Late Bedtimes Are Associated with Lower Behavioral, Cognitive and Motor Performance, Independent of Sleep Duration

It has long been understood that sleep is biologically necessary to sustain life, but little is known about the basic function of sleep.[1] Rapid eye movement sleep is thought to be associated with cognitive functions (such as memory) and growth of the central nervous system, while slow-wave sleep is thought to be restorative.[1] Chronic sleep loss impacts behavior and cognitive function, particularly in terms of memory, attention, concentration, decision making, and problem solving.[1] Sleep problems may hinder the development of self-regulation and executive function.[2]

In comparison studies of children, those with sleep problems had more falls[3] and more externalizing behavior problems, such as poor impulse control, behavioral disinhibition, aggression, and oppositional defiant behavior.[1,4-7] The effects of poor sleep may also be long-lasting, with poor sleep in early childhood predicting poor school age,[8] adolescent,[9] and into young adulthood.[10]

Conflicting guidelines from various bodies for optimal sleep leave clinical recommendations unclear.[11] Perhaps not surprisingly, there are significant differences in parenting behaviors related to sleep across[12,13] and within[14] cultural groups and countries. For example, infants and toddlers from predominantly Asian countries have later bedtimes than those from predominantly Caucasian countries, with bedtimes ranging from an average of 17:45 in New Zealand to 22:29 in Hong Kong.[14] (For comparison, the average time for sleep onset among U.S. children age 7 years(y) was 20:27).[15] In one study, shorter sleep duration for certain categories of SES and ethnic groups were driven by later bedtimes.[16] In some cultural contexts, napping may compensate in part for an accumulated week day sleep deficit.[17]

Much of the evidence relating sleep with cognitive and behavioral functioning in children has focused on children with sleep problems, such as sleep apnea, night-waking and bedtime resistance, or total sleep duration.[18] Fewer studies have examined outcomes given natural variations in sleep practices within a

non-sleep disturbed population. This study provides new evidence on associations of bedtimes themselves, independent of sleep duration, with child cognitive and behavioral functioning.

METHODS

This study relies on data from the Encuesta Longitudinal de la Primera Infancia (Longitudinal Survey of Early Childhood Development, or ELPI), a nationally-representative and longitudinal survey of children in Chile. The survey has collected two waves of data: (1) children born between 2005 and 2009 surveyed in 2010, and (ii) follow-up data on the first sample plus a refreshment sample of children born 2009-2011 collected in 2012. The sample of 16,033 children was selected using a cluster-stratified, random-sampling strategy. Interviewers visited children's homes to collect data on physical, cognitive and socio-emotional development indicators, child care situations throughout infancy and early childhood, family background characteristics, and program participation. Interviews were conducted with the primary caregivers of the children, who were the mothers for 99% of children. The survey and data collection were approved by appropriate ethics committees and conformed to the principles embodied in the Declaration of Helsinski.

Measures

Behavioral outcomes were measured by the Child Behavioral Checklist (CBCL), which measures externalizing and internalizing behaviors as reported by a parent of the child.[19] Separate checklists were employed for children ages 1.5 to 5y and children ages 6y. Externalizing behaviors included aggressive behaviors and attention problems. Internalizing behaviors included anxiety/depression, emotional reactivity, withdrawal and somatic symptoms. For age 6y, CBCL added socialization, following instructions and disruptive conduct to externalizing behaviors. Raw scores in 2012 were used.

Cognitive performance was captured by scores on three cognitive tests: the Spanish version of the Peabody Picture Vocabulary Test (PPVT), measuring receptive and oral vocabulary from 30-60 months; the Battelle Development Inventory, measuring a range of abilities from ages 6-23 months, including cognitive, adaptive, communication, motor, and social skills; and the Test of Learning and Child

Development (TADI), a child development test that was developed in Chile. Motor skills were also collected as part of this measure. Raw scores in 2012 were used for each of these measures.

