Toddler's self-regulation strategies in a challenge context are nap-dependent

ALISON L. MILLER[1], RONALD SEIFER[2], REBECCA CROSSIN[3] and MONIQUE K. LEBOURGEOIS[4]

[1]Department of Health Behavior and Health Education, The University of Michigan School of Public Health, Ann Arbor, MI, USA; [2]Department of Psychiatry and Human Behavior, The Warren Alpert Medical School of Brown University, East Providence, RI, USA; [3]DREAM Charter School, East Harlem, NY, USA; [4]Sleep and Development Laboratory, Department of Integrative Physiology, University of Colorado Boulder, Boulder, CO, USA

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Correspondence
Alison L. Miller, Department of Health Behavior and Health Education, 109 Observatory Avenue, SPH I, Room 3718, School of Public Health, University of Michigan, Ann Arbor, MI 48109-2029, USA.
Tel.: 34-615-7459;
fax: 734-615-2317;
e-mail: alimill@umich.edu

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SUMMARY

Early childhood represents a time of developmental changes in both sleep and self-regulation, a construct reflecting the ability to control one's behaviour, attention and emotions when challenged. Links between sleep and self-regulation processes have been proposed, but experimental evidence with young children is lacking. In the current study, we tested the effects of acute sleep restriction (nap deprivation) on toddlers' self-regulation. Healthy children (n = 12; four males; aged 30–36 months (33.9 $\pm$ 1.7)) slept on a strict schedule (verified with actigraphy and sleep diaries) for 5 days before each of two afternoon assessments following a nap and a no-nap condition (~11-day protocol). Children were videotaped while attempting an unsolvable puzzle, and 10 mutually exclusive self-regulation strategies were later coded. On average, children lost ~90 min of sleep on the no-nap versus the nap day. Nap deprivation resulted in moderate-to-large effects on self-regulation strategies, with decreases in scepticism (d = 0.77; 7% change), negative self-appraisal (d = 0.92; 5% change) and increases in physical self-soothing (d = 0.68; 10% change), focus on the puzzle piece that would not fit (perseveration; d = 0.50; 9% change) and insistence on completing the unsolvable puzzle (d = 0.91; 10% change). Results suggest that sleep serves an important role in the way that toddlers respond to challenging events in their daily lives. After losing daytime sleep, toddlers were less able to engage effectively in a difficult task and reverted to less mature self-regulation strategies than when they were well rested. Over time, chronically missed sleep may impair young children's self-regulation abilities, resulting in risk for social–emotional, behavioural and school problems.

INTRODUCTION

In recent years, sleep has become central to integrative, conceptual frameworks of self-regulation (Hagger, 2010). Self-regulation is the ability to control one's behaviour, cognition, attention and emotion when challenged (Heatherton and Wagner, 2011). Self-regulation strategies include behavioural and cognitive actions that function to maintain or regain such control in an effortful manner (e.g. shifting attention away from a distressing stimulus). Identifying modifiable factors influencing early self-regulation is important, as self-regulation deficits are associated with social–behavioural problems (e.g. externalizing) and school difficulties (e.g. attention problems, poor achievement) (Eisenberg *et al.*, 2010). Sleep plays a key role in the cognitive and affective processes central to self-regulation in school-age children (Sadeh *et al.*, 2002), adolescents (Baum *et al.*, 2013) and adults (Mauss *et al.*, 2012; Pilcher and Huffcutt, 1996). Less is known about younger children.

Understanding how insufficient sleep may affect self-regulation during early childhood is important, as this may inform intervention efforts to enhance developmental outcomes by improving sleep. From 2–5 years of age, total sleep duration decreases (primarily through dropping naps;

Iglowstein *et al.*, 2003), and sleep problems (e.g. bedtime resistance, night-time awakenings) are prevalent (Owens *et al.*, 2000). Essential self-regulation skills, such as persisting at difficult tasks and using distraction and/or cognitive reappraisal to manage emotions, also emerge during this period (Blair *et al.*, 2010). Maturing language and increased cognitive self-awareness enable development of such skills (Brownell and Kopp, 2010). Across the toddler-to-preschool transition, children move typically from physical self-regulation strategies (e.g. thumb-sucking) to verbal and cognitively mediated strategies (e.g. stating how they feel, asking for help; Grolnick *et al.*, 1996; Roben *et al.*, 2012). Children who obtain insufficient sleep may be delayed in such self-regulation milestones and at risk for later problems (Troxel *et al.*, 2013).

