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Chronic sleep curtailment impairs the flexible implementation of task goals in new parents

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SUMMARY Chronic sleep curtailment is a major concern for health in Western societies. Yet, research on potential consequences of long-term sleep curtailment on cognitive functions is still scarce. The present study investigated the link between chronic sleep limitation and executive functions that enable adaptation to changing environmental demands, i.e. the ability to flexibly implement task goals. To address the effects of chronic sleep restriction under real-life conditions, we considered a sample of adults who often suffer from reduced sleep durations over many months. One-hundred and six new parents (infant's age: 6–18 months) were assigned to a sleep-curtailed group (< 7 h of nighttime sleep) and a non-sleep-curtailed group (≥ 7 h of nighttime sleep), respectively, based on their self-reported average nighttime sleep duration over the preceding 6 months. The ability to implement task goals was addressed applying a task-switching paradigm in which participants randomly switched between two tasks. While the two groups did not differ with regard to overall performance level, number of nighttime awakenings, naps during the day, daytime sleepiness, mood, chronic stress level and subjectively perceived cognitive capability, sleep-curtailed new parents showed higher costs for switching between tasks compared with repeating a task than non-sleep-curtailed new parents. This finding on the group level was further substantiated by a negative correlation between nighttime sleep duration and switch costs. With this study, we provide the first evidence for an impairment of the ability to flexibly implement task goals in chronically sleep-deprived new parents and, thus, for a link between chronic sleep curtailment and executive functions.

KEYWORDS chronic sleep curtailment, cognitive control, executive functions, new parents, sleep debt, task switching

INTRODUCTION

Modern Western industrial societies have increasingly suffered from chronic sleep curtailment (e.g. Bonnet and Arand, 1995). In 1982, a study of the American Cancer Society including more than 1.1 million participants revealed a modal sleep duration of 8 h, with 19.7% of the interviewed declaring to sleep < 6.5 h per day (reported in Kripke *et al.*, 2002). Recently, average sleep duration estimated for 1000 randomly chosen US American citizens was found to be only 6 h and 40 min on workdays, with 44% reporting to frequently sleep < 7 h (National Sleep Foundation, 2008).

In contrast to the widespread prevalence of chronic sleep restriction, the knowledge about potential consequences of long-term reductions of sleep duration is still limited. There is some evidence that chronically insufficient sleep negatively affects mood (Dinges *et al.*, 1997), endocrine (Rogers *et al.*, 2000) and metabolic functions (Spiegel *et al.*, 2003), as well as immune (Balachandran *et al.*, 2002) and cardiovascular parameters (Ayas *et al.*, 2003). Evidence is scarce regarding

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the effects of chronically reduced sleep durations on cognitive functions and, to date, limited to sleep-curtailment periods of days up to few weeks only. Some studies indicate that sleep decrease over 1–2 weeks impairs working-memory performance and vigilance (Belenky *et al*., 2003; Van Dongen *et al*., 2003).

Evidence is even less clear concerning potential effects of persistent sleep curtailment on executive functions, i.e. the ability to maintain, shield and pursue goals in the face of distracting irrelevant information as well as flexibly adapting to environmental changes (e.g. Goschke, 2000; Logan, 2003). Herscovitch *et al*., 1980 reported more perseveration errors in the Wisconsin Card Sorting Test (WCST), indicating a reduced flexibility in adapting to environmental changes after five nights of sleep limitation to 40% of normal sleep. In contrast, Stenuit and Kerkhofs (2008) found no change in the flexible adaptation to changes in abstract rules when performing the WCST after three consecutive nights of sleep restriction to 4 h, while within the same study increased interference susceptibility in a Stroop task was revealed.

Studies investigating sleep curtailment over months or years are required to sufficiently address the question of potential effects of the above-described societal trend towards chronically reduced sleep durations on executive functions. However, to the best of our knowledge, there is no research on that topic yet. This is surprising because potential consequences of chronic sleep reduction on executive functions would be of great interest as they play a key role in the control of voluntary actions.

In contrast to this lack of knowledge about potential consequences of long-term sleep curtailment, the effects of acute total sleep loss on executive functions have already been intensely addressed. For example, acute total sleep loss impairs the ability to inhibit an ongoing action upon a stop signal (Chuah *et al*., 2006), increases the inter-individual variability in interference susceptibility (McCarthy and Waters, 1997), and reduces the ability to adopt a preparatory task strategy (Jennings *et al*., 2003). Moreover, acute total sleep loss reduces the flexibility in shifting between different tasks (Heuer *et al*., 2004), and impairs both error detection and post-error adjustments (Tsai *et al*., 2005). As the prefrontal cortex (PFC) mediates many aspects of executive control (Miller and Cohen, 2001), these findings were held to be consistent with the notion that the PFC particularly benefits from sleep, and consequently is most impaired by sleep irregularities (i.e. the PFC–vulnerability hypothesis; Horne, 1993; Muzur *et al*., 2002). It should, however, be noted that recent studies using functional magnetic resonance imaging show that impairments of executive functions under conditions of acute total sleep loss are accompanied by reduced neural activity in a widespread network comprising prefrontal, parietal, temporal and occipital areas, as well as the thalamus (e.g. Chee and Chuah, 2007; Chuah and Chee, 2008; Vandewalle *et al*., 2009). Therefore, observed deficits in executive functions due to acute total sleep loss may result from impaired maintenance of connectivity between brain areas.

