionnaires (HSDQ and PSQI), trait variables (aggression, impulsivity, and attentional control), and Time Awake at the moment of testing were analyzed with two-sided unpaired t-tests from the Stats package (R Core Team, 2016). Time Awake was calculated by subtracting the ‘getting up time’ at the morning of the experimental session (Sleep diary night 3) from the starting time of the shooting task.

All other (repeated measures) variables were analyzed with a linear mixed effects models approach, using the glmer function (for response accuracy) or the lmer function (for all other measures) of the lme4 package (version 1.1.12; Bates, Mächler, Bolker, & Walker, 2015). We used a maximal random-effects structure (Barr, Levy, Scheepers, & Tily, 2013) for all models. The repeated measures nature of the data was modelled by including a per-participant random adjustment to the fixed intercept ("random intercept"), as well as per-participant random adjustments to the slopes of the within-subject factors ("random slopes"). In addition, we included all possible random correlation terms among the random effects.

All categorical predictors were coded using sum-to-zero contrasts. The following contrasts were used: Sleep: 5hr = 1, 8hr = -1; Threat: LT = 1, HT = -1; Stimulus: NoGo = 1, Go = -1; Night (diary and Actiwatch data): Night 1 = 1/0, Night 2 = 0/1, Night 3 = -1/-1, Time (sound ratings): Beginning of task =1, End of task= -1. All *p*-values were determined with parametric bootstrapped Likelihood Ratio Tests (using type 3 tests with 1000 simulations), performed with the mixed-function of the afex package (version 0.16.1; Singmann, Bolker, Westfall, & Aust, 2016), which in turn calls the function PBmodcomp from the package pbkrtest (version 0.4.6; Halekoh & Højsgaard, 2014). Confidence intervals were determined using parametric bootstrapping as implemented in lme4's bootMER function, with 1000 simulations and deriving 95% confidence intervals (95% CI, type "basic") using the function boot.ci of the package boot (version 1.3.18; Canty & Ripley, 2016). Significant interactions were followed by tests of least-squares means using the lsmeans function from the package lsmeans (version 2.23.5; Lenth, 2016). Familywise error correction (*p*-value adjustment) was applied using the Tukey method, where appropriate.

To test the effects of the sleep manipulation, all sleep diary and Actiwatch data were analyzed (in separate models) with fixed effects for the factors Sleep (5hr, 8hr), Night (1, 2, 3), and their interaction.

To test the subjective effects of the threat manipulation in the shooting task, all ratings of the opponents were analyzed (in separate models) with Sleep (5hr, 8hr), Threat (LT, HT), and their interaction as fixed factors. The model for the unpleasantness ratings of the sounds additionally included fixed main and interaction effects for the factor Time (Beginning, End of task).

The behavioral measures of the shooting task (response accuracy, RT, and SSRT) were analyzed in separate models. All models included fixed effects for the factors Sleep (5hr, 8hr), Threat (LT, HT), and their interaction. The models for response accuracy and RT additionally included fixed main and interaction effects for the factor Stimulus (Go, NoGo). Response accuracy (weighed by the number of trials) was analyzed with a generalized model (glmer) with a binomial distribution. As the groups differed significantly in Time Awake at the moment of testing (see Table 1 in main text), and this could be a confounding factor for the effects of Sleep (Thun, Bjorvatn, Flo, Harris, & Pallesen, 2015), we replicated the analyses of all behavioral measures with Time Awake included as a control factor. We extended each of the models described above by adding a fixed effect for Time Awake (as a continuous, centered variable) and its interactions with the other predictors. The results of these analyses showed no significant main or interaction effects of Time Awake (all *p*s >.10), and including this factor did not change the results of any of the original analyses. Therefore, only the results without this factor are reported in the main text.