Inadequate sleep may reduce self-regulation capacity (Hagger, 2010). Controlled studies of school-age children found that sleep restriction impaired observed (Sadeh *et al.*, 2002) and teacher-reported (Gruber *et al.*, 2012) attention, a cognitive self-regulation skill. Sleep is suggested as critical for the development of executive functioning skills such as working memory, behavioural inhibition and attention that enable self-regulation (Touchette *et al.*, 2008; Turnbull *et al.*, 2012), but the few extant studies in younger children are correlational and span a wide age range (Bernier *et al.*, 2010; Touchette *et al.*, 2008). Quasi-experimental work examining behavioural self-regulation in 14-month-olds indicated that less daytime sleep was related to greater negative affect and less mature self-regulation strategies (e.g. self-soothing; Ross and Karraker, 1999), and our experimental work with toddlers confirmed that missing one afternoon nap increased negative facial emotion displays (Berger *et al.*, 2012). Well-controlled studies of sleep and self-regulation in young children are scarce, yet critical for a mechanistic understanding of how insufficient sleep may lead to self-regulation difficulties over this unique period, when children are transitioning from primarily behavioural and parent-mediated self-regulation to cognitively and verbally mediated strategies (Brownell and Kopp, 2010). This study addresses this gap by examining experimentally the effects of acute sleep restriction via nap deprivation on observed behavioural and cognitive self-regulation strategies in 30–36-month-olds, who are developing these skills. We hypothesized that children would show less sophisticated self-regulation (e.g. more ineffective behavioural coping, less cognitive engagement) in a challenge task after missing a nap than after napping.

METHODS

Participants

Details regarding the recruitment and screening of participants have been published previously (Berger *et al.*, 2012). In general, participants were healthy, habitually napping 30–36-month-olds with no sleep or behavioural problems. For this analysis, 80 children were screened; 37 met criteria, 17 were enrolled and 12 completed the study. Incomplete assessments were due to children not sleeping during their nap opportunity on the day of the assessment, sickness or withdrawal from the study. The final sample included 12 toddlers (four males; 10 Caucasian, one African American, one mixed race) aged 30–36 months (33.9 $\pm$ 1.7 months). Four attended full-time daycare, three had in-home childcare and five were cared for exclusively by their parents.

Parents signed a Brown University Institutional Review Board (IRB)-approved consent form. Compensation paid to parents was $25 in cash. Children received small gifts (e.g. stickers, trinkets) at each home assessment and a $75 savings bond at the end of the study.

Protocol

As shown in Fig. 1, children followed a strict daytime nap and nighttime sleep schedule for $\geq$5 days ($\geq$12.5 h time in bed per 24-h day) before each of two randomly ordered in-home 'challenge task' assessments. This individualized bedtime and rise time schedule promotes stabilization of the circadian system and provides needed sleep–wakefulness consistency before the experimental manipulation (nap versus no-nap). Daily correspondence with parents via e-mail or telephone was performed to ensure compliance with study procedures. In the case of a protocol violation [i.e. accidental nap (n = 1); sleep patterns deviating >15 min from established schedule (n = 1); illness (n = 1); use of medications affecting sleep and/or alertness; caffeine consumption], challenge task assessments were rescheduled after another 5 days on the sleep schedule. Children were required to have fallen asleep during their nap opportunity $\geq$50% of days leading up to the challenge assessment. Researchers completed in-home training about study procedures (e.g. actigraphy wear and

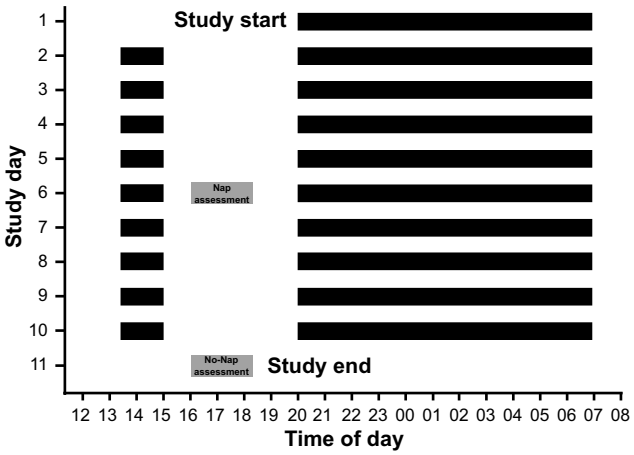

Figure 1. Sample protocol (11 days) for a child following a strict sleep schedule with a 20:00 hours bedtime, an 07:00 hours rise time and a 12:30–14:00 hours afternoon nap opportunity (12.5 h time in bed per 24-h day). Black bars represent time in bed; grey boxes represent the challenge task assessments on nap and no-nap days.

care, completing the sleep diary) with parents prior to the start of the study.