Data on bedtimes were collected from the question, "I realize that children do not fall asleep or wake up at the same time every day. What time does your child fall asleep at night?" Answers were recorded to the nearest minute. The bedtime variable was created as each child's deviation from the median bedtime for the individual child's age in months. The top quartile of this variable represented "late" bedtimes, and the lowest quartile represented "early" bedtimes.

Controls included total sleep duration, which was created using the question for the time the child goes to sleep, a follow up question on what time the child wakes up, and included total nap time per day; a dichotomous variable for whether the child takes a nap; the age in months of the child and its square; child sex; the mother's and the father's last completed grade in school; the hours the mother worked per week; household income quintile; the mother's cognitive scores on the quantitative and vocabulary components of the Wechsler Adults Intelligence Scale (WAIS),[20] and the Home Observation for Measure of the Environment (HOME) score.[21]

Ordinary least squares regressions of the cognitive, motor, and behavioral outcomes were run separately by 12-month age group using Stata 13.1.

RESULTS

The median bedtime for Chilean children was 21:30. Median bedtimes by age and other covariates are listed in table 1. Mean outcomes by age are listed in table 2.

Children with late bedtimes had lower mean CBCL scores than children with early bedtimes for every age (figure 1). In adjusted regressions (table 3), children age 3y with late bedtimes had higher scores for withdrawal symptoms (0.32 [0.09 - 0.56]), somatic complaints (.37 [0.10 - 0.63], $p<0.001$), attention problems (0.21 [0.01 - 0.40], $p<0.01$), aggression (1.52 [0.72 - 2.33], $p<0.001$), and emotional reactivity (0.44 [0.16 - 0.72], $p<0.001$). Children age 6y with late bedtimes had higher scores for anxiety/depression

(0.69 [0.13 - 1.26], p<0.01), withdrawal (0.37 [0.06 - 0.69], p<0.01), somatic symptoms (0.42 [0.08 - 0.76], p<0.01), attention problems (0.70 [0.18 - 1.22], p<0.001), aggression (1.41 [0.60 - 2.22], p<0.001), social problems (0.59 [0.16 - 1.01], p<0.001), thinking problems (0.61 [0.23 - 0.99], p<0.001), and disruptive behavior (0.51 [0.16 - 0.87], p<0.001). Results were similar though less robust for children of other ages.

In adjusted regressions, children with late bedtimes had lower Battelle performance at ages 3y (-2.13 [-3.96 - -0.31], p<0.01), 4y (-1.73 [-3.51 - 0.06],p<0.05), 5y (-1.90 [-3.42 - -0.39],p<0.01), and 6y (-1.41 [-3.01 - 0.19], p<0.05); lower TADI language performance at age 5y (-0.64 [-1.07 - -0.21], p<0.001); and lower motor performance at ages 3y (-0.45 [-0.87 - -0.03], p<0.01) and 5y (-0.60 [-0.90 - -0.29], p<0.001). Results were less consistent for PPVT, where children with late bedtimes at age 2y had higher performance (1.97 [0.45 - 3.50], p<0.01), children with late bedtimes at age 5y had lower performance (-1.45 [-3.10 - 0.19], p<0.05), and children with *early* bedtimes at age 6y had lower performance (-1.78 [-3.54 - -0.01], p<0.001).

In contrast, each additional hour of sleep was p<0.05 in comparatively few behavioral outcomes, including attention problems at ages 2y (-0.08 [-0.18 - 0.01], p<0.05), 3y (-0.06 [-0.12 - 0.00], p<0.05), 4y (-0.08 [-0.15 - -0.01], p<0.001), and 6y (-0.20 [-0.39 - -0.02], p<0.01), aggression at age 3y (-0.32 [-0.58 - -0.07], p<0.01) and 6y (-0.27 [-0.56 - 0.01], p<0.05), and with increased problems with thought processes (-0.23 [-0.37 - -0.10], p<0.001) and disruptive behaviors (-0.11 [-0.23 - 0.02], p<0.05) at age 6y. Each additional hour of sleep was associated with higher cognitive performance only at age 6y for the Battelle inventory (0.59 [0.03 - 1.16], p<0.05), and with lower motor performance at age 6y (0.11 [0.03 - 0.19], p<0.05).