Additional Results Sleep Manipulation Check

Results of the sleep diary after night 3 (the day of the experimental session) are reported in the main text. See table S1 below for the descriptive statistics per night, and tables S2 and S3 for the inferential statistics of the main analysis and post hoc comparisons, respectively. The TST of the Actiwatch showed significant main effects of Sleep and Night, but no significant interaction of Sleep x Night (see Table S2). The TST of the sleep diary showed a significant main effect of Sleep, and no main effect of Night, but an interaction of Sleep x Night. Post hoc tests (see Table S3) showed that the 8hr group slept significantly longer than the 5hr group on all three nights, according to both measures. The subjective reports of the sleep diary (see Table S2) showed significant main effects of Sleep on restedness, alertness, fitness, fatigue, sleepiness, positive mood, and performance ability, and a trend on negative mood. In addition, results showed a significant main effect of Night (i.e., an increase over time) on sleep quality, and a significant Sleep x Night interaction on alertness, fatigue, and sleepiness, and a trend on fitness and performance ability, but no differences in sleep quality. Post hoc tests showed that, compared to the 8 hr group, the 5hr group felt significantly less rested and fit and more fatigued and sleepy after each night (see Table S3), and significantly less alert, positive, and able to perform after the 2nd and 3rd night. In addition, the 5hr group reported an increase in sleepiness over time, which was significant between the first and third night, whereas the 8hr group reported a decrease in sleepiness over time, which was significant for the first compared to the second and third night (see Table S4). Finally, self-reported fatigue and alertness did not change over time in the 5hr group, but in the 8hr group fatigue decreased and alertness increased from the first compared to the second and third night.

Additional Results Threat Manipulation Check

Results of the main effect of Threat are reported in the main text. Besides the reported Threat effects, none of the ratings showed significant main or interaction effects of Sleep. For completeness, these results are reported in detail in below. The sound ratings showed no significant main effect of Sleep (Coef = -0.04 90.13), 95% CI [-0.32, 0.20]; $X^2(1) = 0.12$, $p = 0.72$), nor an interaction of this factor with Threat or Time (Sleep x Threat: Coef = -0.08 (0.13), 95% CI [-0.31, 0.18]; $X^2(1) = 0.40$, $p = 0.56$; Sleep x Time: Coef = -0.03 (0.07), 95% CI [-0.16, 0.11]; $X^2(1) = 0.23$, $p = .63$; Sleep x Threat x Time: Coef = 0.02 (0.06), 95% CI [-0.10, 0.12]; $X^2(1) = 0.07$, $p = .80$). See Table S5 for the inferential statistics of the opponent ratings.

Robustness Checks

The analyses reported in the main text excluded three participants that did not adhere to the sleep protocol (see main text, participants section) and – in the analysis of stop signal reaction times (SSRT) – two participants that did not adhere to stop instructions (see main text, results stop signal reaction times). To verify the impact of our exclusion criteria, and the robustness of the results that are reported in the main text, we re-analyzed our behavioral data (accuracy, RT, SSRT) without making these exclusions. For completeness, these results are reported in detail below.

Exclusions based on sleep protocol adherence. The cut-off for sleep protocol adherence (>90 deviation from target sleeping time) was based on the midpoint between the target sleeping times of both groups. If a person crossed this cut-off, his or her sleeping time was closer to the target sleeping time of the other protocol than of the protocol he or she was assigned to, which invalidates the group assignment for this person. We excluded these participants in the original analyses rather than reassigning them to the other group, in order to keep group assignment random.

When these three participants were not excluded, the results were highly similar to the original analyses reported in the main text: For accuracy (5 hr $n = 28$, 8 hr $n = 27$), the main effects of Sleep (Coef = -0.21 (0.09), *95% CI* [-0.38, -0.03]; $X^2(1) = 5.17$, $p = .03$) and Stimulus (Coef = 0.84 (0.11), *95% CI* [0.62, 1.08]; $X^2(1) = 38.37$, $p = .001$) remained significant, while the effect of Threat (Coef = 0.06 (0.05), *95% CI* [-0.04, 0.15]; $X^2(1) = 1.52$, $p = .23$) and the interaction between Sleep and Threat (Coef = 0.07 (0.04), *95% CI* [-0.01, 0.15]; $X^2(1) = 1.67$, $p = .11$) remained not significant. For RT (5 hr $n = 28$, 8 hr $n = 27$), the main effects of Threat (Coef = 9.54 (2.69), *95% CI* [4.09, 14.90]; $X^2(1) = 9.99$, $p = .001$) and Stimulus (Coef = -23.37 (3.68), *95% CI* [-30.59, -16.08]; $X^2(1) = 31.56$, $p = .001$) also remained significant, and the effect of Sleep (Coef = 11.94 (6.88), *95% CI* [-1.90, 24.95]; $X^2(1) = 3.04$, $p = .096$) and the interaction of Sleep and Threat (Coef = 1.97 (2.69), *95% CI* [-3.25, 7.46]; $X^2(1) = 0.50$, $p = .47$) remained not significant. For the SSRT (where the two participants with deviating stop responses rates were excluded, i.e., 5 hr $n = 27$, 8hr $n = 26$) some results changed: The effect of Sleep was no longer a trend (Coef = 8.18 (5.14), *95% CI* [-1.36, 17.82]; $X^2(1) = 2.57$, $p = .13$), and the effect of Threat was reduced to a trend (Coef = -4.00 (2.29), *95% CI* [-8.47, 0.52]; $X^2(1) = 3.09$, $p = .089$). The interaction of Sleep and Threat remained not significant (Coef = -0.61 (2.29), *95% CI* [-5.12, 4.14]; $X^2(1) = 0.07$, $p = .79$), as in the original analysis.