Alternate forms of the challenge task were administered on two afternoons following nap (baseline) and no-nap (sleep restriction) conditions. In order to reduce the potential influence of sleep inertia on children's self-regulation strategies, the assessment start time for both conditions was 1 h past individual children's scheduled nap wake time. Prior to assessment administration, researchers confirmed the participant's compliance with study rules and the sleep schedule by reviewing printed actograms and sleep diary entries. The in-home assessment context was then set up (i.e. child-sized table and chair, video camera).

Challenge task

Assessments were designed to present a self-regulation challenge. Children were administered an age-appropriate unsolvable board puzzle. The puzzle included one incorrect piece, which prevented task completion and simulated a frustrating event that toddlers could experience in their day-to-day lives. The challenge task was part of a larger protocol designed to elicit both positive and negative emotion responses (details provided in Berger *et al.*, 2012). We computed the percentage of time children displayed each of 10 distinct self-regulation strategies (described below).

Measures

Parent-report screening questionnaires

Child Behaviour Checklist (CBCL 1½–5). The CBCL is a 99-item assessment of early childhood internalizing and externalizing behaviour problems. T-scores are defined as within normal limits (T<60), at-risk (T = 60–69) or clinically significant (T≥70). The CBCL has adequate reliability and validity for clinical instruments (Achenbach and Rescorla, 2000).

The Children's Sleep Habits Questionnaire (CSHQ). The CSHQ is 33-item measure for screening common childhood sleep problems (Owens *et al.*, 2000). Previous findings support the use of the CSHQ as a clinical sleep screener in 2–5-year-olds (Goodlin-Jones *et al.*, 2008).

Assessment of children's sleep schedules

Our standard laboratory procedures for assessing sleep schedule compliance have been described in detail elsewhere (Berger *et al.*, 2012). In short, parents completed a sleep diary and children wore a wrist actigraph for the duration of the study. We used data from actigraphic sleep variables (i.e. lights-out time, rise time, time in bed, sleep start time, sleep end time, sleep period, sleep efficiency) to assess whether children's sleep opportunity, duration and quality differed during the 5 days before each challenge task assessment.

Observational coding of self-regulation strategies

Videotapes of children during the challenge task were coded later by trained researchers using the Observer XT software (Noldus Technologies 2007). Coders were blind to condition and trained on the self-regulation coding categories using standard methods. They consulted with an expert reviewer (AM, a developmental psychologist with observational coding expertise who was also blind to condition) for consensus-coding as needed.

Ten mutually exclusive self-regulation strategies were coded during the challenge task (described in Table 1). The percentage of time in each behaviour state was calculated and 25% of assessments were double-coded to assess reliability. Inter-rater reliability across codes using intraclass correlation coefficients (ICCs) ranged from 0.76 to 1.0, with ICCs for all but one code (self-soothing) >0.90. Self-regulation strategies were based on previous work (Berhenke *et al.*, 2011) and included actions that engaged the examiner (solicit

Table 1 Self-regulation strategies coded in challenge task

Behaviour	*Description*
Self-soothing	Child engages in bodily-directed behaviours (often repetitive; e.g. thumb-sucking, hair-twirling or lip/nail biting)
Focus on misfit piece	Child visually fixates on the misfit puzzle piece; may ignore other pieces
Disruptive behaviour	Child demonstrates aggressive or disruptive behaviours (i.e. yelling, banging, throwing, kicking, hitting)
Negative self-appraisal	Child attributes trouble completing the task to personal attributes (i.e. 'I can't do this')
Insistence on completion	Child accepts or ignores that the misfit puzzle piece does not fit – insists puzzle has been completed
Scepticism	Child makes comment that indicates that s/he knows that something is wrong with the puzzle (e.g. 'this piece doesn't go in my puzzle')
Cognitive reappraisal	Child attempts to reframe, and view puzzle situation in more positive manner (e.g. 'I never liked puzzles anyway')
Self-talk	Child talks to him/herself during the task (any type of talking or verbalization)
Solicit help	Child asks experimenter directly for help with puzzle (e.g. 'can I have a hint?')
Alternate strategies	Child uses appropriate problem-solving strategies to attempt to fit the missing piece (e.g. rotating the misfit piece in the space, looking under the table for the 'missing' puzzle piece)

help), verbal comments about the puzzle task (scepticism, cognitive reappraisal, negative self-appraisal, self-talk, insistence on completion) and predominantly non-verbal behaviours that reflected self-regulation and puzzle problem-solving approaches (physical self-soothing, focus on the puzzle piece that would not fit, disruptive behaviour, alternate problem-solving strategies). In general, we considered physical self-soothing, focusing on the piece that would not fit ('misfit piece'), disruptive behaviour, negative self-appraisal and insistence on completion as less adaptive strategies reflecting a limited capacity to cope with the challenge (listed first in Table 1). We considered scepticism, cognitive reappraisal, self-talk, soliciting help and alternate problem-solving strategies as more adaptive attempts to actively address the challenge, reflecting cognitive engagement with the task (listed second in Table 1).