Given that acute total sleep loss impairs executive functions under laboratory conditions, it is conceivable that chronic sleep curtailment impairs these functions under real-life conditions by, for example, causing an accumulating decrement of executive functions over time. However, because chronic sleep curtailment occurs in the long term and is characterised by a sleep duration reduction rather than total sleep loss, the organism might be able to adapt to it and/or compensate potential consequences for executive functions, resulting in an absence of observable behavioural changes (e.g. Drummond *et al*., 2004, 2005).

To investigate whether and how chronic sleep curtailment affects executive functions, we took advantage of an 'experiment of nature'. Becoming a new parent is often associated with significant changes in sleep duration and sleep quality (e.g. Gay *et al*., 2004). Due to newborns' random sleep–wake patterns, multiple nighttime awakenings and demanding around-the-clock care, many new parents suffer significant decreases in nighttime sleep duration that accumulate to a sleep debt over months or even years (e.g. Gay *et al*., 2004). There are, however, large inter-individual differences in both the development of sleep–wake rhythm in newborns (e.g. Burnham *et al*., 2002) and the amount of sleep curtailment experienced by new parents (e.g. Gay *et al*., 2004; Lee, 1998). While some babies already sleep through the night at the age of 2–7 weeks, others will not have developed a stable circadian sleep–wake rhythm at the age of 1 year (e.g. Meijer and van den Wittenboer, 2007). As a consequence, some new parents may receive significantly less than the 7 h of nighttime sleep for a long period of time, which is considered to be the critical sleep duration required for a sufficient regenerating effect of sleep (cf. Banks and Dinges, 2007; Durmer and Dinges, 2005). In the present study, we thus investigated new parents with infants aged 6–18 months who reported to have suffered from chronic sleep restriction, as indicated by < 7 h of average nighttime sleep duration over the preceding 6 months. Because becoming a new parent is associated with a variety of significant changes that exceed changes in sleep (e.g. Nyström and Öhrling, 2004; Price *et al*., 2000), it is obligatory to contrast new parents with chronic sleep curtailment with a similar group of new parents who are able to obtain sufficient nighttime sleep, i.e. report an average nighttime sleep duration of 7 h or more, and to control for additional variables that might act as confounders (e.g. chronic stress).

With respect to executive functions, we focused on the ability to flexibly implement and pursue task goals, which is crucial for the successful management of novel or fast-changing situations. For this, we applied a task-switching paradigm (e.g. Allport *et al*., 1994; Meiran, 1996; Rogers and Monsell, 1995). Within a task-switching setting, participants perform two tasks, each specified by a well-defined stimulus–response mapping. Performance is typically better when a given task is preceded by the same task (task repetition) than when it is preceded by a different task (task switch). The performance difference between switch trials and repetition trials is referred to as switch costs and is supposed to reflect cognitive control processes that aim at implementing a new task goal when required. Furthermore, it has been demonstrated that these switch costs depend on the level of preparation (e.g. Rogers and Monsell, 1995; Rubinstein *et al*., 2001). Whereas some part of the switch costs decreases with increasing preparation time (i.e. endogenous component; Koch, 2001; Meiran, 1996), another part persists even under conditions of long preparation time (i.e. exogenous component; Meiran, 2000; Rubinstein *et al*., 2001; see Fig. 1). We used a version of the task-switching paradigm that allowed for this theoretical distinction by manipulating the available preparation time.

This study investigated whether new parents who suffer from chronic sleep limitation differ from non-sleep-curtailed new parents with regard to the flexible implementation of task goals. If chronic sleep curtailment impairs the ability to flexibly implement task goals, sleep-curtailed new parents will show increased switch costs compared with non-sleep-curtailed new parents. In addition, results from this study may allow further specification of potential effects of chronic sleep curtailment on specific types of switch cost components.

MATERIALS AND METHODS

Participants

Participants were recruited in the context of a large survey study that randomly selected 1000 couples out of all Dresden residents' couples with infants between the age of 6 and 18 months on the day of recruitment. These 1000 couples were asked to complete mail questionnaires about sleep, stress, habits and eating behaviour. From the 192 couples that gave consent to further participation, 53 couples were randomly chosen for a more detailed assessment in our laboratory. They gave their written informed consent prior to their inclusion in the study in accordance with the 1964 Declaration of Helsinki and the guidelines of the local ethics committee. None of the persons included in this study reported any physical or psychiatric conditions. All participants had normal or corrected-to-normal vision.

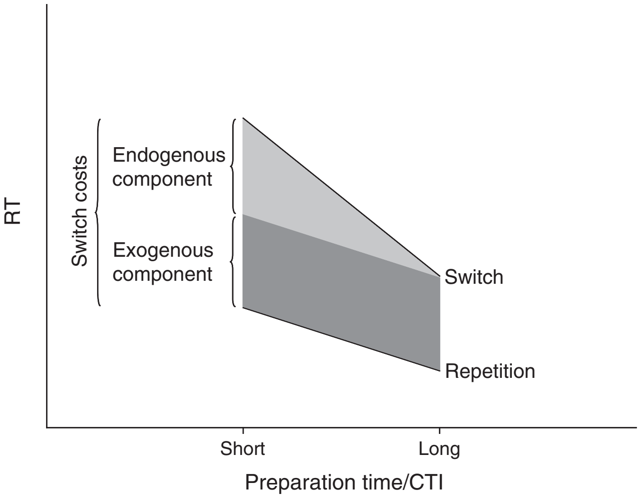

Figure 1. Effects of task transition (switch versus repetition) and preparation time/cue–target interval (CTI; short versus long) on response times (RT). Switch costs are calculated by subtracting performance in repetition trials from performance in switch trials. Considering the CTI, these switch costs can be further subdivided into switch costs that decrease with increasing preparation time (i.e. endogenous component, highlighted in light grey) and switch costs that persist even under conditions of sufficient preparation time (i.e. exogenous component, highlighted in dark grey).

