Child temperament influences the association between sleep and cognition

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Research Master's thesis, November 2012

Developmental Psychopathology in Education and Child Studies

Faculty of Social and Behavioral Sciences

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Abstract

This study examined whether temperament is a moderator of the association between sleep duration and the cognitive functions alertness, inhibition, and working memory in 130 children (56 boys and 74 girls) aged 9 to 11 years. The children completed a short 3-min version of the Psychomotor Vigilance Task (PVT), a GoNogo task and a visual Digit Span test. Furthermore, a questionnaire regarding temperament (EATQ-R) was filled out by the children. Parents kept a sleep log for a week. ANCOVA results showed that the relation between average sleep duration on weekdays and alertness (PVT mean reaction time (RT) and PVT number of lapses) was moderated by the temperament traits extraversion ($p_{\text{PVT\_RT}}$ = .030, η^2 = .05; $p_{\text{PVT\_lapses}}$ = .076, η^2 = .03) and negative affectivity ($p_{\text{PVT\_RT}}$ = .039, η^2 = .04; $p_{\text{PVT\_lapses}}$ = .057, η^2 = .04). Relatively high levels of extraversion or low levels of negative affectivity were associated with more adverse effects of inadequate sleep on alertness. For inhibition and working memory this effect was not found. No significant interaction effects appeared for the other temperament traits: effortful control and affiliativeness. We conclude that the sensitivity for sleep related cognitive decrements in children can be partly explained by differences in temperamental traits.

Keywords: children, sleep duration, temperament, alertness, inhibition, working memory

Introduction

There is substantial evidence for an association of sleep duration with cognitive performance (Astill et al., 2012) and educational achievement in children (Dewald et al., 2010). Studies employing an experimental curtailment of sleep in children (Carskadon et al., 1981; Sadeh et al., 2003) indicate that a complete deprivation of sleep during one single night, as well as a small but ‘chronic’ sleep reduction of less than one hour per night, can both affect task performance, but experimental studies are scarce so far. Longitudinal studies indicate that a period of relatively short sleep during childhood relates to worse performance on tasks several years later in development, even when sleep had normalized during the last years before cognitive assessment (Friedman et al., 2009; Touchette et al., 2007).

The cognitive domains which have been found associated with short sleep in children are mainly confined to the executive function domain, which comprises functions necessary for an individual to adapt to changing situations that require creativity, flexibility, self-control, and discipline (Diamond & Lee, 2011). This corroborates previous findings that sleep deprivation induces altered activation patterns in the prefrontal cortex (Goel et al., 2009), a brain region highly involved in executive functioning. The range of function domains that are sensitive to sleep curtailment seems more restricted in children than in adults. For instance, in adults sleep plays an important role in the consolidation, enhancement, and reorganization of relevant neural networks and homeostatic downscaling of irrelevant synaptic connections, processes that are essential to explicit memory (e.g., Diekelmann & Born, 2010). However, recent meta-analytic findings suggest that these processes seem to rely less on sleep in children (Astill et al., 2012). Even more surprising, sustained attention, which is the capacity to remain attentive and respond to stimuli for a prolonged period of time, is a very sensitive cognitive domain for sleep deprivation in adults, but was not found related to short sleep in children. This is possibly due to an incomplete development of connectivity between different brain networks involved in sustained attention (Astill et al., 2012).

These findings are highly relevant given that approximately one out of three children suffers from sleep problems (Fricke-Oerkermann et al., 2007; Mindell & Meltzer, 2008), the considerable decline in sleep duration in children over the last decennia (Matricciani et al., 2012), and the current rapid increase in the use of electronic devices that compromise sleep when used in the evening, such as computers, televisions, and mobile phones (Cain & Gradisar, 2010). An important step that needs to be taken with regard to research on sleep and cognition is to unravel which human characteristics predict high sensitivity for cognitive decrements in relation to short sleep. This is particularly relevant in children, since any stagnation in the course of child development can have extensive consequences.

One important psychological domain that might predict increased sensitivity for sleep-related decrements in cognitive performance is temperament. Temperament is the innate inclination to behave in particular ways, which is relatively stable across various kinds of situations and over the course of time (Zentner & Bates, 2008). Different approaches for temperament classifications exist, based upon various theories, and leading to different temperamental dimensions. However, there are some common traits that recur in different models, such as the proneness to experience feelings of fear, anger, and sadness (negative affectivity), or the ease with which a child approaches novel stimuli or situations (extraversion). There is a considerable theoretical basis, based upon which moderation of the sleep-cognition relation by temperament can be assumed. It is well known that sleep restriction induces a drop in physiological arousal level (Cote et al., 2008). Arousal levels that are too low (or too high) are disadvantageous to achieve efficient information processing by the brain (Aston-Jones & Cohen, 2005; Yerkes & Dodson, 1908). That might hold in particular for tasks requiring constant alertness due to high time-on-task demands and for tasks with high-task complexity. In such conditions with high task demands, combined with low arousal, the system falls short in accomplishing the necessary energetic adjustments in effort to increase arousal or activation and, thereby, to achieve efficient task performance (Sanders, 1983).