Hypotheses

The overall aim of this study was to examine the effects of acute sleep restriction on toddler's self-regulation strategies in a challenge context. We hypothesized that children would use (a) more strategies reflecting ineffective coping (self-soothing, focus on the misfit piece, disruptive behaviour, negative self-appraisal, insistence on completion) and (b) fewer strategies reflecting active cognitive engagement (scepticism, cognitive reappraisal, self-talk, solicit help, alternate problem-solving strategies) in the no-nap than in the nap condition.

Analysis

Analyses were performed with the IBM spss statistics package version 21.0 (IBM Corp., Armonk, NY, USA). Repeated-measures analyses (nap versus no-nap) of continuous data (% time in self-regulation state during challenge task) were performed with paired *t*-tests. Summary statistics are presented as means and standard deviations (mean $\pm$ SD). The significance level for analyses was set at 0.05 (one-tailed tests). Effect size in SD units was computed for % time in self-regulation state mean comparisons (d = mean no-nap $-$ mean nap/SD pooled). An effect size of 0.25 was considered small, 0.50 considered medium and $\geq$0.75 considered large (Cohen, 1988).

RESULTS

Behavioural and sleep problem status

Children scored below clinical cutoffs on the CBCL internalizing (40.9 $\pm$ 7.1) and externalizing (43.8 $\pm$ 7.9) subscales. With regard to reported sleep problems, participants were below the mean of published norms from a sample of preschool children with sleep disturbance on the CSHQ total (39.0 $\pm$ 3.8) and all CSHQ subscales, including bedtime resistance (6.6 $\pm$ 0.7), sleep onset delay (1.5 $\pm$ 0.7), sleep duration (3.6 $\pm$ 0.7), sleep anxiety (4.3 $\pm$ 0.6), night waking (3.3 $\pm$ 0.7), parasomnias (6.8 $\pm$ 0.8), sleep-disordered breathing (2.0 $\pm$ 0.0) and daytime sleepiness (11.0 $\pm$ 2.2) (Goodlin-Jones *et al.*, 2008).

Protocol verification

As shown in Table 2, no differences were found between actigraphic napping and night-time sleep measures (i.e. lights-out time, rise time, time in bed, sleep start time, sleep end time, sleep period, sleep efficiency) during the 4 days before each challenge task assessment (nap versus No-nap conditions). However, nap deprivation resulted in significant changes in children's sleep period during the 24 h before each afternoon assessment. Although average bedtime, rise time, sleep start time, sleep end time and sleep efficiency on the night prior to afternoon assessments were the same, children spent less time in bed (by 113 min) and had shorter sleep periods (by 91 min) during the 24 h before no-nap than nap assessments (Table 2).

Napping patterns

Approximately 15% of daytime naps occurred at daycare or preschool, with sleep timing and duration the same as those taken at home. On average, toddlers napped the same number of days leading up to the nap and no-nap challenge assessments (3.3 days; Table 2). Furthermore, the number of days napping in both conditions was similar within individuals: 75% (n = 7) had no difference between conditions, 16% (n = 2) napped for 1 less day in the nap than the no-nap condition and 25% (n = 3) napped for 1 more day in the nap than the no-nap condition. The average difference in napping (nap $-$ no-nap) between conditions was 0.08 $\pm$ 0.67. Thus, we considered our participants 'habitual' nappers, meeting part of their regular sleep need via daytime naps.

Sleep restriction effects on self-regulation strategies

Given the small sample size, parametric and non-parametric repeated-measures test were used however, results showed identical outcomes. Thus, we present findings from the parametric tests for ease of interpretation. Acute sleep restriction had moderate-to-strong effects on some but not all self-regulation strategies children employed during the challenge task (Table 3, Fig. 2). As hypothesized, toddlers showed a decrease in scepticism in the no-nap than the nap condition (7%). Missing an afternoon nap also resulted in a 10% increase in self-soothing, a 9% increase in focus on the misfit piece and a 10% increase in insistence on completion, in comparison to after napping. Contrary to our expectation, we found a 4% decrease in negative self-appraisal for children in the no-nap compared to the nap condition. As shown in Table 3, the percentage of time that children employed different strategies varied within the nap and no-nap