Sleep curtailment

All 106 participants were asked to self-characterise their long-term sleep behaviour by reporting: (i) the hours they slept on average per night over the last 6 months; (ii) the average number of nighttime awakenings over the last 6 months; and (iii) the average duration of naps during the day over the last 6 months. We assigned the participants to two groups: a chronically sleep-curtailed group (< 7 h of nighttime sleep) and a non-sleep-curtailed group (≥ 7 h of nighttime sleep), based on their self-reported average nighttime sleep duration. The 7-h cut-off criterion was chosen on the basis of recent publications that postulate an average sleep duration of at least 7 h daily as indispensable (cf. Banks and Dinges, 2007; Durmer and Dinges, 2005). This led to a sleep-curtailed group consisting of 46 participants and a non-sleep-curtailed group of 60 participants.

The participants further completed the following questionnaires: (i) the Epworth Sleepiness Scale (ESS; Johns, 1991) to assess subjectively perceived daytime sleepiness; (ii) the Positive and Negative Affect Schedule (PANAS; Watson *et al*., 1988) as a mood measurement; and (iii) the Trier Inventory of Chronic Stress (TICS; Schulz *et al*., 2004), a German questionnaire measuring chronic stress over the preceding 3 months. In addition, they were asked to evaluate their own current level of subjectively perceived cognitive capability on a six-point ordinal scale from 1 = 'gut' (well) to 6 = 'schlecht' (bad).

Task switching

All participants conducted an explicit-cuing version of the task-switching paradigm (Meiran, 1996), switching between the two tasks to categorise a single-digit number (1–9 except for 5) as smaller or larger than five or as odd or even, respectively. Task order was random, resulting in two types of task transition, i.e. trials in which the preceding task switched (switch trials) and trials in which the task was repeated (repetition trials), respectively. A cue (i.e. square or diamond) presented at the beginning of each trial indicated the task to be performed. Half of the participants were instructed to categorise the target referring to its magnitude when a square was presented and to its parity when a diamond appeared. For the other half the mapping was reversed. After a cue–target interval (CTI) of either 200 ms (short CTI) or 1000 ms (long CTI), the target stimulus was added. Participants were instructed to respond left if the target was smaller than five or odd, and to respond right if the target was larger than five or even. For example, the targets 1 and 3 require the left response in both the magnitude and the parity task, as the same targets (1–9 except for 5) and responses (left versus right) exist for both tasks. Equivalently, the targets 6 and 8 require the right response in both tasks (congruent targets). On the other hand, the targets 2, 4, 7 and 9 require different responses in each task (incongruent targets). This results in performance decrements for incongruent targets compared with congruent targets, denoting the target-congruency effect (TCE; e.g. Meiran, 1996). The TCE is typically interpreted as a measure of stimulus-based interference from the currently irrelevant task (e.g. Kiesel *et al*., 2007).

Both task cue and target stimulus were presented until a response was given. After a correct response, the screen remained blank for 500 ms. In the case of a wrong response, the word 'falsch' (false) was presented for 500 ms combined with an acoustic signal (sinus tone) through loudspeakers. If no response was given within 5000 ms, the feedback 'zu langsam' (too slow) appeared together with the tone. The time between feedback offset and task–cue onset was reversed to the subsequently following CTI to ensure a constant response–target interval of 1700 ms.

All stimuli were centrally presented white against black on a 17-inch monitor of an IBM-compatible personal computer. Viewing distance was approximately 50 cm. The two task cues (i.e. square and diamond) had a side length of 2.98° visual angle, the target stimuli (i.e. single-digit numbers 1–9 except for 5) extended between 0.34 and 0.69° horizontally and 1.03° vertically. Participants responded by pressing the 'Alt' and 'Alt Gr' key of a standard QWERTZ keyboard with the left and right index finger, respectively. Stimulus presentation and data recording were realised using Presentation software (Version 0.71; Neurobehavioral Systems, Inc., Albany, CA, USA). The experiment consisted of two practice blocks of 12 trials each and three experimental blocks of 64 trials each, respectively. In each experimental block, all combinations of task, CTI and target were presented twice. The experimental procedure (questionnaires + cognitive testing) took place between 10:00 and 12:00 hours for all participants, to minimise potential influences of time of day.

Data analysis

Individual overall switch costs were calculated by subtracting mean performance in switch trials from mean performance in repetition trials for response times (RT) and error rates, respectively. The preparation-dependent endogenous switch cost component was calculated by subtracting the switch costs for trials with long CTI from the switch costs for trials with short CTI. The preparation-independent exogenous component equates switch costs in trials with long CTI (see Fig. 1).

Analyses of variance (ANOVAS) with the within-subject factors task transition (switch versus repetition), CTI (short versus long) and target congruency (incongruent versus congruent), and the between-subject factor sleep curtailment (sleep-curtailed versus non-sleep-curtailed) were conducted on mean RT and error rates. The first trial of each block as well as post-error trials (8.74%) were excluded, as it is not clear whether they should be considered as repetition trials or switch trials. For the RT analysis only, error trials (5.57%) as well as RT differing more than 2.5 standard deviations from the mean RT of each participant and condition (2.21%) were also excluded.