The foregoing implies that sleep restriction could particularly affect individuals with low intrinsic arousal levels, since sleep restriction lowers their arousal levels to even lower and - thus - more detrimental levels. In contrast, individuals with high arousal levels might theoretically even benefit from sleep restriction, since their high arousal level might decrease to a more optimal level. There are individual differences in basic physiological arousal level which are related to particular temperamental traits. It has been shown that resting state electroencephalogram (EEG) alpha activity was positively related to extraversion scores, which suggests that extraverted individuals are cortically less aroused than introverts (Hagemann et al., 2009). Hence, extraverts might show marked performance decrements after sleep restriction, while this effect might be less pronounced or absent in introverts. In line with this, Taylor and McFatter (2003) found that extravert adults typically show greater cognitive and psychomotor impairments than introverts after a period of sleep deprivation. Two subsequent studies in adults (Killgore et al., 2007; Rupp et al, 2010) also found that the temperament trait extraversion compared to introversion was associated with more negative consequences after sleep deprivation (i.e., greater declines in psychomotor vigilance test (PVT) response speed and more frequent lapses of attention). This indicates that individual differences in extraversion can partly explain variation in the vulnerability to adverse effects of sleep deprivation on vigilance.

Furthermore, temperamental differences, for instance in negative affectivity, entail variation of subjective emotional experiences during the day, and might therefore alter the need for (Rapid Eye Movement) sleep to reprocess the information in the brain (Walker & Van der Helm, 2009). Although individuals with high neuroticism show equal sleep durations compared to low neurotic persons (Soehner et al., 2007), their levels of daytime sleepiness are generally higher (Gau, 2002), which suggests an increased need for sleep. Further, children with a lower vagal tone (i.e., less adaptive physiological regulation and higher emotional reactivity) were more vulnerable to problem behavior related to sleep problems (El-Sheikh et al., 2007). However, previous studies in adults did not find that individual differences in neuroticism were related to performance differences induced by sleep deprivation (Killgore et al., 2007; Taylor & McFatter, 2003). Hence, findings are inconsistent and scarce so far.

The present study is the first to investigate possible moderation of sleep-cognition associations by different temperamental traits in children. The study focuses on the cognitive domains alertness, inhibition, and working memory, which are essential to higher order functioning and that form the foundation for learning processes in children (Brock et al., 2009). Although alertness has not been found associated with sleep duration in the general child population (Astill et al., 2012), it is included as outcome measure in this study since we hypothesize that the association may be relevant for particular temperamental subgroups. We further hypothesize that short sleep is particularly related to worse task performance in children showing high levels of negative affectivity or extraversion. For other temperamental traits, the analyses are explorative since theory-driven hypotheses are not yet apparent.

Method

Participants

One hundred thirty children (56 boys and 74 girls) and their parent(s) participated in the study. The mean age of the children was 10.5 years (range 9-11 years, SD = 0.8). Children 12 years or over were excluded since sleep-wake rhythm changes dramatically during pubertal development (Sadeh et al., 2009). Almost all children had a Dutch nationality (97%), the remaining 3% was of European, Asian, or African origin. The educational level of the parents was relatively high since 90% of the respondents and 84% of their partners completed higher secondary school or higher vocational education/university. Medication was used by 18 children: asthma medication (n = 11), psychostimulants for attention deficit/hyperactivity disorder (ADHD) (n = 5), melatonin (n = 1), miscellaneous (n = 3). Five children (4 boys) were excluded since they used psychostimulants and/or melatonin and these medicines are known to influence both sleep and cognitive performance. Furthermore, two girls previously diagnosed with anxiety disorder were excluded for the same reason. In the remaining sample a number of eight parents (7%) reported that their child had ever received one or more psychiatric diagnoses (dyslexia: n = 6, miscellaneous: n = 3), and 13 (11%) of the children suffer from one or more physical diseases (asthma: n = 8, allergy: n = 4, miscellaneous: n = 5). Pubertal development was assessed using a self-report questionnaire (Dutch translation of the Pubertal Developmental Scale (Petersen et al., 1988)), resulting in a score on a four point scale (1 = no development; 2 = has just begun; 3 = is definitely underway; 4 = development is complete). In this sample, pubertal development was M = 1.54, (SD = 0.51) in girls, and M = 1.29 (SD = 0.35) in boys.

Procedure

The participants were recruited from regular primary schools across the Netherlands or through acquaintances of the researchers in the period January to June 2012. Fifty primary schools were contacted and 12 gave informed consent to cooperate in this research project (24%). Thereupon, parents of children aged 9 to 11 years received information about the study. Of the approached parents, 161 (13%) were willing to participate. After having received informed consent, a research week was planned in which the parent and child filled out several digital questionnaires concerning demographic data, pubertal development, sleep characteristics, temperament, and behavioural problems. Completion took approximately 30 minutes for both parent and child. Furthermore, a sleep log was kept daily by the parent, for approximately three minutes each day during the research week. In addition, the children were asked to perform a digital memory task composed of two sessions (eight minutes each) at home. On the last day of the research week, three neurocognitive tasks (PVT, PVT GoNogo, and Digit Span) were administered at school or at home (duration 30 minutes). Test order was equal for each participant. The tests were not administered before 10:00 h and not at Mondays or weekends.

Instruments

Sleep duration. A digital sleep log was kept by parents on seven consecutive nights, starting on the evening a week before the day of task administration. The sleep log contained questions on the time the lights went off, number of minutes the child needed to fall asleep (sleep onset latency, SOL), and time of morning awakening. Assumed sleep duration for weekdays was calculated (the time interval from sleep onset [lights out + SOL] until morning awakening), provided that at least three weekdays were present. Weekend data were excluded since weekend sleep usually differs from that during weekdays, and cognitive assessments in this study took place during weekdays. Parental sleep logs have shown satisfactory agreement with objective actigraphy data in children (Werner et al., 2008).