Table 2 Actigraphic sleep measures during the 4 days, as well as 24 h before each challenge task assessment

	Nap		*No-Nap*		*Statistics*		
	Mean	*SD*	*Mean*	*SD*	*t*	*d*	*P*
4 days before assessments							
Daytime sleep (nap)							
Days napping (fell asleep)	3.3	0.89	3.3	0.87	–0.43	0.00	0.67
Lights-out time	13:23	0:45	13:22	0:49	0.04	0.02	0.97
Rise time	15:13	0:33	15:16	0:40	–0.23	0.08	0.82
Time in bed (min)	110.3	19.6	113.9	15.2	–10.05	0.21	0.31
Sleep start time	13:49	0:57	13:55	0:59	–0.35	0.10	0.73
Sleep end time	15:12	0:51	15:14	0:52	–0.45	0.04	0.66
Sleep period (min)	84.00	20.5	78.6	11.8	–0.49	0.32	0.63
Sleep efficiency (%)	93.4	4.9	94.1	2.8	–0.99	0.18	0.35
Nighttime sleep							
Lights-out time	19:59	0:28	20:03	0:28	–0.80	0.14	0.44
Rise time	6:51	0:27	6:53	0:25	–0.56	0.08	0.58
Time in bed (min)	651.4	40.4	650.4	39.7	0.20	0.02	0.84
Sleep start time	20:40	0:33	20:41	0:35	–0.56	0.03	0.59
Sleep end time	6:40	0:28	6:44	0:24	–0.70	0.15	0.50
Sleep period (min)	599.5	41.9	602.9	39.3	–0.48	0.08	0.64
Sleep efficiency (%)	85.2	3.8	83.4	5.0	10.93	0.41	0.08
Total 24 h sleep							
Time in bed (min)	761.7	39.7	764.4	37.5	–0.45	0.07	0.66
Sleep period (min)	682.3	40.2	681.5	33.6	–0.75	0.02	0.46
24 h before assessments							
Daytime sleep (nap)							
Lights-out time	13:16	0:41	–	–	–	–	–
Rise time	15:06	0:53	–	–	–	–	–
Time in bed (min)	110.3	20.4	–	–	–	–	–
Sleep start time	13:37	0:48	–	–	–	–	–
Sleep end time	14:58	0:55	–	–	–	–	–
Sleep period (min)	81.6	16.6	–	–	–	–	–
Sleep efficiency (%)	94.6	3.0	–	–	–	–	–
Nighttime sleep							
Lights-out time	19:55	0:30	20:00	0:24	–10.09	0.18	0.29
Rise time	7:00	0:26	7:03	0:23	–0.29	0.12	0.77
Time in bed (min)	665.3	44.3	662.6	33.8	–10.1	0.07	0.31
Sleep start time	20:33	0:47	20:31	0:30	–0.42	0.05	0.69
Sleep end time	6:51	0:30	6:54	0:31	0.59	0.10	0.57
Sleep period (min)	617.7	53.7	623.2	39.3	–0.49	0.12	0.63
Sleep efficiency (%)	87.4	5.6	84.0	7.8	10.27	0.50	0.24
Total 24 h sleep							
Time in bed (min)	761.7	39.7	662.6	33.8	110.3	20.7	0.001
Sleep period (min)	682.3	40.2	623.2	39.3	70.6	10.5	0.001

One-tailed paired *t*-tests were performed between nap and no-nap conditions.

conditions. For example, although focusing on the misfit piece was the most common strategy observed in both conditions, toddlers rarely demonstrated cognitive reappraisal or disruptive behaviour during the task.

Figure 3 shows individual variability in children's self-regulatory responses to nap deprivation. In the nap condition, we observed moderate variation (0–35%) in the percentage of time that children engaged in verbal strategies (e.g. scepticism, negative self-appraisal). In the no-nap condition, approximately half the sample showed a decrease in both these strategies. Individual variability in self-soothing and focus on the misfit piece was considerable (0–60%), with some children showing dramatic changes and others exhibiting no change or the opposite effect. Finally, when well-rested, we observed little-to-no variability (<5%) in children's insistence on completion; however, after missing a nap, one participant had a dramatic increase (this same child showed the greatest decrease in focusing on the misfit piece with nap deprivation), three showed small-to-moderate increases, while the majority exhibited no change between conditions.