RESULTS

Participants' characteristics

While the sleep-curtailed new parents reported significantly shorter average nighttime sleep duration with regard to the preceding 6 months ($t_{104} = 17.25$, $P < 0.001$), neither the number of nighttime awakenings nor the total duration of naps during the day was different from the non-sleep-curtailed new parents (both $t < 1$; see also Table 1). Likewise, no differences were noted between the two groups for ESS, PANAS and TICS scores or subjectively perceived cognitive capability (all $P \geq 0.20$; see Table 1).

RT

Task-switching performance

The ANOVA revealed significant main effects of task transition (switch: 1126 ms, repetition: 883 ms; $F_{1,104} = 243.59$, $P < 0.001$, $\eta^2 = 0.70$), CTI (short CTI: 1087 ms, long CTI: 922 ms; $F_{1,104} = 251.35$, $P < 0.001$, $\eta^2 = 0.71$) and target congruency (incongruent: 1047 ms, congruent: 962 ms; $F_{1,104} = 72.73$, $P < 0.001$, $\eta^2 = 0.41$). Furthermore, a significant two-way interaction between task transition and CTI ($F_{1,104} = 27.37$, $P < 0.001$, $\eta^2 = 0.21$) suggested a preparation-dependent reduction of switch costs from 289 ms with short CTI to 197 ms with long CTI. A three-way interaction between task transition, CTI and target congruency ($F_{1,104} = 4.59$, $P < 0.05$, $\eta^2 = 0.04$) revealed that switch costs with short CTI were slightly increased for congruent targets (302 ms) compared with incongruent targets (276 ms), whereas this pattern was reversed for long CTI (switch costs for congruent targets: 175 ms; switch costs for incongruent targets: 220 ms). The two-way interactions task transition × target congruency and CTI × target congruency were not significant (both $F < 1$).

Effects of chronic sleep curtailment on task-switching performance

Most important for the current study, while mean RT did not differ between groups ($F_{1,104} = 1.04$, $P = 0.31$, $\eta^2 = 0.01$), sleep-curtailed new parents showed increased switch costs compared with non-sleep-curtailed new parents ($F_{1,104} = 6.70$, $P < 0.05$, $\eta^2 = 0.06$; see Table 2 and Fig. 2).

We further found no differences between sleep-curtailment conditions regarding CTI ($F_{1,104} = 1.32$, $P = 0.25$, $\eta^2 = 0.01$), target congruency, the interaction between task

Table 1 Comparison of sleep-curtailed and non-sleep-curtailed new parents with respect to demographic, sleep-related and psychological variables

	Sleep-curtailed new parents (n = *46*)	*Non-sleep-curtailed new parents* (n = *60*)	*Test statistic*	P-*value*
Demographic variables				
Age (years)	32.37 (5.92)	30.34 (5.88)	$t_{104} = 1.76$	0.08
Gender (number of males)	*n* = 27 (58.70%)	*n* = 26 (43.33%)	Fisher's exact	0.17
Infant age (months)	12.33 (3.00)	12.52 (3.50)	$t_{104} = 0.30$	0.77
Level of education*	2.76 (0.97)	2.78 (1.01)	$U = 1291.50$	0.56
Sleep-related variables (referring to the preceding 6 months)				
Nighttime sleep duration (h)	5.86 (0.34)	7.37 (0.55)	$t_{104} = 17.25$	<0.001
Nighttime awakenings (*n*)	1.76 (1.07)	1.73 (1.06)	$t_{104} = 0.15$	0.89
Total duration of naps during the day (h)	0.22 (0.47)	0.21 (0.48)	$t_{104} = 0.06$	0.95
Psychological variables				
ESS	9.24 (3.47)	9.29 (2.98)	$t_{104} = 0.09$	0.93
PANAS negative	9.93 (6.03)	9.08 (5.61)	$t_{104} = 0.74$	0.46
PANAS positive	21.40 (5.05)	22.84 (6.02)	$t_{104} = 1.30$	0.20
TICS†	15.93 (7.44)	15.32 (8.42)	$t_{104} = 0.39$	0.70
Subjectively perceived cognitive capability	2.54 (0.96)	2.40 (0.96)	$t_{104} = 0.76$	0.45

ESS, Epworth Sleepiness Scale; PANAS, Positive and Negative Affect Schedule; TICS, Trier Inventory for the Assessment of Chronic Stress. Values are given as means (SD) unless stated otherwise.

*Assessed with a four-point ordinal scale: 1 = no degree; 2 = O-levels; 3 = A-levels; 4 = university degree.

†Data values and statistical analysis refer to the TICS Screening Scale, a 12-items short version of the test to assess the global chronic stress level, range 0–48, with larger values indicating a higher global chronic stress level. The statistical outcome equals the analysis of the total of nine scale scores representing nine aspects of chronic stress ($F_{9,94} = 0.57$, $P = 0.82$).

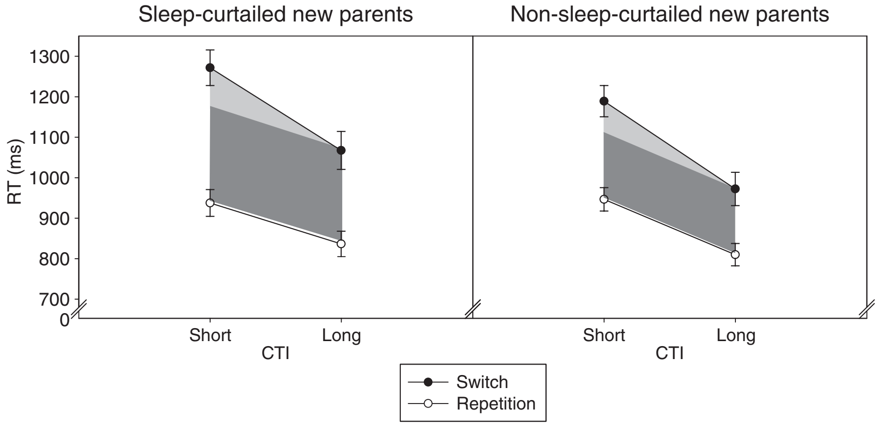

Figure 2. Response times (RT) as a function of cue–target interval (CTI; short versus long) and task transition (switch versus repetition) for sleep-curtailed and non-sleep-curtailed new parents, respectively. Error bars represent standard errors. The RT difference between switch trials and repetition trials denotes the switch costs that consist of a preparation-dependent endogenous component (highlighted in light grey) and a preparation-independent exogenous component (highlighted in dark grey).