Temperament. The Early Adolescent Temperament Questionnaire–Revised (EATQ-R) is a self-report questionnaire used to measure reactive and regulative temperament traits of children and adolescents (Ellis & Rothbart, 2001). It contains 65 items that were answered on a 5-point Likert scale (ranging from almost never true to almost always true). The EATQ-R consists of four main temperament factors that each comprises various temperament scales: Extraversion/Surgency (high intensity pleasure, low levels of shyness, low levels of fear), Negative Affectivity (fear, frustration), Effortful Control (activation control, attention, inhibitory control), and Affiliativeness (affiliation, perceptual sensitivity, and pleasure sensitivity). To compose the factor Effortful Control three items (39, 41, 63) were excluded according to a Dutch study (Hartman, 2000) in which it was found that the three separate scales activation control, attention, and inhibitory control were unreliable. However, other studies showed that the psychometric properties of the EATQ-R were acceptable (Ellis & Rothbart, 2001; Muris & Meesters, 2009). The internal consistency for the four temperament factors was calculated and they were acceptable: Extraversion/Surgency (α = .74), Negative Affectivity (α = .75), Effortful Control (α = .82), and Affiliativeness (α = .71).

Tasks

Psychomotor Vigilance Task (PVT). A three minute version of the PVT was used to assess alertness (Basner et al., 2011). Participants were instructed to monitor a square on the computer screen, and to press a button as quickly as possible each time when a counter appeared within the square. After pressing, the counter stopped and displayed the reaction time (RT) in milliseconds, to motivate the children to keep their RT as low as possible. The interval between the last response and the next stimulus varied randomly from two to five seconds. The mean RT and the number of lapses (RT $\geq$ 355ms) were used as measures of alertness. The 3-minute PVT with a lowered lapse threshold (355ms instead of 500ms) has been shown to be a useful tool for assessing alertness (Basner et al., 2011).

PVT-GoNogo. To assess the children's inhibitory capacity an adaptation of the 3-minute PVT (as described above) was made during which the children were instructed to monitor a grey square on the computer screen and to press the button if a counter appeared within the grey square. However, when the counter appeared in a red square, they had to wait until it returned grey and a new counter started. The outcome measure was the percentage of correct rejections on the Nogo-trials (RT > 10 seconds). Higher scores indicate better inhibitory capacities.

Digit Span. A visual Digit Span test was used to examine the child's working memory capacity. Series of digits were displayed on the computer screen and the children were required to repeat the sequences in the same order (forward condition) or in reversed order (backward condition) by typing the numbers on the keyboard. The backward condition was administered immediately after the forward condition. The digit series increased in length (starting with series of two numbers) and each length was presented twice with different digit series. The procedure discontinued after two consecutive errors at the same item length. The length of the longest correctly repeated digit span was used as a measure of working memory capacity, both for the forward and backward condition.

Statistical analyses

The normality of the study variables was inspected by means of descriptive statistics, histograms, and quantile-quantile plots (Q-Q-plots). Furthermore, boxplots and scatterplots were used to detect univariate and bivariate outliers. A few extreme univariate outliers (> ±3 *SD*) were identified and these were excluded from further analyses. Most variables were normally distributed (standardized skewness and kurtosis between -3 and 3), except the PVT measures mean RT and number of lapses, and the PVT GoNogo variable (Table 1). Logarithmic transformations (for right-skewed variables) and inverse and square root transformations (for the left-skewed variables) did not yield normal distributions. Partial correlations (pairwise deletion) between sleep, temperament, and cognitive performance were calculated, controlling for age and gender. Correlation coefficients between .10 and .30 correspond with a small effect, medium effects with $.30 > r < .50$, and large effects with $r > .50$ (Cohen, 1988). Since sleep duration declines with aging, the variable sleep duration was converted into a *Z*-score taking into account the age of the participants. Negative *Z*-scores indicate that children sleep less than average within their age group and positive *Z*-scores reflect the opposite. A median-split procedure was used for temperament measures to create groups with relatively high vs. low scores, in order to facilitate interpretation of interaction effects. Analyses of Covariance (ANCOVA) were performed to investigate the relation of sleep duration and temperament on neurocognitive functions (alertness, inhibition, working memory), while controlling for demographic variables age and gender. Potential moderation of the association between sleep duration and cognitive performance by temperament was analysed by entering a Sleep duration X Temperament-group interaction term in the ANCOVA models. In case the direction of sleep effects on cognitive variables were opposite for both temperament groups, the main effects were not interpreted because this can lead to erroneous conclusions (Siero et al., 2009). For each ANCOVA analysis listwise deletion was used. Effect sizes were estimated by means of eta squared (η^2). Large effects correspond with $\eta^2 \geq .14$, moderate effects with $\eta^2 \geq .06$, and $\eta^2 \leq .14$, and weak effects with $\eta^2 \leq .06$ (Cohen, 1988). All analyses were conducted with the Statistical Package for Social Sciences (SPSS) version 19.0. A probability level of $\alpha = .05$ (two-sided) was used to indicate statistical significance.