DISCUSSION

Self-regulation has been conceptualized as a limited resource that requires energy, similar to a muscle (Heatherton and Wagner, 2011). Sleep may be critical for the

Table 3 Percent time toddlers exhibited self-regulation strategies during the unsolvable puzzle (challenge) task (n = 12)

	Nap		*No-Nap*		*Statistics*		
	M	*SD*	*M*	*SD*	*t*	*d*	*P*
Self-Soothing	7.3	12.1	17.5	17.2	−2.41	0.68	0.017
Focus on Misfit Piece	17.5	15.6	26.5	20.4	−1.66	0.50	0.046
Disruptive Behavior	0.0	0.0	0.3	0.7	−1.41	0.59	0.092
Negative Self-Appraisal	6.7	8.5	2.4	5.1	2.54	0.93	0.014
Insistence on Completion	0.7	1.4	11.2	16.2	−2.15	0.91	0.028
Skepticism	12.9	11.4	5.8	6.2	2.32	0.77	0.020
Cognitive Reappraisal	0.2	0.7	0.6	1.2	−0.62	0.13	0.270
Self-Talk	7.0	9.2	5.6	7.1	0.54	0.17	0.300
Solicit Help	2.6	4.0	1.2	2.0	1.04	0.44	0.161
Alternate strategies	7.8	7.1	8.5	11.6	−0.18	0.07	0.427

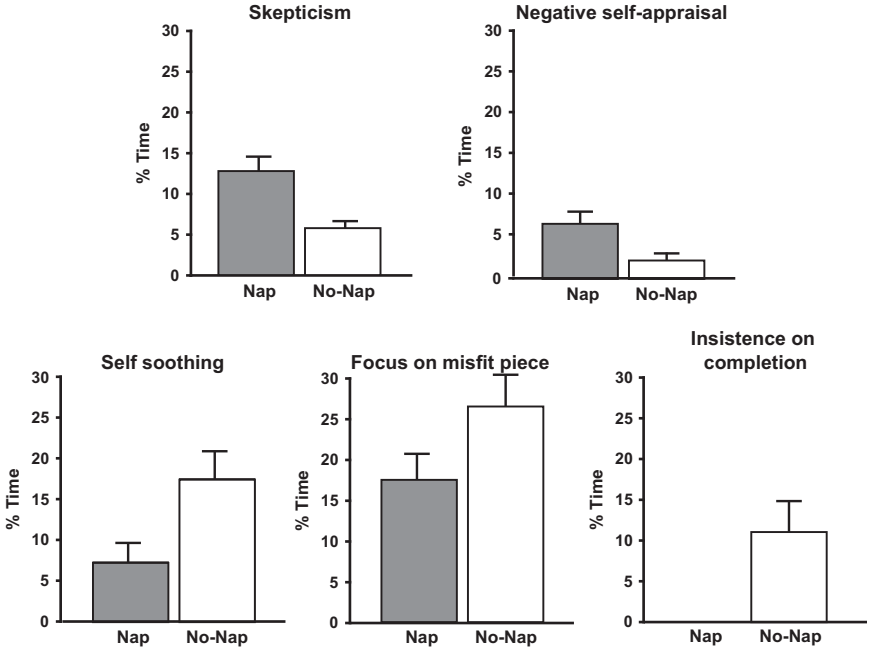

Figure 2. Differences in children's mean self-regulation responses (percentage of time exhibiting the self-regulation behaviour) between nap and no-nap conditions. One-tailed paired *t*-tests ($P < 0.05$).

development of self-regulation skills and their effective use. As proposed by Hagger (2010), prolonged wakefulness may reduce the capacity for self-regulation, which can then be restored through sleep. In this study, we employed a well-controlled experimental design to examine the effects of acute sleep restriction on young children's self-regulation strategies in a challenge context. We found support for our hypothesis that removing one daytime nap would lead to changes in observed self-regulation strategies related to cognitive engagement with the task, and in the skills needed to cope with challenge. Specifically, in our sample of healthy, good-sleeping 30–36-month-olds, eliminating one afternoon nap caused decreases in scepticism and negative self-appraisal and increases in physical self-soothing, focus on the misfit piece and insistence that the child had completed an impossible puzzle. Findings suggest that inadequate sleep promotes children using less active cognitive engagement and more immature coping strategies when presented with a challenging task. Results are discussed with regard to the role of sleep for self-regulation of cognitive, behavioural and emotion processes associated with adaptation and school readiness in early childhood.

