Changes in subjective motivation and effort during sleep restriction moderate interindividual differences in attentional performance in healthy young men

Gina Marie Mathew*[1], Stephen M. Strayer[1], David S. Bailey[1], Katherine Buzzell[1], Kelly M. Ness[1], Margeaux M. Schade[1], Nicole G. Nahmod[1], Orfeu M. Buxton[1], & Anne-Marie Chang[1,2]

[1]Department of Biobehavioral Health, College of Health and Human Development, Pennsylvania State University, University Park, PA, USA

[2]College of Nursing, Pennsylvania State University, University Park, PA, USA

Correspondence:

Gina Marie Mathew

219 Biobehavioral Health Bldg

University Park, PA 16802

Tel: +1 814 863-7256

Email: gina@psu.edu

Table S1. Trajectory of self-report measures and PVT performance across baseline days (*N* = 15)

Outcome	Mean (*SEM*)			*b (SEM)*	Pairwise comparisons *t* (*SEM*)[a]		
	BL1	BL2	BL3		2 vs 1	3 vs 1	3 vs 2
Self-report[b]							
Alertness	55.88 (3.69)	55.25 (4.07)	57.11 (3.69)	.62 (1.34)	−−−	−−−	−−−
Motivation	66.58 (4.83)	64.07 (5.02)	67.92 (4.83)	.69 (1.05)	−−−	−−−	−−−
Effort	2.17 (.13)	2.11 (.14)	2.21 (.13)	.02 (.04)	−−−	−−−	−−−
PVT[c]							
False starts[‖]	3.39 (.61)	2.37 (.65)	2.60 (.61)	−.39* (.18)	−2.46* (.42)	−2.23* (.35)	.58 (.41)
Lapses	4.37 (1.39)	3.96 (1.45)	4.62 (1.39)	.13 (.33)	−−−	−−−	−−−
Response speed (s)	3.44 (.17)	3.40 (.18)	3.39 (.17)	−.03 (.03)	−−−	−−−	−−−

Note. All models except effort include *time of day*.

b, unstandardized beta; BL, baseline; PVT, psychomotor vigilance task; s, seconds; SEM, standard error of the mean; *t*, Student's *t*-test statistic.

[a]Pairwise comparisons only made where *b* was significant.

[b]Alertness: 0 (low) to 100 (high); motivation: 0 (low) to 100 (high); effort: 1 (low) to 4 (high).

[c]False starts = reaction times < 100 ms; lapses = reaction times ≥ 500 ms; response speed = 1 / reaction time in seconds.

[‖]*df* for pairwise *t*-test = 201.

*$p < .05$, two-tailed.

Table S2. Total sleep time, sleep efficiency, and sleep architecture, measured with polysomnography (*N* = 15)

Measure	Mean (*SEM*) by Condition			*F*(2,101)	Pairwise comparisons: *Mean difference*[a] (*SEM*)			Significant Differences
	BL	SR	REC		SR vs. BL	REC vs. BL	REC vs. SR	
TST (hrs)	8.55 (.12)	4.76 (.09)	9.01 (.12)	937.57***	−3.79*** (.12)	.46** (.14)	4.25*** (.12)	SR < BL < REC
SME (%)	85.53 (1.29)	95.06 (1.01)	90.23 (1.27)	33.34***	9.53*** (1.20)	4.70** (1.42)	−4.83*** (1.18)	SR > REC > BL
N1 (min)	51.17 (3.75)	17.78 (3.38)	41.47 (3.73)	109.28***	−33.39*** (2.48)	−9.70** (2.95)	23.69*** (2.44)	SR < REC < BL
N2 (min)	256.07 (6.71)	130.47 (5.46)	270.19 (6.62)	399.13***	−125.61*** (5.93)	14.12 (7.03)	139.73*** (5.83)	SR < BL, REC
N3 (min)	72.05 (6.96)	72.52 (6.63)	69.77 (6.94)	.38	.47 (3.21)	−2.28 (3.81)	−2.75 (3.16)	BL = SR = REC
REM (min)	133.66 (5.30)	64.60 (4.43)	159.00 (5.23)	285.02***	−69.06*** (4.41)	25.34*** (5.23)	94.40*** (4.34)	SR < BL < REC
N1 (%TST)	10.02 (.95)	6.23 (.88)	7.83 (.94)	27.50***	−3.79*** (.52)	−2.19** (.61)	1.60** (.51)	SR < REC < BL
N2 (%TST)	49.93 (1.75)	45.74 (1.54)	50.09 (1.74)	9.04***	−4.19** (1.27)	.16 (1.50)	4.35** (1.24)	SR < BL, REC
N3 (%TST)	14.18 (1.90)	25.40 (1.77)	12.76 (1.89)	102.80***	11.22*** (1.05)	−1.42 (1.25)	−12.64*** (1.03)	SR > BL, REC
REM (%TST)	25.84 (1.11)	22.65 (.91)	29.33 (1.10)	25.49***	−3.19** (.97)	3.50** (1.15)	6.68*** (.95)	SR < BL < REC