Results

Descriptive and preliminary analyses

Table 1 provides an overview of the descriptive statistics of the study variables. Table 2 shows the partial correlations between sleep, temperament, and cognitive performance variables, controlled for age and gender.

Table 1
Descriptive statistics of the study variables

	N	*M*	*SD*	Min.	Max.	Std. Skewness	Std. Kurtosis
Sleep duration							
Average assumed sleep duration weekdays (minutes)	100	596.51	33.32	512	690	0.851	-0.228
Temperament [a]							
Extraversion	115	-3.77	9.66	-28.00	18.00	-0.296	-0.664
Negative Affectivity	115	36.23	8.26	16.00	53.00	-0.394	-0.517
Effortful Control	115	46.95	8.55	23.00	64.00	-1.956	0.333
Affiliativeness	115	50.46	6.99	38.00	70.00	2.757	-0.262
Alertness							
PVT[b] mean RT (ms)	116	357.97	66.32	229	569	5.613	3.339
PVT number of lapses (≥ 355ms)	117	16.29	10.93	1	43	3.344	-0.628
Inhibition							
PVT GoNogo (% correct rejections)	106	81.76	17.68	15.38	100.00	-7.613	7.951
Working Memory							
Digit Span Forward	120	5.41	0.99	3	8	0.457	0.694
Digit Span Backward	119	4.45	1.15	1	7	-1.099	0.573

[a] Higher score indicates more of the trait; [b] Psychomotor Vigilance Task

Table 2
Partial correlations between sleep, temperament, and cognitive performance, controlled for age and gender

		1	2	3	4	5	6	7	8	9	10
1	Average assumed sleep duration weekdays (*Z*-score)	---	-.14	.13	-.10	.11	.14	.02	.04	-.19	-.32**
2	Extraversion		---	-.63**	.36**	-.10	-.35**	-.30**	-.04	.21*	.18
3	Negative Affectivity			---	-.50**	.26**	.35**	.34**	-.09	-.20*	-.31**
4	Effortful Control				---	-.16	-.32**	-.24*	.15	.04	.20*
5	Affiliativeness					---	.07	.13	.03	-.13	-.04
6	PVT[a] mean RT						---	.77**	-.09	-.14	-.18
7	PVT number of lapses							---	-.02	-.11	-.18
8	PVT GoNogo								---	-.06	-.09
9	Digit Span Forward									---	.32**
10	Digit Span Backward										---

**Correlation is significant at α = .01 (2-tailed) *Correlation is significant at α = .05 (2-tailed)
[a] Psychomotor Vigilance Task

Sleep duration and cognitive performance: moderation by temperament

Extraversion

Alertness: The ANCOVA revealed a significant interaction of Sleep duration X Extraversion on PVT mean RT: $F(1,86) = 4.89$, $p = .030$, $\eta^2 = .05$. A similar interaction pattern was found for number of lapses: $F(1,86) = 3.22$, $p = .076$, $\eta^2 = .03$. Figure 1 shows that within the group of relatively high extraversion, longer sleep duration was associated with faster responses ($r = -.17$, $p = .139$) and less lapses ($r = -.16$, $p = .153$), while in the low extraversion (introvert) group, a longer sleep duration was associated with slower responses ($r = .26$, $p = .038$) and more lapses ($r = .12$, $p = .213$). *Inhibition:* Extraversion did not significantly moderate the association between sleep duration and inhibition. Moreover, the main effects of sleep duration and extraversion on inhibition were also not significant (Table 3). *Working memory:* No significant interaction effect was found for sleep duration and extraversion on Digit Span Forward or on Digit Span Backward. The ANCOVA with Digit Span Forward revealed a tendency toward significance for extraversion ($F(1,89) = 3.03$, $p = .085$, $\eta^2 = .03$): Children who are relatively introvert seem to have lower DSF-scores ($M = 5.31$, $SD = 0.93$) than children with high levels of extraversion ($M = 5.58$, $SD = 1.10$), while for Digit Span Backward no significance was found. On the other hand, the main effect of sleep duration was significant for Digit Span Backward ($F(1,88) = 9.19$, $p = .003$, $\eta^2 = .09$), but not for Digit Span Forward. Longer average assumed sleep duration is associated with lower DSB-scores ($r = -.32$, $p = .002$).