transition and CTI, as well as the interaction between task transition and target congruency (all $F < 1$). The ANOVA only revealed a significant three-way interaction between CTI, target congruency and sleep curtailment ($F_{1,104} = 4.56$, $P < 0.05$, $\eta^2 = 0.04$). However, subsequent *t*-tests revealed no difference between TCE for short CTI and TCE for long CTI for non-sleep-curtailed new parents ($t_{59} = 1.01$, $P = 0.32$), and only a marginally significant TCE increase from short CTI (60 ms) to long CTI (106 ms) for sleep-curtailed new parents ($t_{45} = 1.74$, $P = 0.09$). The four-way interaction was not significant ($F_{1,104} = 1.46$, $P = 0.23$, $\eta^2 = 0.01$).

In an attempt to understand the switch cost increase in sleep-curtailed new parents compared with non-sleep-curtailed new parents better, additional *post hoc* analyses were conducted. First, we correlated the nighttime sleep duration within the preceding 6 months with the overall switch costs to test whether the revealed group difference can be further substantiated when using a more detailed scaling of nighttime sleep duration that exceeds a simple dichotomy. This led to a negative correlation between nighttime sleep duration and switch costs ($r = -0.21$, $P < 0.05$). The shorter the sleep at night, the higher the overall switch costs. Next, we conducted additional *t*-tests for independent measures to separately analyse the effect of chronic sleep curtailment on the two switch cost components. This revealed increased exogenous switch costs for sleep-curtailed new parents compared with non-sleep-curtailed new parents ($t_{104} = 1.84$, $P < 0.05$, one-tailed; see Table 2 and Fig. 2), whereas endogenous switch costs did not differ significantly between groups ($t < 1$). Similarly to the analysis of overall switch cost, we correlated the nighttime sleep duration within the preceding 6 months with the exogenous component of switch costs to test whether the group difference is supplemented when analysing the link between these variables on a more detailed level. Indeed, nighttime sleep duration correlated negatively with exogenous switch costs ($r = -0.18$, $P < 0.05$, one-tailed). The shorter new parents have slept at night, the higher the exogenous switch costs. Third, we tested whether new mothers and new fathers differed with regard to the revealed group difference in switch costs. For that, we repeated the ANOVA with the additional between-subject factor gender. The important interaction between the factors task transition and sleep curtailment was confirmed ($F_{1,102} = 6.19$, $P < 0.05$, $\eta^2 = 0.06$), but was not modulated by gender ($F < 1$). Finally, to test whether subjectively perceived cognitive potential and objectively measured performance correspond, we conducted a *post hoc* correlation analysis on self-reported subjective cognitive capability and switch costs, which did not reveal a link between these factors ($r = -0.10$, $P = 0.31$).

Error rates

Task-switching performance

Error rates showed significant main effects of task transition (switch: 8.94%, repetition: 4.95%; $F_{1,104} = 61.06$, $P < 0.001$, $\eta^2 = 0.37$), CTI (short: 7.45%, long: 6.44%; $F_{1,104} = 8.84$, $P < 0.01$, $\eta^2 = 0.08$) and target congruency (incongruent: 10.39%, congruent: 3.50%; $F_{1,104} = 79.10$, $P < 0.001$, $\eta^2 = 0.43$). Moreover, the ANOVA revealed a significant two-way interaction between task transition and target congruency, with increased switch costs for incongruent targets (5.98%) compared with congruent targets (2.00%; $F_{1,104} = 26.46$, $P < 0.001$, $\eta^2 = 0.20$). All further task-switching-specific interactions refrained from significance.

Effects of chronic sleep curtailment on task-switching performance

With respect to the research question addressed, neither the main effect of sleep curtailment on error rates nor any interaction of sleep curtailment with one or more of the other factors was significant.

DISCUSSION

The present study is the first that links chronic sleep curtailment with the ability to flexibly adapt to changing environmental demands. A randomly selected, representative group of new parents conducted an explicit-cuing version of the task-switching paradigm. Performance of new parents reporting to have slept <7 h per night on average over the preceding 6 months (sleep-curtailed group) was contrasted to performance of new parents reporting at least 7 h of average nighttime sleep duration (non-sleep-curtailed group; cf. Banks and Dinges, 2007; Durmer and Dinges, 2005). RT analysis revealed increased switch costs for sleep-curtailed new parents in comparison to non-sleep-curtailed new parents. This switch costs difference between the two groups cannot be attributed to a general response slowing, as mean RT levels were similar. Therefore, sleep-curtailed new parents showed a decreased ability to flexibly implement task goals in order to switch tasks in a fast-changing environment.

Importantly, this finding was not only found at the group comparison level, but was additionally confirmed by a negative correlation between the self-reported average nighttime sleep duration over the preceding 6 months and the amount of switch costs: The less time new parents reported to have slept at night, the more they were impaired in the flexible task goal implementation, as reflected in increased switch costs.