Because including non-adherent participants causes the group factor to not reliably reflect actual sleeping time, as explained above, we performed an additional exploratory analysis in which we included actual sleeping time (average sleeping time based on self-report (i.e., TST diary, see Table 1 of main text) as a standardized continuous predictor in the analyses, instead of the categorical group factor. This accounts for individual variation in adherence to the sleep protocol. For SSRT this analysis showed, in contrast to the analysis presented above, a significant main effect of Sleep (Coef = -12.90 (4.97), *95% CI* [-22.53, -3.16]; $X^2(1) = 6.57$, $p = .018$), while – as in the analysis above – the effect of Threat was again a trend (Coef = -4.01 (2.28), *95% CI* [-8.16, 0.18]; $X^2(1) =3.14$, $p = .080$), and the interaction of Sleep and Threat not significant (Coef = -1.68 (2.29), 95% CI [-6.29, 2.99]; $X^2(1) = 0.56$, $p = .458$). For accuracy and RT the results were the same as in the original analysis and the analysis reported above (Accuracy: Threat Coef = 0.06 (0.05), *95% CI* [-0.04, 0.15]; $X^2(1) =1.42$, $p = .24$; Stimulus Coef = 0.84 (0.11), *95% CI* [0.61, 1.07]; $X^2(1) =38.15$, $p = .001$; Sleep Coef = 0.21 (0.09), *95% CI* [0.04, 0.39]; $X^2(1) =5.35$, $p = .034$; Sleep x Threat Coef = -0.04 (0.04), *95% CI* [-0.13, 0.05]; $X^2(1) =0.92$, $p = .35$; RT: Threat Coef = 9.29 (2.67), *95% CI* [4.40, 14.27]; $X^2(1) = 9.57$, $p = .003$; Stimulus Coef = -23.67 (3.70), *95% CI* [-31.04,-16.28]; $X^2(1) =32.19$, $p = .001$; Sleep Coef = -11.93 (6.87), *95% CI* [-26.21, 1.10]; $X^2(1) =3.00$, $p = .082$; Sleep x Threat Coef = -3.61 (2.65), *95% CI* [-8.57, 1.60]; $X^2(1) = 1.74$, $p = .17$).

Together, these findings suggest that the results of the original analyses are robust. For accuracy and response times it did not matter whether non-adhering participants were included or excluded. For the SSRT results, a small reduction in the effect of sleep was observed. However, this was only the case when Sleep was used as a *categorical* factor in the model, based on group assignment. When Sleep was included as a *continuous* variable in the model (which can be argued to make more sense when including non-adhering participants), the effect of Sleep was significant. These results suggest that including non-adhering participants in the model with Sleep as a categorical factor, weakened the effect of Sleep because the sleeping time of the non-adhering participants was closer to the target sleeping time of the non-assigned group than the assigned group, thereby reducing group differences in sleep. Furthermore, these results suggest that including Sleep as a continuous factor is more sensitive to the effects of Sleep on SSRT, likely because it takes individual differences in sleep time into account and explains more variance.