Cognitive engagement decreases with sleep restriction

Self-regulated learning involves cognitive, motivational and self-evaluative components (Pintrich and De Groot, 1990). Evaluating one's strengths and weaknesses is an important metacognitive strategy, appearing as early as at age 3 years (Whitebread *et al.*, 2009). We found that nap deprivation resulted in less scepticism, a behaviour indicating that children were cognitively engaged enough to realize that something was wrong with the puzzle and comment to the examiner. Although we hypothesized that negative self-appraisal statements would increase with sleep restriction, we found the opposite. Considering negative self-appraisal

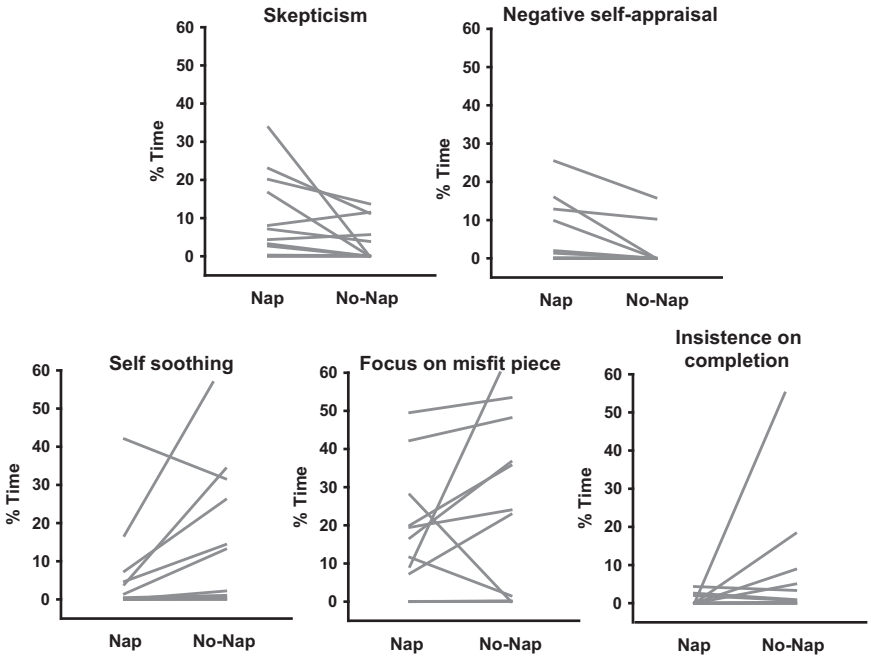

Figure 3. Individual differences in children's self-regulation strategies in the nap and no-nap conditions.

as a realistic self-evaluation of performance, however, this finding makes sense. Although toddlers are not yet capable of engaging in high-level metacognitive reflections, they have the rudimentary ability to evaluate the situation and their own performance appropriately. Studies of preschoolers suggest that such task-relevant 'private speech' during challenging tasks reflects externally displayed metacognitive processes, and predicts better academic achievement (Manning *et al*., 1994; Winsler *et al*., 2011) and classroom adjustment (Winsler *et al*., 2011). Here, when children had not napped, they were less likely to state that the puzzle was 'faulty' (scepticism) or to evaluate their own abilities realistically (negative self-appraisal). These findings suggest that even missing one nap has a negative effect on these important metacognitive self-regulation processes.

Consistent with previous findings in older children and adolescents (Fallone *et al*., 2001; Randazzo *et al*., 1998), sleep restriction did not cause changes in all observed toddler self-regulation behaviours, perhaps suggesting differential effects on higher- versus lower-order cognitive skills (Gomez *et al*., 2011). Our findings suggest that sleep restriction reduced children's higher-level metacognitive abilities to evaluate the puzzle task appropriately as too difficult, but may not have interfered as much with their propensity to simply keep working on the task (i.e. problem-solving) or to talk about it (i.e. self-talk, reappraisal). The level of sophistication in problem-solving and self-talk increases dramatically from 2 to 3 years of age, so the effects of missing sleep on such behaviours may become more pronounced with development. Of note, many of the self-regulation behaviours we assessed probably also reflect children's underlying executive functioning capabilities such as attention and working memory, which have been shown to be impaired under poor sleep conditions in older children (Sadeh *et al*., 2002; Steenari *et al*., 2003). Sleep is suggested increasingly as being critical for executive functioning skills, even in very young children (Gomez *et al*., 2011; Kopasz *et al*., 2010; Turnbull *et al*., 2012). Although we did not assess memory or other executive functioning domains, such skills may be an important mechanism underlying the association of sleep deprivation and poor observed self-regulation as we saw in the current study; future work in this area is warranted.