DISCUSSION

The findings reported here are consistent with previous literature suggesting that lack of sleep can impair cognitive, motor, and behavioral functioning. While previous studies have often examined total sleep

duration in samples in which sleep problems have already been reported, this study brings to light an association between late bedtimes and lower cognitive, motor, and behavioral functioning, independent of total sleep duration, within a cultural context of later mean bedtimes.

If bedtimes matter, then we have further evidence for the importance of circadian rhythms in sleep health. It is well-known that light and dark play a role in wakefulness and sleepiness; [1]Garcia et al. provide a useful framework for advanced and delayed sleep phase syndrome, where individuals can feel tiredness before or after cultural expectations of bedtimes.[22] In this framework, children with advanced sleep phase would feel sleepy between 17:00-19:30, prior to when the "normal" sleep phase begins. These children would then tend to have early morning waking between 5:00-7:00. In contrast, children with delayed sleep phase would experience insomnia between 19:30 pm, which is "bedtime" in this framework, and 23:30. These children would tend to have difficulty waking between 7:30 and 11:30.

If there is a disconnect between natural circadian rhythms and cultural sleep patterns among children, then we may observe more cases of what might be termed sleep onset insomnia in some cultures.[23] If cultural expectations are that children be present for activities such as family dinners that occur late into the evening in some cultures, then more children in these cultures may be thrown out of natural circadian rhythms, suffer sleep problems, and be impacted in their cognitive, motor, and behavioral functioning. It is important to take into account the cultural context when determining normal versus problematic sleep, and when tailoring sleep recommendations to what is optimal for child development within these varied contexts.[24]

This study had some obvious limitations. First, the bedtimes and wake times were self-reported, not based on any specific day, and not measured. As a result, there may be substantial measurement error in the key variables. However, measurement error has been shown to bias estimates downwards [citation], and there is no reason to believe that measurement error is biased in any particular direction. Second, only a limited set of behavioral, cognitive, and motor outcomes were examined. It could be that children behave differently day to day than indicated by the tests examined here.

The finding that children with early bedtimes had lower PPVT scores (age 6y) and that those with late bedtimes had higher PPVT scores (age 2y) is consistent with Werchan and Gomez 2014, who found that wakefulness, not sleep, promotes generalization of word learning.[25] However, the negative association between bedtimes and cognitive, behavioral, and motor performance, independent of total sleep duration, would be consistent with impairment due to a disconnect between children's natural circadian rhythms and the expectations of sleep and bedtimes in their homes.