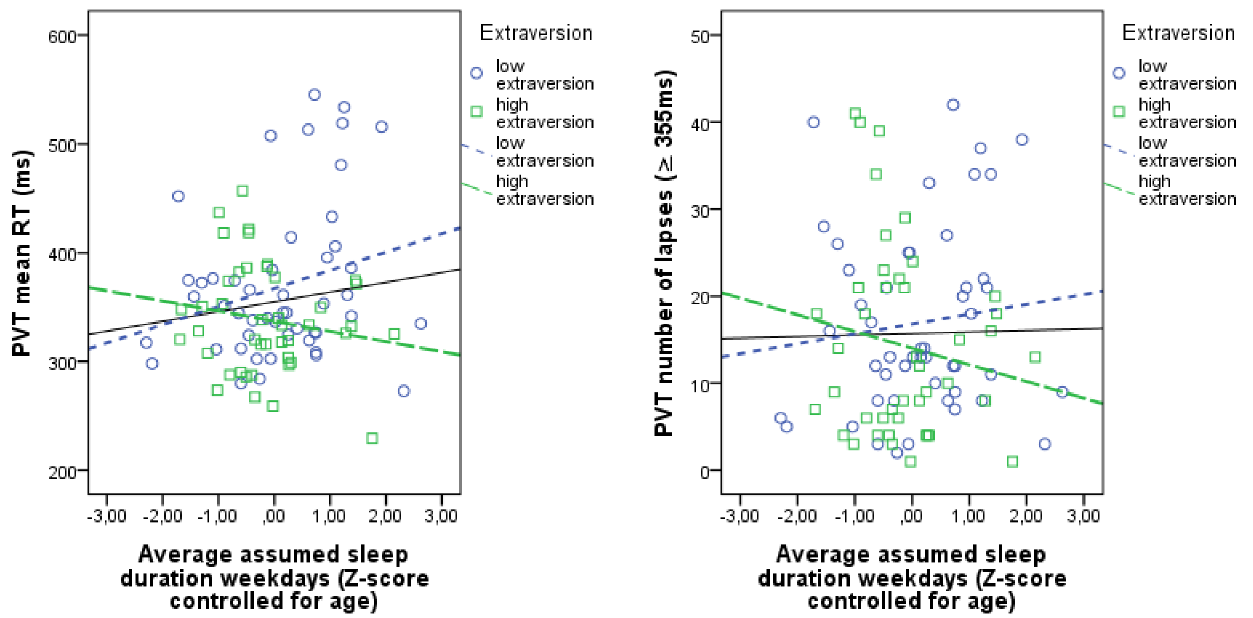

Figure 1. Interaction effect of sleep duration and extraversion on alertness.

Table 3

Results of the ANCOVA's with sleep duration, temperament, Sleep duration X Temperament interaction on cognitive performance, controlled for age and gender

	Alertness		**Inhibition**	**Working Memory**	
	PVT[a] mean RT	PVT number of lapses	PVT GoNogo	Digit Span Forward	Digit Span Backward
Extraversion					
Sleep duration X Temperament	$F(1,86) = 4.89, p = .030$*	$F(1,86) = 3.22, p = .076$	$F(1,77) = 0.05, p = .819$	$F(1,88) = 0.02, p = .888$	$F(1,87) = 0.13, p = .718$
Sleep Duration	$F(1,86) = 0.24, p = .629$	$F(1,86) = 0.11, p = .738$	$F(1,78) = 0.86, p = .357$	$F(1,89) = 1.39, p = .242$	$F(1,88) = 9.19, p = .003$**
Temperament	$F(1,86) = 5.93, p = .017$*	$F(1,86) = 1.59, p = .211$	$F(1,78) = 0.01, p = .935$	$F(1,89) = 3.03, p = .085$	$F(1,88) = 0.79, p = .378$
Negative Affectivity					
Sleep duration X Temperament	$F(1,86) = 4.39, p = .039$*	$F(1,86) = 3.73, p = .057$	$F(1,77) = 0.05, p = .828$	$F(1,88) = 0.45, p = .503$	$F(1,87) = 0.13, p = .715$
Sleep duration	$F(1,86) = 0.28, p = .601$	$F(1,86) = 0.22, p = .639$	$F(1,78) = 0.92, p = .341$	$F(1,89) = 3.20, p = .077$	$F(1,88) = 9.51, p = .003$**
Temperament	$F(1,86) = 7.18, p = .009$**	$F(1,86) = 5.11, p = .026$*	$F(1,78) = 0.27, p = .606$	$F(1,89) = 3.53, p = .064$	$F(1,88) = 5.28, p = .024$*
Effortful Control					
Sleep duration X Temperament	$F(1,86) = 0.39, p = .537$	$F(1,86) = 0.29, p = .594$	$F(1,77) = 0.22, p = .638$	$F(1,88) = 0.20, p = .655$	$F(1,87) = 0.28, p = .599$
Sleep Duration	$F(1,87) = 1.34, p = .251$	$F(1,87) = 0.03, p = .869$	$F(1,78) = 1.14, p = .289$	$F(1,89) = 3.92, p = .051$	$F(1,88) = 9.57, p = .003$**
Temperament	$F(1,87) = 4.74, p = .032$*	$F(1,87) = 1.29, p = .259$	$F(1,78) = 2.23, p = .139$	$F(1,89) = 0.50, p = .483$	$F(1,88) = 1.83, p = .179$
Affiliativeness					
Sleep duration X Temperament	$F(1,86) = 2.20, p = .142$	$F(1,86) = 0.17, p = .682$	$F(1,77) = 0.04, p = .848$	$F(1,88) = 1.31, p = .256$	$F(1,87) = 0.07, p = .800$
Sleep Duration	$F(1,87) = 1.51, p = .222$	$F(1,87) = 0.04, p = .852$	$F(1,78) = 0.84, p = .363$	$F(1,89) = 3.46, p = .066$	$F(1,88) = 9.41, p = .003$**
Temperament	$F(1,87) = 0.76, p = .386$	$F(1,87) = 0.51, p = .477$	$F(1,78) < 0.01, p = .960$	$F(1,89) = 0.26, p = .614$	$F(1,88) = 1.25, p = .267$