Note. The baseline (BL) condition was 3 nights, but the first night was excluded from analyses; the sleep restriction (SR) condition was 5 nights; the recovery (REC) condition was 2 nights. Out of 135 considered nights (two baseline nights, five sleep restriction nights, and two recovery nights; nine nights * 15 participants), *n* = 17 nights were excluded due to missing or unscorable data.

[a]*p* was corrected with Tukey's Honestly Significant Difference (HSD) test.

BL, baseline nights 2-3 during in-lab study period; N1, non-rapid eye movement stage 1; N2, non-rapid eye movement stage 2; N3, non-rapid eye movement stage 3; REC, recovery; REM, rapid eye movement; SEM, standard error of the mean; SME, sleep maintenance efficiency; SR, sleep restriction; TST, total sleep time.

**$p < .01$, ***$p < .001$, two-tailed.

Table S3. Comparison of psychomotor vigilance task (PVT) performance during sleep restriction and recovery days to baseline by change in self-reported alertness, motivation, or effort (*N* = 15)

Outcome[a]	Level[b]	BL[c] (ref)	SR					REC	
			1	2	3	4	5	1	2
MODERATOR: CHANGE IN SUBJECTIVE ALERTNESS FROM BL TO SR									
False starts	*Mean*	4.73 (.93)	5.08 (.46)	**5.79 (.46)**	**5.71 (.46)**	**6.09 (.51)**	**5.84 (.54)**	4.91 (.62)	5.18 (.80)
Lapses	*Mean*	7.16 (2.21)	8.29 (.73)	**9.50 (.73)**	**11.02 (.73)**	**10.23 (.82)**	**11.00 (.85)**	**9.54 (.97)**	6.20 (1.26)
Response speed (s)	*Mean*	3.15 (.20)	**2.98 (.05)**	**2.88 (.05)**	**2.73 (.05)**	**2.76 (.06)**	**2.71 (.06)**	**2.99 (.07)**	3.24 (.09)
MODERATOR: CHANGE IN SUBJECTIVE MOTIVATION FROM BL TO SR									
False starts	*M−1SD*	5.25 (1.18)	5.29 (.64)	**6.67 (.64)**	**7.38 (.64)**	**8.38 (.72)**	**7.59 (.75)**	4.64 (.85)	6.24 (1.08)
Lapses	*M−1SD*	7.95 (3.06)	9.01 (1.04)	**10.85 (1.04)**	**13.01 (1.04)**	**13.31 (1.17)**	**14.09 (1.23)**	***10.64 (1.38)***	6.97 (1.74)
	M+1SD	6.41 (3.06)	7.63 (1.05)	***8.20 (1.04)***	**9.09 (1.04)**	7.18 (1.17)	7.98 (1.22)	8.51 (1.38)	5.45 (1.75)
Response speed (s)	*Mean*	3.14 (.19)	**2.98 (.05)**	**2.88 (.05)**	**2.73 (.05)**	**2.76 (.06)**	**2.71 (.06)**	**2.99 (.07)**	3.24 (.09)
MODERATOR: CHANGE IN SUBJECTIVE EFFORT FROM BL TO SR									
False starts	*Mean*	4.71 (.93)	5.08 (.46)	**5.78 (.46)**	**5.70 (.46)**	**6.08 (.52)**	**5.82 (.54)**	4.90 (.62)	5.23 (.80)
Lapses	*M+1SD*	5.98 (3.10)	7.27 (1.03)	**10.45 (1.01)**	**13.69 (1.01)**	**10.05 (1.14)**	**10.27 (1.18)**	**9.51 (1.42)**	7.70 (1.66)
Response speed (s)	*Mean*	3.14 (.20)	**2.98 (.05)**	**2.88 (.05)**	**2.74 (.05)**	**2.76 (.06)**	**2.71 (.06)**	**2.99 (.07)**	3.25 (.09)