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Table 2. Outcome Statistics

	Age 1		Age 2		Age 3		Age 4		Age 5		Age 6	
	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N	Mean [SD]	N
Child Behavioral Checklist												
Anxiety/ Depression	3.68 [2.55]	600	4.09 [2.87]	1393	4.33 [2.99]	3293	4.38 [3.08]	3183	4.25 [3.09]	3111	5.53 [4.09]	1855
Withdrawn	2.21 [1.9]	600	2.7 [2.34]	1393	2.93 [2.35]	3293	2.76 [2.32]	3183	2.52 [2.26]	3111	2.01 [2.32]	1855
Somatic Complaints	2.23 [2.36]	600	2.79 [2.57]	1393	3.09 [2.62]	3290	3.23 [2.66]	3181	3.27 [2.78]	3109	1.98 [2.47]	1855
Attention Problems	3.57 [2]	600	3.58 [2.06]	1393	3.72 [1.97]	3293	3.6 [2.03]	3183	3.41 [1.99]	3111	5.41 [3.91]	1855
Aggression	13.49 [8.07]	600	13.9 [8.5]	1393	13.76 [8.35]	3293	12.75 [8.25]	3183	11.57 [8.01]	3111	7.68 [6.09]	1855
Emotional Reactivity	2.31 [2.53]	600	2.84 [2.83]	1393	3.05 [2.89]	3293	3.12 [2.92]	3183	2.98 [2.97]	3111	na	na
Sleep Problems	2.9 [2.64]	600	2.92 [2.7]	1393	2.81 [2.61]	3293	2.73 [2.51]	3183	2.75 [2.62]	3111	na	na
Social Problems	na	na	na	na	na	na	na	na	na	na	4.21 [3.17]	1855
Thinking Problems	na	na	na	na	na	na	na	na	na	na	2.31 [2.78]	1855
Disruptive Behavior	na	na	na	na	na	na	na	na	na	na	2.37 [2.63]	1855
Internalizing	10.43 [7.4]	600	12.42 [8.54]	1393	13.4 [8.8]	3290	13.48 [8.79]	3181	13.02 [9.02]	3109	9.52 [7.33]	1855
Externalizing	17.05 [9.48]	600	17.49 [9.98]	1393	17.47 [9.69]	3293	16.35 [9.69]	3183	14.98 [9.37]	3111	10.05 [8.13]	1855
PPVT	na	na	7.85 [8.14]	814	15.7 [11.7]	3280	30.13 [15.55]	3174	44.43 [6.51]	3103	54.67 [16.33]	1860
TADI Cognitive	16.56 [3.64]	1172	23.83 [5.2]	1386	32.77 [6.07]	3246	42.1 [5.16]	3162	47.48 [3.67]	3072	49.95 [2.82]	1837
TADI Motor	18.43 [3.66]	1176	26.66 [4.49]	1389	33.22 [4.63]	3235	40.15 [3.98]	3157	44.12 [2.95]	3082	45.77 [1.93]	1830
TADI Language	17.57 [3.4]	1176	26.26 [4.85]	1382	33.76 [4.94]	3245	42.6 [5.76]	3161	49.22 [4.27]	3080	52.58 [3.08]	1852
Battelle	82.6 [16.19]	1084	111.34 [17.91]	1377	133.69 [19.93]	3234	157.87 [19.29]	3132	174.89 [15.54]	3070	184.66 [12.54]	1843