The version of the task-switching paradigm used in the present study allows further elaboration of the observed switch costs difference and therefore the processes affected (e.g.

Table 2 Response times (ms) for sleep-curtailed and non-sleep-curtailed new parents, respectively

	Sleep-curtailed new parents (n = 46)			*Non-sleep-curtailed new parents* (n = 60)		
	Switch	*Repetition*	*Switch costs**	*Switch*	*Repetition*	*Switch costs*
Overall	1167 (350)	885 (225)	282 (193)	1080 (254)	876 (198)	203 (131)
Short CTI	1271 (366)	937 (236)	334 (194)	1188 (245)	945 (216)	243 (145)
Long CTI	1064 (353)	833 (227)	231 (231)	969 (278)	809 (199)	161 (160)
Endogenous component†			103 (179)			82 (164)
Exogenous component‡			231 (231)			161 (160)

CTI, cue–target interval.
Values are given as means (SD).
*Calculated as difference between switch trials and repetition trials.
†Calculated as difference between switch costs in trials with short CTI and switch costs in trials with long CTI.
‡Corresponds to switch costs in trials with long CTI.

Rogers and Monsell, 1995; Rubinstein *et al.*, 2001). Manipulating the preparation time allowed differentiation of two switch cost components. Preparation-dependent switch costs (i.e. endogenous switch cost component) reflect cognitive control processes that allow first steps towards the implementation of a new task goal before the target stimulus is presented (e.g. Meiran, 2000; Rogers and Monsell, 1995). Preparation-independent switch costs (i.e. exogenous switch cost component), however, are assumed to result from additional cognitive control processes, which occur only after presentation of the target stimulus (Rogers and Monsell, 1995). The nature of these processes is currently debated. Exogenous switch costs are proposed to represent a second process necessary to implement the current task goal, such as a process of task rule activation (Rubinstein *et al.*, 2001; see also Allport *et al.*, 1994; Meiran, 2000; Schuch and Koch, 2003 for a critical discussion). Alternatively, exogenous switch costs may reflect cognitive control processes dealing with interference due to the currently irrelevant task (for a broad discussion of possible interference effects in task-switching situations, see Kiesel *et al.*, in press). Our results showed that chronic sleep curtailment affected only preparation-independent but not preparation-dependent switch costs. Moreover, the link between chronic sleep curtailment and preparation-independent switch costs was supplemented by a negative correlation between these variables. The less new parents reported to have slept at night during the preceding 6 months, the higher these preparation-dependent costs. Thus, the revealed impairment of flexible task goal implementation in sleep-curtailed new parents, compared with non-sleep-curtailed new parents, seems to be mainly due to decrements in cognitive control processes that proceed after the current task is fully specified by the presentation of the target.

The results of the present study further show that increased switch costs in sleep-curtailed new parents cannot simply be attributed to higher stimulus-based interference from the currently irrelevant task. This conclusion can be derived by investigating the TCE, the performance difference between targets that require the same response for both tasks and targets that require different responses for each task (e.g. Kiesel *et al.*, 2007). Our results reveal no evidence for changes in stimulus-based interference in sleep-curtailed new parents compared with normally sleeping new parents, as the TCE is similar in both groups. The observed performance difference between sleep-curtailed and non-sleep-curtailed new parents can also not be solely attributed to changes in hormone levels due to pregnancy, lactation or gender. First, it is likely that both groups experienced similar physiological changes (e.g. hormonal changes) as they all were new parents with infants at the same age. Second, a *post hoc* analysis clearly showed that the effect of sleep curtailment on switch costs was not mediated by gender. Further, sleep-curtailed and non-sleep-curtailed new parents showed similar durations of daytime naps. Thus, the sleep-curtailed group did not compensate for insufficient nighttime sleep duration. The absolute group difference in average nighttime sleep duration therefore directly reflects the absolute group difference in overall sleep. Moreover, sleep-curtailed and non-sleep-curtailed new parents did not differ in respect to the average number of nighttime awakenings over the preceding 6 months, indicating that self-reported sleep quantity contributes to an understanding of the observed performance difference more than subjectively perceived sleep quality. Both mood and chronic stress were ruled out as potential confounders for the revealed performance difference between sleep-curtailed and non-sleep-curtailed new parents as their self-reported levels did not differ. Additionally, sleep-curtailed new parents did not report more daytime sleepiness than non-sleep-curtailed new parents.

An interesting additional observation of the present study is a discrepancy between subjectively perceived performance potential and objectively measured performance level. Although sleep-curtailed new parents showed significantly worse performance in a situation that requires flexible behavioural adaptation to environmental changes in terms of switching between different task goals than non-sleep-curtailed new parents, both groups rated their cognitive capability on a comparable level. This leads to the assumption that the chronically sleep-curtailed new parents are not aware of their cognitive impairments. This conclusion is supplemented by the fact that a *post hoc* analysis revealed no correlation between subjectively perceived cognitive capability and objectively assessed switch costs.