Exclusions based on adherence to task instructions. The decision to exclude participants with deviating stop respond rates (>.20 deviation from the target rate of 0.5) was based on recommendations in the literature (see e.g., Leotti & Wager, 2010; Verbruggen &

Logan, 2009), as such deviations lead to biased SSRT estimates. As precise cut-off values for this criterion are often not mentioned in the literature, we based our criterion value on recommendations from a colleague with ample experience with stop-signal tasks (Bram Zandbelt, personal communication). This criterion corresponded with a Z value > 2.5, which is a common cut-off value for outliers.

As may be expected, including the two participants that did not adhere to stop instructions (5 hr $n = 28$, 8hr $n = 27$) caused the SSRT results to change: The effect of Sleep on SSRT was no longer a trend (Coef = 9.27 (5.69), *95% CI* [-2.14, 20.53]; $X^2(1) = 2.68$, $p = .107$) and the effect of Threat was no longer significant (Coef = -2.31 (2.51), *95% CI* [-6.96, 2.56]; $X^2(1) = 0.87$, $p = .377$). The interaction of Sleep and Threat remained not significant (Coef = -0.63 (2.51), *95% CI* [-5.82, 4.01]; $X^2(1) = 0.06$, $p = .813$), as in the original analysis.

Based on the argument that non-adherence was specific to stop instructions (as reflected in non-deviating values on accuracy and reaction times of Go and NoGo trials), in the original analyses non-adhering participants were only excluded from the SSRT analysis and not from the accuracy and RT analyses. However, our robustness analysis showed that *excluding* these participants from these analyses as well (5 hr $n = 27$, 8hr $n = 26$) did not change the results. For accuracy the main effects of Sleep (Coef = -0.23 (0.09), *95% CI* [-0.41, -0.04]; $X^2(1) = 5.83$, $p = .025$) and Stimulus (Coef = 0.80 (0.11), *95% CI* [0.58, 1.03]; $X^2(1) = 35.53$, $p = .001$) remained significant, while the effect of Threat (Coef = 0.05 (0.05), *95% CI* [-0.05, 0.15]; $X^2(1) = 1.01$, $p = .34$) and the interaction between Sleep and Threat (Coef = 0.06 (0.04), *95% CI* [-0.03, 0.14]; $X^2(1) = 1.67$, $p = .15$) remained not significant. For RT the main effects of Threat (Coef = 9.88 (2.87), *95% CI* [4.29, 15.37]; $X^2(1) = 9.49$, $p = .002$) and Stimulus (Coef = -23.89 (3.90), *95% CI* [-31.81, -16.01]; $X^2(1) = 29.72$, $p = .001$) remained significant, and the effect of Sleep (Coef = 11.78 (7.00), *95% CI* [-1.60, 25.90]; $X^2(1) = 2.86$, $p = .11$) and the interaction of Sleep and Threat (Coef = 2.15 (2.87), *95% CI* [-3.90, 8.00]; $X^2(1) = 0.52$, $p = .46$) remained not significant.

Taken together, these findings confirm that participants’ non-adherence to task instructions was specific for behavior on stop trials (i.e., not responding to stop-signals) but did not affect responses on Go and No Go trials (accuracy and RT).

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Table S1. Means (*M*) and Standard Deviations (*SD*) of Sleep Diary and Actiwatch Data

	5hr (*n* = 28)			8hr (*n* = 24)		
	Day 1 *M (SD)*	*Day 2* *M (SD)*	*Day 3* *M (SD)*	*Day 1* *M (SD)*	*Day 2* *M (SD)*	*Day 3* *M (SD)*
TST actiwatch[1]	288.75 (33.24)	282.32 (31.56)	277.41 (29.58)	460.57 (34.47)	446.37 (35.58)	435.78 (47.94)
Sleep diary						
TST	282.43 (37.76)	300.26 (19.98)[2]	283.86 (38.73)	478.25 (47.40)	472.04 (42.00)	486.38 (33.10)
Sleep quality	6.55 (2.67)	6.96 (2.03)	7.32 (1.89)	6.62 (1.47)	7.21 (0.83)	7.96 (1.04)
Sleepiness	6.43 (2.04)	6.64 (2.02)	7.29 (1.46)	4.92 (2.21)	3.79 (1.77)	3.71 (2.07)
Fatigue	6.00 (2.34)	6.32 (1.72)	6.75 (1.32)	4.96 (2.05)	3.63 (1.56)	3.79 (2.00)
Fitness	5.00 (1.96)	4.86 (1.78)	4.71 (1.38)	5.96 (1.81)	6.58 (1.47)	6.67 (1.55)
Well-rested	5.12 (1.69)	4.82 (1.47)	4.79 (1.69)	6.67 (1.55)	7.21 (1.25)	7.21 (1.53)
Alertness	5.07 (1.76)	4.93 (1.46)	4.86 (1.08)	5.73 (1.67)	6.54 (1.38)	6.54 (1.35)
Positive mood	5.36 (1.70)	5.00 (2.13)	5.14 (1.69)	6.25 (1.62)	6.46 (1.50)	6.62 (1.50)
Negative mood	3.00 (1.61)	3.14 (2.09)	2.68 (1.85)	2.46 (1.84)	2.17 (1.40)	2.00 (1.67)
Performance ability	5.39 (1.64)	5.00 (1.39)	4.93 (1.51)	5.62 (1.56)	5.96 (1.73)	6.08 (1.84)