**Significant at $\alpha = .01$ (2-tailed) *Significant at $\alpha = .05$ (2-tailed)

[a] Psychomotor Vigilance Task

Negative Affectivity

Alertness: The ANCOVA revealed a significant Sleep duration X Temperament interaction for the alertness measure PVT mean RT: $F(1,86) = 4.39$, $p = .039$, $\eta^2 = .04$, and a trend for PVT number of lapses: $F(1,86) = 3.73$, $p = .057$, $\eta^2 = .04$. The results depicted in Figure 2 indicate that there is a negative association between sleep duration and alertness ($r_{\text{PVT\_RT}} = -.19$, $p = .092$; $r_{\text{PVT\_lapses}} = -.24$, $p = .047$), which is confined to children with low levels of negative affectivity. Children with high levels of negative affectivity show a positive association ($r_{\text{PVT\_RT}} = .294$, $p = .029$; $r_{\text{PVT\_lapses}} = .15$, $p = .171$), suggesting that longer sleep results into worse performance. Since negative affectivity and extraversion were strongly correlated, both moderation effects could rely on the same underlying mechanism. Therefore, we analysed whether the interaction term Sleep duration X Negative Affectivity remained significant after introduction of the interaction term Sleep duration X Extraversion. The analyses showed that the interaction of sleep duration and negative affectivity lost its significance (PVT mean RT: $F(1,84) = 1.87$, $p = .175$; PVT number of lapses: $F(1,84) = 1.54$, $p = .218$). *Inhibition*: No significant Sleep duration X Temperament interaction was found for the PVT GoNogo outcome variable. There were also no significant main effects for sleep duration, or negative affectivity (Table 3). *Working memory*: Similarly, there was no significant Sleep duration X Negative Affectivity interaction for Digit Span Forward, nor for Digit Span Backward (Table 3). However, the main effects of sleep duration ($F(1,88) = 9.51$, $p = .003$, $\eta^2 = .09$) and negative affectivity ($F(1,88) = 5.28$, $p = .024$, $\eta^2 = .05$) on Digit Span Backward were significant. For Digit Span Forward these main effects tended toward significance (sleep duration: $F(1,89) = 3.20$, $p = .077$, $\eta^2 = .03$; negative affectivity: $F(1,89) = 3.53$, $p = .064$, $\eta^2 = .03$). For both Digit Span conditions, longer assumed average sleep duration was related to poorer memory performance ($r_{\text{DSF}} = -.19$, $p = .060$; $r_{\text{DSB}} = -.32$, $p = .002$). Moreover, children with relatively high negative affectivity performed worse on Digit Span ($M_{\text{DSF}} = 5.21$, $SD_{\text{DSF}} = 0.89$; $M_{\text{DSB}} = 4.19$, $SD_{\text{DSB}} = 1.18$) compared to children with low negative affectivity ($M_{\text{DSF}} = 5.63$, $SD_{\text{DSF}} = 1.08$; $M_{\text{DSB}} = 4.76$, $SD_{\text{DSB}} = 1.08$).

Effortful Control

Alertness: No significant interaction effect was found for Sleep duration X Effortful Control on PVT mean RT or PVT number of lapses. In addition, the main effect of sleep duration was also not significant for both PVT measures (Table 3). The ANCOVA with PVT mean RT as dependent variable revealed a significant main effect for effortful control ($F(1,87) = 4.74$, $p = .032$, $\eta^2 = .05$). Children with low effortful control had higher average RT's on the PVT,

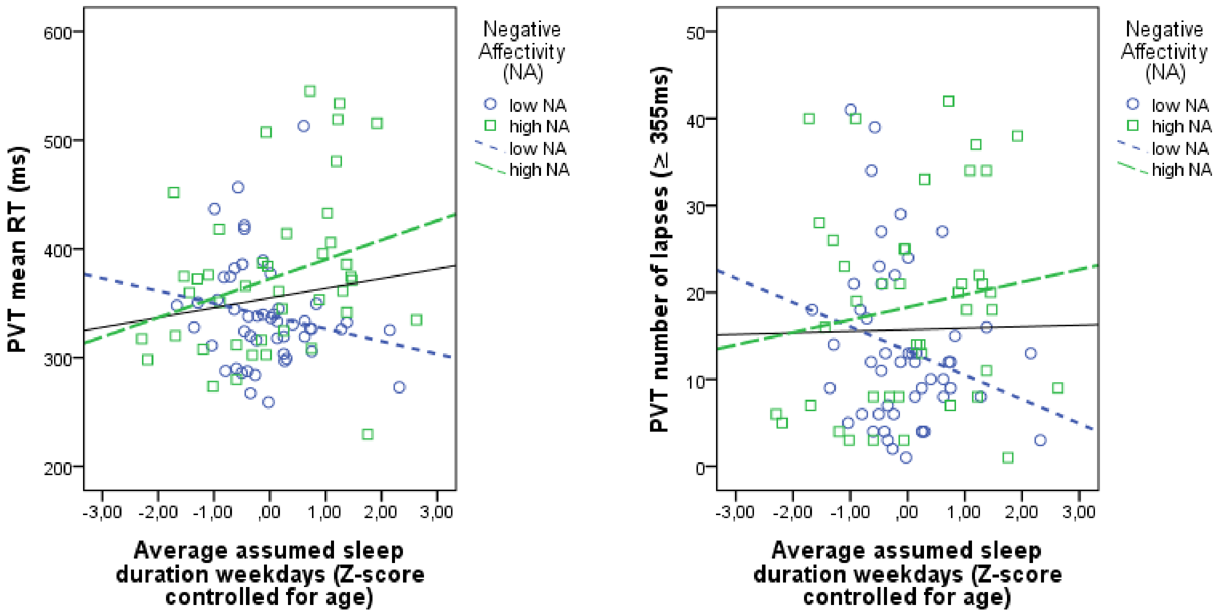

Figure 2. Interaction effect of sleep duration and negative affectivity on alertness.