In sum, the present study contrasted new parents reporting chronic sleep curtailment over the preceding 6 months and new parents who obtained sufficient nighttime sleep within the same period regarding their ability to flexibly implement task goals when indicated by changing environmental demands. For the first time, we provide evidence for impairments of executive functions that serve the flexible adaptation to changing environmental demands in chronically sleep-curtailed new parents. Thereby, we directly address the gap between the fact that chronic sleep curtailment has become a major concern for health in modern Western societies and the lack of research about potential effects on cognitive key abilities required for a successful management of novel situations. Our results show that not only acute total sleep loss in a laboratory setting is able to impair executive functions but that significant decrements can also be observed with chronic sleep curtailment under real-life conditions. This is of even greater importance as in the present study sleep reduction was only moderate (sleep-curtailed new parents: 5.86 h; non-sleep-curtailed new parents: 7.27 h). Our findings contradict studies that claim an insensitivity of higher cognitive functions to influences of acute total sleep loss (e.g. Binks *et al.*, 1999). Some authors even argue that particularly difficult tasks may trigger compensatory mechanisms in response to acute total sleep loss (e.g. Drummond *et al.*, 2005). In this context it is feasible that in the present study of chronic sleep curtailment adaptive and/or compensatory mechanisms were either insufficient or even absent.

The results of this study might be of particular interest for individuals who experience high work demands on an everyday basis and need to constantly rely on fast and flexible goal shifting and cognitive control while, at the same time, often suffering from chronic sleep curtailment (e.g. doctors, workers in crisis management, members of the armed forces). Finally, our study provides promising perspectives for further research on cognitive effects of chronic sleep curtailment as the investigation of new parents, as a model of chronic sleep curtailment, appears to be useful for this research agenda. As a fairly new approach it leaves room for further improvement. First, future investigations should monitor the effects of chronic sleep curtailment in a longitudinal design that allows capture of sleep durations without memory bias with a more detailed temporal resolution. Second, inter-individual differences in sleep need should ideally be assessed by respective documentation of parents' sleep behaviour before the birth of the baby. In addition, objective measurements of sleep (i.e. actigraphy) should be employed. While the control group studied here (new parents who do not suffer from chronic sleep curtailment) allowed control of a number of potential confounders (e.g. hormone levels), it would also be interesting to include individuals who are not currently challenged by parenthood. These experiments are currently being conducted in our laboratory, with data becoming available within the next 3 years.

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REFERENCES

Allport, D. A., Styles, E. A. and Hsieh, S. Shifting intentional set: exploring the dynamic control of tasks. In: C. Umilta and M. Moscovitch (Eds) *Conscious and Nonconscious Information Processing: Attention and Performance XV*. MIT Press, Cambridge, 1994: 421–452.

Ayas, N. T., White, D. P., Manson, J. E. *et al.* A prospective study of sleep duration and coronary heart disease in women. *Arch. Intern. Med.*, 2003, 163: 205–209.

Balachandran, D. D., Ewing, S. B., Murray, B. J., LeBeau, L. and Mullington, J. M. Human host response during chronic partial sleep deprivation. *Sleep*, 2002, 25: A106–A107.

Banks, S. and Dinges, D. F. Behavioral and physiological consequences of sleep restriction. *J. Clin. Sleep Med.*, 2007, 3: 519–528.

Belenky, G., Wesensten, N. J., Thorne, D. R. *et al.* Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *J. Sleep Res.*, 2003, 12: 1–12.

Binks, P. G., Waters, W. F. and Hurry, M. Short-term total sleep deprivation does not selectively impair higher cortical functioning. *Sleep*, 1999, 22: 328–334.

Bonnet, M. H. and Arand, D. L. We are chronically sleep deprived. *Sleep*, 1995, 18: 908–911.

Burnham, M. M., Goodlin-Jones, B. L., Gaylor, E. E. and Anders, T. F. Nighttime sleep-wake patterns and self-soothing from birth to one year of age: a longitudinal intervention study. *J. Child Psychol. Psychiatry*, 2002, 43: 713–725.

Chee, M. W. L. and Chuah, Y. M. L. Functional neuroimaging and behavioral correlates of capacity decline in visual short-term memory after sleep deprivation. *Proc. Natl. Acad. Sci. USA*, 2007, 104: 9487–9492.

Chuah, L. Y. M. and Chee, M. W. L. Functional neuroimaging of sleep deprived healthy volunteers and persons with sleep disorders: a brief review. *Ann. Acad. Med. Singap.*, 2008, 37: 689–694.

Chuah, Y. M. L., Venkatraman, V., Dinges, D. F. and Chee, M. W. L. The neural basis of interindividual variability in inhibitory efficiency after sleep deprivation. *J. Neurosci.*, 2006, 26: 7156–7162.

Dinges, D. F., Pack, F., Williams, K. *et al.* Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4–5 hours per night. *Sleep*, 1997, 20: 267–277.

Drummond, S. P. A., Brown, G. G., Salamat, J. S. and Gillin, J. C. Increasing task difficulty facilitates the cerebral compensatory response to total sleep deprivation. *Sleep*, 2004, 27: 445–451.

Drummond, S. P. A., Meloy, M. J., Yanagi, M. A., Orff, H. J. and Brown, G. G. Compensatory recruitment after sleep deprivation and the relationship with performance. *Psychiatry Res. Neuroimaging*, 2005, 140: 211–223.

Durmer, J. S. and Dinges, D. F. Neurocognitive consequences of sleep deprivation. *Semin. Neurol.*, 2005, 25: 117–129.

Gay, C. L., Lee, K. A. and Lee, S.-Y. Sleep patterns and fatigue in new mothers and fathers. *Biol. Res. Nurs.*, 2004, 5: 311–318.

Goschke, T. Intentional reconfiguration and involuntary persistence in task set switching. In: S. Monsell and J. Driver (Eds) *Attention and Performance XVIII: Control of Cognitive Processes*. MIT Press, Cambridge, 2000: 331–355.