Note. 5hr = partial sleep deprivation (five hour night $^{-1}$); 8hr = no sleep deprivation (eight hour night $^{-1}$); TST = Total Sleep Time (in minutes). Sleep diary self-report variables were measured on a 10-point Likert scale (1 = not at all, 10 = very much). [1] 5hr *n* = 22, 8hr *n* = 23 (7 missing values). [2] *n* = 27 (1 missing value).

Table S2. Sleep Protocol Manipulation Check Results Main Analyses

	Sleep			Night		Sleep x Night	
	$X^2(1)$	*p*	*95% CI*	$X^2(2)$	*p*	X^2 (2)	*p*
TST actiwatch	107.32	.001	[-89.58, -74.08]	8.54	.015	1.23	.54
Sleep diary							
TST	136.80	.001	[-102.33,-87.71]	0.97	.62	6.52	.039
Sleep quality	0.78	.39	[-0.53, 0.20]	12.13	.007	0.97	.63
Sleepiness	26.77	.001	[0.87,1.87]	3.48	.20	16.95	.001
Fatigue	24.82	.001	[0.67,1.49]	3.35	.20	13.33	.003
Fitness	14.34	.001	[-1.15,-0.41]	1.42	.54	5.48	.08
Well-rested	34.35	.001	[-1.34,-0.76]	0.26	.88	3.83	.15
Alertness	14.09	.002	[-0.98,-0.33]	3.34	.20	7.95	.023
Positive mood	8.54	.009	[-1.09,-0.21]	0.74	.72	3.38	.20
Negative mood	2.88	.079	[-0.06,0.80]	4.41	.12	1.29	.53
Performance ability	4.35	.049	[-0.76,-0.01]	0.02	.99	5.28	.07

Note. X^2, *p* and 95% *CI* indicate Chi-square estimates (with degrees of freedom), *p*-values and 95% confidence intervals. Confidence intervals for effect for Night are not reported as this factor contains three levels (i.e., two contrasts).

Table S3. Sleep Protocol Manipulation Check Results Post Hoc Comparisons Sleep (5hr, 8hr) by Night

		Night 1	*Night 2*	*Night 3*
	df	*t (p)*	*t (p)*	*t (p)*
TST actiwatch[1]	105.47	-16.01 (<.0001)	-15.29 (<.0001)	-14.76 (<.0001)
Sleep diary				
TST	128.64	-18.89 (<.0001)	-16.50 (<.0001)	-19.54 (<.0001)
Sleep quality	127.9	-0.14 (.89)	-0.49 (.628)	-1.27 (.208)
Sleepiness	90.49	2.80 (.006)	5.29 (<.0001)	6.63 (<.0001)
Fatigue	112.09	2.01 (.047)	5.21 (<.0001)	5.71 (<.0001)
Fitness	94.96	-2.06 (.043)	-3.70 (.0004)	-4.19 (.0001)
Well-rested	129.61	-3.59 (.0005)	-5.56 (<.0001)	-5.65 (<.0001)
Alertness	99.44	-1.61 (.111)	-3.95 (.0001)	-4.12 (.0001)
Positive mood	75.31	-1.87 (.065)	-3.05 (.003)	-3.10 (.003)
Negative mood	78.88	1.10 (.273)	1.99 (.050)	1.38 (.171)
Performance ability	93.68	-0.52 (.606)	-2.14 (.035)	-2.58 (.011)

Note. 5hr = partial sleep deprivation (five hour night $^{-1}$); 8hr = no sleep deprivation (eight hour night $^{-1}$); TST = Total Sleep Time (in minutes). Sleep diary self-report variables were measured on a 10-point Likert scale (1 = not at all, 10 = very much). [1] 5hr *n* = 22, 8hr *n* = 23 (7 missing values). *df*, *t*, and *p* indicate degrees of freedom, *t*-values, and *p*-values (FWE corrected).