Table 3. Ordinary Least Squares Regressions of Behavioral Outcomes

	Child Behavioral Checklist						
	Anxiety/ Depression	Withdrawn	Somatic Complaints	Attention Problems	Aggression	Emotional Reactivity	Sleep Problems
	Age 2						
Total hours sleep per day	0.09 [-0.04 - 0.22]	-0.04 [-0.15 - 0.07]	0.04 [-0.08 - 0.16]	-0.08* [-0.18 - 0.01]	-0.18 [-0.57 - 0.21]	-0.05 [-0.18 - 0.08]	-0.04 [-0.16 - 0.09]
Early Bedtime	-0.11 [-0.48 - 0.26]	0.05 [-0.26 - 0.36]	0.11 [-0.23 - 0.44]	0.01 [-0.26 - 0.28]	0.26 [-0.85 - 1.38]	0.15 [-0.22 - 0.51]	-0.14 [-0.50 - 0.21]
Late Bedtime	0.04 [-0.39 - 0.48]	0.33* [-0.04 - 0.69]	0.41** [0.02 - 0.80]	0.34** [0.02 - 0.65]	0.94 [-0.36 - 2.24]	0.20 [-0.23 - 0.63]	1.04*** [0.63 - 1.45]
	Age 3						
Total hours sleep per day	-0.05 [-0.15 - 0.04]	-0.02 [-0.09 - 0.06]	0.04 [-0.05 - 0.12]	-0.06* [-0.12 - 0.00]	-0.32** [-0.58 - -0.07]	0.00 [-0.09 - 0.09]	-0.08** [-0.17 - -0.00]
Early Bedtime	-0.05 [-0.30 - 0.21]	0.12 [-0.09 - 0.32]	-0.05 [-0.28 - 0.18]	0.05 [-0.12 - 0.22]	0.35 [-0.35 - 1.05]	0.06 [-0.18 - 0.30]	-0.20* [-0.43 - 0.02]
Late Bedtime	0.16 [-0.13 - 0.45]	0.32*** [0.09 - 0.56]	0.37*** [0.10 - 0.63]	0.21** [0.01 - 0.40]	1.52*** [0.72 - 2.33]	0.44*** [0.16 - 0.72]	0.92*** [0.66 - 1.18]
	Age 4						
Total hours sleep per day	-0.02 [-0.13 - 0.08]	-0.02 [-0.10 - 0.06]	-0.07 [-0.16 - 0.02]	-0.08** [-0.15 - -0.01]	-0.15 [-0.42 - 0.13]	-0.09* [-0.19 - 0.01]	-0.08* [-0.16 - 0.01]
Early Bedtime	-0.09 [-0.35 - 0.17]	-0.11 [-0.32 - 0.09]	0.01 [-0.22 - 0.25]	0.04 [-0.14 - 0.21]	-0.02 [-0.72 - 0.68]	-0.08 [-0.32 - 0.17]	-0.40*** [-0.61 - -0.19]
Late Bedtime	0.02 [-0.28 - 0.33]	0.04 [-0.20 - 0.28]	0.1 [-0.18 - 0.37]	0.04 [-0.17 - 0.25]	0.93** [0.11 - 1.76]	0.1 [-0.19 - 0.39]	0.85*** [0.60 - 1.10]
	Age 5						
Total hours sleep per day	-0.06 [-0.17 - 0.04]	-0.08* [-0.16 - 0.00]	-0.02 [-0.12 - 0.08]	-0.05 [-0.12 - 0.02]	-0.21 [-0.50 - 0.07]	-0.03 [-0.13 - 0.08]	-0.05 [-0.14 - 0.04]
Early Bedtime	0.01 [-0.25 - 0.28]	0.01 [-0.19 - 0.21]	0.04 [-0.20 - 0.28]	-0.08 [-0.25 - 0.10]	-0.21 [-0.90 - 0.47]	0.03 [-0.22 - 0.28]	-0.28** [-0.50 - -0.05]
Late Bedtime	0.27* [-0.05 - 0.59]	0.23* [-0.01 - 0.46]	0.2 [-0.09 - 0.49]	0.11 [-0.10 - 0.31]	1.40*** [0.57 - 2.22]	0.43*** [0.12 - 0.74]	1.10*** [0.82 - 1.37]

	Anxiety/ Depression	Withdrawn	Somatic Complaints	Attention Problems	Aggression	Social Problems	Thinking Problems	Disruptive Behavior
	Age 6							
Total hours sleep per day	-0.05 [-0.25 - 0.14]	-0.03 [-0.15 - 0.08]	-0.06 [-0.18 - 0.06]	-0.20** [-0.39 - -0.02]	-0.27* [-0.56 - 0.01]	-0.09 [-0.24 - 0.06]	-0.23*** [-0.37 - -0.10]	-0.11* [-0.23 - 0.02]
Early Bedtime	0.02 [-0.45 - 0.48]	0.05 [-0.21 - 0.32]	-0.09 [-0.37 - 0.19]	0.08 [-0.36 - 0.51]	0.28 [-0.40 - 0.95]	0.15 [-0.21 - 0.51]	0.04 [-0.28 - 0.35]	0.00 [-0.29 - 0.30]
Late Bedtime	0.69** [0.13 - 1.26]	0.37** [0.06 - 0.69]	0.42** [0.08 - 0.76]	0.70*** [0.18 - 1.22]	1.41*** [0.60 - 2.22]	0.59*** [0.16 - 1.01]	0.61*** [0.23 - 0.99]	0.51*** [0.16 - 0.87]

Notes: additional controls include age, age squared, child sex, whether child napped, father's and mother's highest grade completed, hours mother worked per week, household income quintile, mother's quantitative and vocabulary WAIS scores, and HOME scores. * p<0.05, **p<0.01, ***p<0.001