i.e. worse performance (M = 368.73, SD = 69.69) than children with high effortful control (M = 339.91, SD = 53.69). However, this main effect of temperament could not be demonstrated for PVT number of lapses. *Inhibition:* The ANCOVA revealed no significant Sleep duration X Temperament interaction on the PVT GoNogo outcome variable, nor were there any significant main effects for sleep duration or effortful control. *Working memory:* The interaction effects of Sleep duration X Effortful Control on Digit Span Forward and Digit Span Backward were not significant. Further, the main effects of temperament were not significant. However, the main effect of sleep duration was significant for Digit Span Backward (F(1,88) = 9.57, p = .003, η^2 = .09), and tended toward significance for Digit Span Forward (F(1,89) = 3.92, p = .051, η^2 = .04), with longer sleep duration relating to worse performance.

Affiliativeness

For neither of the three cognitive domains (Alertness, Inhibition, Working memory) a significant Sleep duration X Affiliativeness interaction was found, nor were any main effects, except for a significant main effect of sleep duration for Digit Span Backward (F(1,88) = 9.41, p = .003, η^2 = .09) and a trend towards significance for Digit Span Forward (F(1,89) = 3.46, p = .066, η^2 = .03).

Discussion

Our study is the first to reveal that multiple temperament traits moderate the association between sleep duration and cognitive functioning in children. As hypothesized, the analyses of covariance revealed a significant interaction effect for the temperament trait extraversion. Children relatively low in extraversion performed worse (i.e., higher mean RT and more lapses) on the Psychomotor Vigilance Task (PVT) with a longer assumed (age-corrected) sleep duration. The opposite relation was found for children relatively high in extraversion; their alertness performances decreased with shorter sleep durations. This suggests that relatively extravert children were more vulnerable to inadequate sleep. Our results are in correspondence to previous findings in adults (Killgore et al., 2007; Rupp et al., 2010; Taylor & McFatter, 2003), which showed that extravert persons experienced more negative consequences after a period of sleep deprivation compared to introverts.

The observed opposite sleep-alertness associations in introverts and extraverts can be explained by a difference in baseline (tonic) levels of cortical arousal (Hagemann et al., 2009). According to an influential theory by Eysenck (1967), which has been corroborated in later studies (e.g., Beauducel et al., 2006), extravert persons have lower-than-optimal basal cortical arousal levels, whereas introverts are assumed to have higher-than-optimal arousal levels. Consistent with the Yerkes-Dodson inverted-U hypothesis, which relates performance and arousal level, performances are maximal at an optimal level of arousal (Yerkes & Dodson, 1908). When the actual arousal level differs from the optimal (whether higher or lower) the performance will deteriorate. Since sleep loss decreases the arousal level (Cote et al., 2008; Sanders, 1983) this is advantageous for introvert persons, because their arousal level comes closer to the optimum. In contrast, the initial low arousal level in extraverts further decreases as consequence of inadequate sleep, in a direction that is disadvantageous to cognitive performance. This might explain why introverts performed better and extraverts performed worse on the alertness task under the condition of inadequate sleep and that such interaction effect was not found for inhibition and working memory. Interestingly, a dissociation of sustained attention from central executive functions has been established in previous research. Sauseng et al. (2007) showed that local frontal-midline theta power, arising from the anterior and motor cingulate gyrus, was associated with performance on a sustained attention task. They proposed that the attentional system associated with local frontal-midline theta activity might promote energetic adjustments in effort to increase arousal or activation. In contrast, long-range interregional theta coupling between prefrontal and parietal brain areas were modulated by memory load task manipulations, and reflected integrative processes, probably mediated by a central executive system. The current data suggest the arousal-theory of temperamental influences on the sleep-cognition relationship holds particularly for the sustained attentional system, while the central executive system is less closely related to variations in arousal.

The temperament trait negative affectivity also showed a significant interaction effect with sleep duration on alertness. A positive association between average assumed sleep duration and the PVT measures was found for children relatively high in negative affectivity. For these children, increased sleep duration was associated with worse performance. In contrast, children with relatively low levels of negative affectivity performed better on the alertness measure when they slept longer than average within their age group. This suggests that children with low levels of negative affectivity are more sensitive to insufficient sleep. Interestingly, those findings are in contrast to our initial hypotheses, since we expected that children with high levels of negative affectivity would be more vulnerable to short sleep duration. Furthermore, the findings contradict previous studies in adults which did not find that individual differences in neuroticism, a personality trait closely related to negative affectivity, were related to performance differences induced by sleep deprivation (Killgore et al., 2007; Taylor & McFatter, 2003).