Notes: See Equation 1 for calculation of the change in subjective alertness, motivation, or effort from the baseline reference point (the day succeeding the third baseline night; BL) through sleep restriction (SR) and Figure 4 for the change value per participant. For significant *day*^{2}**change* interactions (see Table 2), comparisons to BL were made at 1 standard deviation (*SD*) below (M–1SD) and 1 *SD* above (M+1SD) the mean of change in subjective alertness, motivation, or effort. Estimates were obtained by re-centering the change value at 1 *SD* below or above the mean (*N* = 15 in all analyses; refer to Statistical Analyses). For non-significant interactions, comparisons to BL were made at the mean of change in subjective alertness, motivation, or effort. Comparisons to BL were not completed if the trajectory of the outcome across the study was not significant (ie, for false starts at M+1SD change in subjective motivation and for lapses at M−1SD change in subjective effort; see Table 2). Outcomes refer to each 10-minute task administration. All models include *time of day of task administration*. Values are estimated marginal means from linear mixed modeling with the standard error of the mean (*SEM*) in parentheses.

BL, baseline; PVT, psychomotor vigilance task; REC, recovery; s, seconds; SR, sleep restriction.

[a]Level of moderator (change in subjective alertness, motivation, or effort from baseline to SR).

[b]Last baseline day (succeeding third baseline night).

[c]False starts = reaction times < 100 ms; lapses = reaction times ≥ 500 ms; response speed = 1 / reaction time in seconds.

Bold values indicate SR or REC day was significantly different from BL ($p < .05$). ***Bold italic*** values indicate SR or REC day was marginally different from BL ($p < .10$). Underlined values indicate the difference in a PVT outcome between given day and baseline significantly differed between *M−1SD* and *M+1SD* levels of the moderator ($p < .05$).

Table S4. Effect of hours into sleep restriction on self-report measures and psychomotor vigilance task (PVT) performance across five sleep restriction days (N = 15)

Outcome	*b* (*SEM*)	
Self-report[a]		
Alertness	−.118***	(.024)
Motivation[§]	−.078***	(.019)
Effort	.002*	(.001)
PVT[b]		
False starts[§]	.008	(.005)
Lapses[§]	.030***	(.007)
Response speed (s)[§]	−.003***	(< .0005)

Note. Time into sleep restriction was calculated as hours past 05:30 AM (wake time) on the day succeeding the first sleep restriction night.

[a]Alertness: 0 (low) to 100 (high); motivation: 0 (low) to 100 (high); effort: 1 (low) to 4 (high).

[b]False starts = reaction times < 100 ms; lapses = reaction times ≥ 500 ms; response speed = 1 / reaction time in seconds.

b, unstandardized beta; PVT, psychomotor vigilance task; s, seconds; SEM, standard error of the mean.

[§]Model includes time of day of self-report or PVT administration due to improved model fit.

*p < .05; ***p < .001, two-tailed.