Herscovitch, J., Stuss, D. and Broughton, R. Changes in cognitive processing following short-term cumulative partial sleep deprivation and recovery oversleeping. *J. Clin. Neuropsychol.*, 1980, 2: 301–319.

Heuer, H., Kleinsorge, T., Klein, W. and Kohlisch, O. Total sleep deprivation increases the costs of shifting between simple cognitive tasks. *Acta Psychol. (Amst.)*, 2004, 117: 29–64.

Horne, J. A. Human sleep, sleep loss, and behaviour: implications for the prefrontal cortex and psychiatric disorder. *Br. J. Psychiatry*, 1993, 162: 413–419.

Jennings, J. R., Monk, T. H. and van der Molen, M. W. Sleep deprivation influences some but not all processes of supervisory attention. *Psychol. Sci.*, 2003, 14: 473–479.

Johns, M. W. A new method for measuring daytime sleepiness: the Epworth Sleepiness Scale. *Sleep*, 1991, 14: 540–545.

Kiesel, A., Steinhauser, M., Wendt, M. *et al.* Control and interference in task switching – a review. *Psychol. Bull.*, in press.

Kiesel, A., Wendt, M. and Peters, A. Task switching: on the origin of response congruency effects. *Psychol. Res.*, 2007, 71: 117–125.

Koch, I. Automatic and intentional activation of task sets. *J. Exp. Psychol. Learn. Mem. Cogn.*, 2001, 27: 1474–1486.

Kripke, D. F., Garfinkel, L., Wingard, D. L., Klauber, M. R. and Marler, M. R. Mortality associated with sleep duration and insomnia. *Arch. Gen. Psychiatry*, 2002, 59: 131–136.

Lee, K. A. Alterations in sleep during pregnancy and postpartum: a review of 30 years of research. *Sleep Med. Rev.*, 1998, 2: 231–242.

Logan, G. D. Executive control of thought and action: in search of the wild homunculus. *Curr. Dir. Psychol. Sci.*, 2003, 12: 45–48.

McCarthy, M. E. and Waters, W. F. Decreased attentional responsivity during sleep deprivation: orienting response latency, amplitude, and habituation. *Sleep*, 1997, 20: 115–123.

Meijer, A. M. and van den Wittenboer, G. L. H. Contribution of infants' sleep and crying to marital relationship of first-time parent couples in the 1st year after childbirth. *J. Fam. Psychol.*, 2007, 21: 49–57.

Meiran, N. Reconfiguration of processing mode prior to task performance. *J. Exp. Psychol. Learn. Mem. Cogn.*, 1996, 22: 1423–1442.

Meiran, N. Modeling cognitive control in task-switching. *Psychol. Res.*, 2000, 63: 234–249.

Miller, E. K. and Cohen, J. D. An integrative theory of prefrontal cortex function. *Annu. Rev. Neurosci.*, 2001, 24: 167–202.

Muzur, A., Pace-Schott, E. F. and Hobson, J. A. The prefrontal cortex in sleep. *Trends Cogn. Sci.*, 2002, 6: 475–481.

National Sleep Foundation. *Sleep in America Poll*, 2008. Available at: http://www.sleepfoundation.org (accessed 20 September 2009).

Nyström, K. and Öhrling, K. Parenthood experiences during child's first year: literature review. *J. Adv. Nurs.*, 2004, 46: 319–330.

Price, S., McKenry, P. and Murphy, M. (Eds) *Families Across Time: A Life Course*. Roxbury, Los Angeles, 2000.

Rogers, R. D. and Monsell, S. Costs of a predictable switch between simple cognitive tasks. *J. Exp. Psychol. Gen.*, 1995, 124: 207–231.

Rogers, N. L., Price, N. J., Mullington, J. M., Szuba, M. P., Van Dongen, H. P. and Dinges, D. F. Plasma cortisol changes following chronic sleep restriction. *Sleep*, 2000, 23: A70–A71.

Rubinstein, J. S., Meyer, D. E. and Evans, J. E. Executive control of cognitive processes in task switching. *J. Exp. Psychol. Hum. Percept. Perform.*, 2001, 27: 763–797.

Schuch, S. and Koch, I. The role of response selection for inhibition of task sets in task shifting. *J. Exp. Psychol. Hum. Percept. Perform.*, 2003, 29: 92–105.

Schulz, P., Schlotz, W. and Becker, P. *Trierer Inventar zum Chronischen Stress.* Hogrefe, Göttingen, 2004.

Spiegel, K., Leproult, R., Tasali, E., Penev, P. and van Cauter, E. Sleep curtailment results in decreased leptin levels and increased hunger and appetite. *Sleep*, 2003, 26: A174.

Stenuit, P. and Kerkhofs, M. Effects of sleep restriction on cognition in women. *Biol. Psychol.*, 2008, 77: 81–88.

Tsai, L.-L., Young, H.-Y., Hsieh, S. and Lee, C.-S. Impairment of error monitoring following sleep deprivation. *Sleep*, 2005, 28: 707–713.

Van Dongen, H. P. A., Maislin, G., Mullington, J. M. and Dinges, D. F. The cumulative cost of additional wakefulness: dose–response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*, 2003, 26: 117–126.

Vandewalle, G., Archer, S. N., Wuillaume, C. *et al.* Functional magnetic resonance imaging-assessed brain responses during an executive task depend on interaction of sleep homeostasis, circadian phase, and PER3 genotype. *J. Neurosci.*, 2009, 29: 7948–7956.

Watson, D., Clark, L. A. and Tellegen, A. Development and validation of brief measures of positive and negative affect: the PANAS scales. *J. Pers. Soc. Psychol.*, 1988, 54: 1063–1070.