Eysenck (1967) stated that extraversion and neuroticism are distinct dimensions, but several studies revealed a negative correlation between the two dimensions (e.g., Buckingham et al., 2001). We also found a strong negative correlation between extraversion and negative affectivity (r = -.63). In addition, we found that the interaction Sleep duration X Negative Affectivity lost significance after controlling for the interaction Sleep duration X Extraversion, suggesting that both effects might rely on similar mechanisms. Thus, the observed opposite relation between sleep duration and alertness in children with high versus low negative affectivity might also be explained by differences in arousal level just as with extraversion. According to Eysenck (1967) differences in the personality dimension neuroticism are due to individual differences in the stability of the autonomic nervous system in response to and recovery of stressful situations. Persons with high negative affectivity are assumed to have higher cortical arousal levels due to increased autonomic activation than individuals with low levels of negative affectivity (Eysenck 1967). In line with the Yerkes-Dodson hypothesis (Yerkes & Dodson, 1908), insufficient sleep will have a positive influence on the arousal level of children with relatively high levels of negative affectivity, because sleep deprivation decreases their arousal to a more optimal performance level. For children with relatively low levels of negative affectivity, their lower basal arousal level is probably further diminished after inadequate sleep with negative consequences on performance.

For the other temperament traits effortful control and affiliativeness, no significant interaction effect with sleep duration was found on any of the examined cognitive functions. However, all analyses revealed a significant main effect for sleep duration on Digit Span Backward. In contradiction to earlier findings (Steenari et al., 2003), we found that longer assumed average sleep duration was related to poorer Digit Span Backward performances. This surprising result may be explained by the neural efficiency hypothesis, which argues that poor performing individuals may have less efficient neural circuits (Haier et al., 1988). In line with this hypothesis it is found that persons who perform high on working memory tasks showed overall less brain activation, but more specific prefrontal cortex activation (i.e., greater neural efficiency) than low-performing subjects (Rypma et al., 2002). Geiger et al. (2010) extended the original neural efficiency hypothesis by including the efficiency of sleep-related neural processing. According to their theory, children who sleep less compared to their peers, show more efficient information processing (i.e., neuronal recovery) at night and therefore need less sleep. That might explain why we found that longer sleep in children was associated with decreased working memory performance. Nevertheless, this explanation would imply that a negative association between sleep duration and the executive function inhibition was found as well, which was not the case in our study. However, the results showed that on average the children performed well on the inhibition task (scores were skewed to the maximal score which is disadvantageous for detecting effects), while that was not the case for the working memory task. This suggests that the inhibition task was easier to perform than the working memory task, thus the working memory task would be more sensitive to a neural system which processes information more efficiently. The neural efficiency hypothesis would therefore be more applicable to the working memory task than to the inhibition task.

This study has several strengths such as the relatively large sample size with carefully selected participants, and a sleep problem prevalence rate (42% scored above the clinical cut-off point of the Sleep Disturbance Scale for Children (Bruni et al., 1996)) which is in accordance with previous studies (Mindell & Meltzer, 2008). Furthermore, the instruments were carefully chosen and a broad range of temperamental traits was analysed. Additionally, sleep duration was assessed prospectively by means of parental sleep logs, and included only weekdays during which cognitive assessments took place, and which are most relevant to educational achievement. Previous studies have shown that parent sleep logs are reliable and valid compared to actigraphy for the assessment of sleep start, sleep end, and assumed sleep in children (Werner et al., 2008). Moreover, a meta-analysis has shown that parent reports of sleep duration show comparable associations with cognitive performance to actigraphic measures (Astill et al., 2012). However, objective sleep assessments by means of EEG or actigraphy would have allowed us to also include other sleep variables such as sleep efficiency, which has been related to cognitive performance as well (Astill et al, 2012).

We emphasize that the present study employs an association design, which implies that the etiology of short sleep is probably heterogeneous. Where short sleep often signifies a deficiency in sleep duration due to for instance sleep problems, inappropriate bedtimes, or early school start times, it is likely that in a part of the short-sleeping children sleep duration is sufficient. Those children might need less sleep, for instance due to a higher neural efficiency, such as explained above. Hence, the most valid way to study the effects of short sleep on cognition, and the moderation of temperament therein, would be with a long-term experimental reduction of sleep. However, such studies are commonly considered unethical, let alone in a considerably large sample such as in this study, which was needed in order to achieve a sufficient amount of variance in temperamental traits.

The results of this study have two major implications. First, the association between sleep duration and cognitive performance in children varies with different temperamental traits. As for alertness, children with high levels of negative affectivity or relatively introvert children perform better with shorter sleep durations, while children with low levels of negative affectivity and relatively extravert children perform worse with shorter sleep. That indicates that temperament is an important factor to include in future research on sleep and cognition in children. Of note, we do not infer that sleep reduction should be applied in introvert and negatively affected children. Although sleep deprivation in depressive patients has been shown effective against depressive symptoms, including improvements in concentration (Giedke & Schwarzler, 2002; Landness et al., 2011), these effects are probably related to depression-related abnormalities in sleep, and are often followed by immediate relapse after regular sleep.

A second implication is that sleep reduction in children can have positive effects within one cognitive domain, while it has negative effects in other domains. Namely, in extraverted children or children with low negative affectivity short sleep was associated with worse alertness and at the same time with better working memory. This dissociation in effects of sleep on different cognitive functions is only observable when accounting for the different temperamental traits. As discussed above, a dissociation of sustained attention from central executive functions has been established in previous research (Sauseng et al., 2007). The findings explain how the direction of the association between sustained attention and sleep can be moderated by temperament-related differences in tonic arousal levels, while the relation between central executive functions and sleep duration remain constant. Our study did not include a physiological measure of arousal, which would be an important addition for future research, since it would provide more insight into the actual role of arousal on the sleep-temperament-performance relation. Although our findings should be interpreted with caution, they provide a novel perspective on the field and warrant further exploration in future studies.

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