Table S4. Sleep Protocol Manipulation Check Results Post Hoc Comparisons Night by Sleep (5hr, 8hr)

		5 hr			8 hr		
		Night 1 vs. 2	*Night 1 vs. 3*	*Night 2 vs. 3*	*Night 1 vs. 2*	*Night 1 vs. 3*	*Night 2 vs. 3*
	df	*t (p)*	*t (p)*	*t (p)*	*t (p)*	*t (p)*	*t (p)*
TST actiwatch[1]	86	0.73 (.749)	1.28 (.410)	0.55 (.845)	1.64 (.235)	2.86 (.015)	1.22 (0.443)
Sleep diary							
TST	99/99.9	-2.03 (.111)	-0.17 (.98)	1.86 (.155)	0.68 (.775)	-0.89 (.647)	-1.57 (.262)
Sleep quality	100	-1.01 (.571)	-1.89 (.147)	-0.88 (.654)	-1.33 (.380)	-3.04 (.008)	-1.71 (.206)
Sleepiness	100	-0.63 (.802)	-2.53 (.034)	-1.90 (.144)	3.08 (.008)	3.31 (.004)	0.23 (.972)
Fatigue	100	-0.84 (.678)	-1.96 (.126)	-1.12 (.503)	3.23 (.005)	2.83 (.015)	-0.40 (.914)
Fitness	100	0.47 (.886)	0.94 (.617)	0.47 (.886)	-1.90 (.144)	-2.16 (.084)	-0.25 (.965)
Well-rested	100	0.87 (.662)	0.97 (.597)	0.10 (.994)	-1.43 (0.327)	-1.43 (0.327)	0.00 (1.00)
Alertness	100	0.52 (.863)	0.78 (.719)	0.26 (.964)	-2.72 (.021)	-2.72 (0.21)	0.00 (1.00)
Positive mood	100	1.43 (.329)	0.86 (.667)	-0.57 (.835)	-0.77 (.720)	-1.39 (.349)	-0.62 (.810)
Negative mood	100	-0.53 (.858)	1.19 (.462)	1.72 (.204)	1.00 (.579)	1.57 (.263)	0.57 (.836)
Performance ability	100	1.36 (.367)	1.61 (.248)	0.25 (.967)	-1.07 (.537)	-1.47 (.311)	0.40 (.916)