More use of immature coping strategies with sleep restriction

Previous experimental studies indicate that sleep restriction increases negative mood in children (Berger *et al*., 2012) and adolescents (Baum *et al*., 2013), and that sleep deprivation can increase perceived stress (Minkel *et al*., 2012). Furthermore, adults reporting poorer sleep quality are less likely to use cognitive reappraisal strategies in response to an emotional challenge (Mauss *et al*., 2012). We extend these findings by showing that missing one daytime nap increased physical self-soothing, a less mature strategy than verbally mediated responses in toddlers (Grolnick *et al*., 1996). Verbal skills are foundational for effective self-regulation; children who can verbalize their feelings may manage challenging situations more effectively (Roben *et al*., 2012). We also found that, when sleep-restricted compared to well-rested, toddlers tended to maintain a perseverative focus on the misfit puzzle piece and insist that the puzzle had been completed even though it had not been. Most definitions of adaptive self-regulation emphasize shifting strategies to suit the context or situation at hand (e.g. McClelland and Cameron, 2012; Wrosch *et al*., 2003) while appropriately

ignoring irrelevant stimuli (MacCoon *et al.*, 2004; Posner and Rothbart, 2000); perseveration thus represents a less adaptive strategy. Over time, persistent use of ineffective strategies, coupled with not verbalizing for help from peers or caregivers, may increase children's risk for academic and social–behavioural difficulties.

Variability in sleep restriction effects

We found notable variation among individuals in behaviours reflecting cognitive engagement (scepticism, negative self-appraisal) in the well-rested condition; that is, children ranged in their levels of these behaviours in this condition. We found less variability between children in the no-nap condition; most children decreased in these behaviours when sleep-restricted. The opposite pattern emerged for coping behaviours (self-soothing, focus on misfit piece, insistence on completion), with greater variability in the no-nap condition. These differences in patterns of variability in response to the manipulation are intriguing, and suggest that it may be important in future work with larger samples to consider not only overall response to insufficient sleep, but also individual characteristics of children (e.g. temperament; Troxel, 2013) that may determine their sensitivity to insufficient sleep.

Implications

Our experimental findings have important implications for understanding links between insufficient sleep, self-regulation, social–emotional functioning and learning. When toddlers skipped just one afternoon nap of ~90 min and were asked to complete an unsolvable puzzle, we observed decreased metacognitive comments and increased immature strategies. Little is known about how poor sleep may affect the development of self-regulation over time (Bernier *et al.*, 2010). Our puzzle task approximates situations that children may encounter at school; it is worth considering whether children who obtain chronically inadequate (daytime and/or night-time) sleep also demonstrate self-regulation difficulties in real-world contexts. Sleep restriction appears to affect the very skills children need to succeed at school. Children who cannot remain cognitively engaged or realistically evaluate their own performance, or become upset and frustrated when challenged, are less likely to learn effectively in busy classroom settings with many distractions (McClelland and Cameron, 2012). If children chronically miss sleep, they may also struggle to initially acquire or retain the information to which they are exposed (Gomez *et al.*, 2011; Kopasz *et al.*, 2010). These are at least two specific pathways through which chronic sleep deprivation may result in poor self-regulation and impaired learning skills and ultimately lower academic achievement. More research on sleep and the specific mechanisms and brain circuitry associated with self-regulation of cognition, behaviour and emotion would elucidate these processes more clearly.

Limitations and future directions

As with all research, the current study had limitations. First, although our puzzle task appeared to challenge our participants, it was conducted in a laboratory-type format in the home, and thus was not highly naturalistic. It would be valuable to examine how sleep restriction affects child behaviour in real-world settings, which may pose greater self-regulation challenges. Secondly, our overall design precluded the ability to balance the nap and no-nap conditions for this study (seven of 12 children in the final analysis received the nap condition first). We found no order effects on any outcomes, but the study is likely underpowered to detect such effects. Additionally, our sample size was small. Although the experimental design is a strength, and large nap-dependent effects on self-regulation were observed, future studies using larger samples are needed to confirm our results and to understand individual sensitivity to sleep loss in early childhood. Finally, findings may not be widely generalizable, as our sample consisted of good sleepers with few behaviour problems, which was necessary given protocol demands but may not be the norm for very young children (Owens *et al.*, 2000). We only examined napping, and it is important to consider whether other forms of sleep restriction would have similar effects. Examining how acute sleep restriction affects self-regulation among children with chronic sleep difficulties and determining the longitudinal impact of early sleep restriction on developmental outcomes are important areas of future research.

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AUTHOR CONTRIBUTIONS

AM conceptualized and designed the study, drafted the initial manuscript, interpreted the results, reviewed and revised the manuscript drafts and approved the final manuscript. RS conceptualized and designed the study, provided data analytical support, reviewed and revised the manuscript drafts and approved the final manuscript. RC coded the data for the study and approved the final manuscript. MKL conceptualized and designed the study, analysed the data, interpreted the results, reviewed and revised the manuscript drafts and approved the final manuscript.

CONFLICT OF INTEREST

No conflicts of interest declared.

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