Table 4. Ordinary Least Squares Regressions of Cognitive and Motor Outcomes

	PPVT	TADI Cognitive	Battelle	TADI Language	TADI Motor
	Age 2				
Total hours sleep per day	-0.07 [-0.54 - 0.40]	-0.05 [-0.26 - 0.16]	-0.12 [-0.87 - 0.63]	0.08 [-0.11 - 0.27]	-0.09 [-0.28 - 0.10]
Early Bedtime	-0.26 [-1.60 - 1.08]	0.35 [-0.26 - 0.95]	0.88 [-1.25 - 3.01]	0.04 [-0.51 - 0.58]	-0.18 [-0.73 - 0.36]
Late Bedtime	1.97** [0.45 - 3.50]	0.57 [-0.14 - 1.27]	-0.22 [-2.71 - 2.27]	-0.05 [-0.68 - 0.58]	0.02 [-0.61 - 0.66]
	Age 3				
Total hours sleep per day	0.17 [-0.18 - 0.51]	0.07 [-0.10 - 0.24]	0.11 [-0.47 - 0.69]	0.04 [-0.11 - 0.18]	0.03 [-0.10 - 0.16]
Early Bedtime	-0.16 [-1.09 - 0.78]	-0.08 [-0.53 - 0.37]	0.57 [-1.01 - 2.15]	0.25 [-0.14 - 0.64]	0.17 [-0.19 - 0.54]
Late Bedtime	0.21 [-0.87 - 1.30]	-0.51* [-1.04 - 0.01]	-2.13** [-3.96 - -0.31]	-0.04 [-0.49 - 0.41]	-0.45** [-0.87 - -0.03]
	Age 4				
Total hours sleep per day	-0.06 [-0.56 - 0.43]	0.12 [-0.04 - 0.27]	-0.04 [-0.64 - 0.56]	-0.06 [-0.24 - 0.11]	-0.04 [-0.17 - 0.08]
Early Bedtime	-0.02 [-1.28 - 1.23]	-0.14 [-0.53 - 0.25]	-0.5 [-2.02 - 1.02]	-0.03 [-0.47 - 0.41]	0.12 [-0.20 - 0.44]
Late Bedtime	1.07 [-0.41 - 2.55]	-0.38 [-0.83 - 0.08]	-1.73* [-3.51 - 0.06]	-0.12 [-0.64 - 0.39]	-0.2 [-0.57 - 0.17]
	Age 5				
Total hours sleep per day	-0.15 [-0.71 - 0.42]	0 [-0.13 - 0.12]	-0.31 [-0.83 - 0.20]	-0.08 [-0.22 - 0.07]	-0.04 [-0.15 - 0.06]
Early Bedtime	0.75 [-0.61 - 2.11]	-0.05 [-0.35 - 0.26]	0.21 [-1.04 - 1.46]	0.08 [-0.27 - 0.44]	-0.17 [-0.43 - 0.08]
Late Bedtime	-1.45* [-3.10 - 0.19]	-0.33* [-0.69 - 0.04]	-1.90** [-3.42 - -0.39]	-0.64*** [-1.07 - -0.21]	-0.60*** [-0.90 - -0.29]
	Age 6				
Total hours sleep per day	0.12 [-0.63 - 0.86]	0.08 [-0.05 - 0.21]	0.59** [0.03 - 1.16]	0.09 [-0.05 - 0.23]	0.11** [0.03 - 0.19]
Early Bedtime	-1.78** [-3.54 - -0.01]	-0.31** [-0.61 - -0.01]	-1.32* [-2.65 - 0.01]	-0.29* [-0.62 - 0.03]	0 [-0.20 - 0.20]
Late Bedtime	0.21 [-1.90 - 2.33]	-0.06 [-0.42 - 0.30]	-1.41* [-3.01 - 0.19]	0.09 [-0.31 - 0.48]	-0.16 [-0.40 - 0.08]

Figure 1. Median CBCL score by age, early versus late bedtime quartiles.