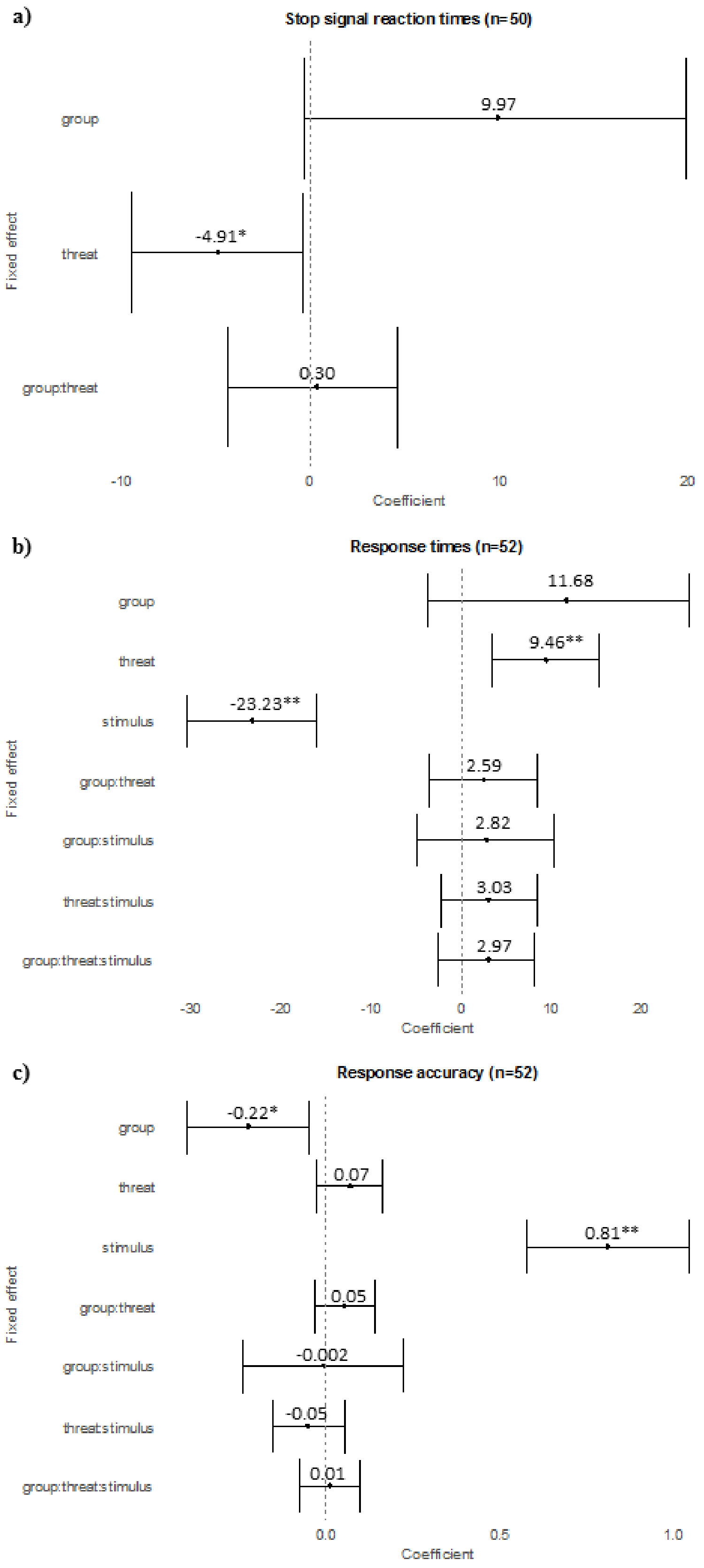
Note. 5hr = partial sleep deprivation (five hour night $^{-1}$); 8hr = no sleep deprivation (eight hour night $^{-1}$); TST = Total Sleep Time (in minutes). Sleep diary self-report variables were measured on a 10-point Likert scale (1 = not at all, 10 = very much). [1] 5hr *n* = 22, 8hr *n* = 23 (7 missing values). *df*, *t*, and *p* indicate degrees of freedom, *t*-values, and *p*-values.

Table S5. Threat Manipulation Check Results Main Analyses

	Threat			Sleep			Threat x Sleep		
	X^2 *(1)*	*p*	*95% CI*	X^2 *(1)*	*p*	*95% CI*	X^2 *(1)*	*p*	*95% CI*
Certainty	1.20	.29	[-0.06, 0.02]	0.27	0.61	[-0.24, 0.40]	1.20	0.28	[-0.02, 0.06]
Motivation	26.27	.001	[0.49,0.98]	0.81	0.38	[-0.48,0.17]	0.10	0.75	[-0.21, 0.29]
Valence	39.54	.001	[0.72,1.31]	0.30	0.61	[-0.22, 0.37]	0.16	0.68	[-0.35, 0.24]
Arousal	32.94	.001	[-1.27,-0.65]	1.27	0.28	[-0.55, 0.15]	1.95	0.19	[-0.08, 0.49]
Dominance	2.83	.10	[-0.63, 0.03]	0.03	0.92	[-0.30, 0.35]	0.09	0.77	[-0.28, 0.40]

Note. X^2, *p* and 95% *CI* indicate Chi-square estimates (with degrees of freedom), *p*-values and 95% confidence intervals.

Figure S1. Fixed Effect Estimates and 95% CI of Behavioral Results



Note. Point estimates represent the unstandardized regression coefficients (i.e., slopes). Lines represent the 95% confidence intervals (*95% CI*). *$p < .05$, **$p < .01$