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The Relationship Between Sleep Duration and Mood in Adolescents: A systematic review and meta-analysis

Running head: Sleep Duration and Mood in Adolescents

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SUMMARY

Insufficient sleep has been argued to result in deleterious changes to mood in adolescents and offers promise as a modifiable risk factor. A systematic review of the literature regarding sleep duration and mood in adolescents was conducted using the academic databases PsycINFO, PubMed, Medline, Scopus, and EMBASE to identify relevant literature. Seventy-four studies, including 361,505 adolescents were sourced out of the 1534 references identified, 73 of which were appropriate for meta-analysis. Pooled results indicated that less sleep was associated with a 55% increase in the likelihood of mood deficits. Positive mood showed the largest relationship with sleep duration, followed by anger, depression, negative affect and anxiety. Effect sizes also varied according to study design, how sleep was operationalised, and geographical region, but not according to the inclusion of covariates. Sleep duration has a significant negative impact on a range of mood states in healthy adolescents. These effects were witnessed across all geographical regions, highlighting that sleep is a universal and modifiable risk factor for preventing mood deficits in this at-risk population.

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Keywords: adolescence, teens, sleep duration, mood, affect, depression, anxiety.

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INTRODUCTION

Despite being identified as a strong correlate of adolescent mental and physical health, academic performance, and relationship quality (1-3), literature examining the causal contributors to adolescent mood is limited which, in turn, hinders the development of intervention strategies. Understanding causal contributors to mood is paramount for adolescents, who run a heightened risk of developing a mood disorder as the result of the psychological, social and physiological shifts that occur at this developmental stage (4). One survey of over 10,000 U.S. adolescents aged 13 to 18 years found a lifetime prevalence of anxiety disorders of 31.9% and a lifetime prevalence of mood disorders of 14.3% (5). Adolescence is a vulnerable period during which the onset of many mood disorders occur (6, 7). Mood disorders such as depression and anxiety often have a chronic and recurrent course, with earlier age of onset associated with poorer educational, social and quality of life outcomes (4). Indeed, mental illness conveys one of the largest disease burdens of all health conditions in terms of both mortality and morbidity (8), with depression projected to be the second leading cause of disease burden worldwide by 2020 (9).

One factor posited to have a causal relationship with mood is sleep (10-12). Research has identified sufficient sleep as a contributor to optimal mood and the ability to better regulate emotions (12-14). Despite the extant evidence highlighting the importance of sleep across a range of psychological outcomes, the overwhelming majority of adolescents obtain insufficient sleep (15-17). For example, a National Sleep Foundation Poll reported that more than 87% of U.S. high school students obtain less than the recommended hours of sleep (18). It is recommended that adolescents obtain between 8 and 10 hours of sleep per night (14, 19, 20), however, bedtimes delay across adolescence while the need to rise for school remains the same or moves even earlier, thus limiting sleep (21, 22). Several factors unique to

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adolescence contribute to short sleep, including the puberty-related delay in circadian timing, slower accumulation of homeostatic sleep pressure in the evening, earlier school start times, diminished parental involvement in setting bedtimes, and increased autonomy over the use of electronic devices

Considering the prevalence of shortened sleep in adolescents, and the importance of mood as a contributor to mental health, it is imperative to consider the effects of insufficient sleep on adolescent mood. A recent systematic review and meta-analysis examined the relationship between sleep and depression in adolescents across 23 studies (23). The meta-analysis revealed that depressed adolescents experienced more wakefulness in bed through taking longer to fall asleep and more wakefulness during the night, and they reported more subjective sleep disturbances. Examination of the longitudinal trajectories of both sleep and depression suggested that sleep disturbance was a precursor for the development of depression (23). The present review expands on this work by examining mood more broadly, to include a range of both positive and negative mood states, rather than focusing solely on mental health diagnoses. While positive and negative mood are sometimes conceptualised as occurring at either end of the same spectrum of mood, they can also be regarded as independent constructs. As such, including discrete mood states acknowledges that, (a) mood occurs on a spectrum broader and more nuanced than simply the presence or absence of mental illness, and (b) that positive moods also play an important role in mental health.

In addition, while the relationship between sleep and mood is relatively well established in clinical samples, less is known about whether mood changes are induced in otherwise healthy adolescents when subjected to shorter sleep durations. As such, the present review includes only non-clinical samples of adolescents. Establishing a causal relationship between sleep and mood in healthy adolescents will support the development of mainstream interventions regarding sleep that may be implemented by schools, policymakers and parents

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to assist in the healthy development of adolescents and foster an early intervention approach to sleep and mental health. The present review examines the academic literature to understand the relationship between sleep duration and mood in adolescents. We also investigate whether the relationship between sleep duration and mood varies according to factors such how sleep is measured, which mood state is assessed, geographical location, study design, and the inclusion of covariates.

METHOD

A literature search was used to identify original studies examining the relationship between sleep duration and mood in adolescents. Relevant literature was sourced using the academic databases PsycINFO, PubMed, Medline, Scopus, and EMBASE in December 2018. The following basic search string was developed through pre-searches in PubMed and applied in all four databases: ((happiness OR suicidal OR antagonism OR apathy OR oppositionality OR euphori* OR depress* OR tense* OR tension OR irrita* OR annoyed OR hostil* OR hate* OR frustrat* OR rage OR moods OR mood OR moody OR anxious* OR temper OR emotion* OR anxiety OR distress* OR anger* OR angry OR happy* OR sad OR sadness OR confus* OR upset) AND ("sleep duration" OR "sleep deprivation" OR "sleep loss" OR "total sleep" OR "sleep restriction") AND (adolescen* OR youth* OR teenager* OR teen OR teens)). Searches occurred on December 14 and 17, 2018. All terms were searched with a combination of the fields “Title”, “Abstract” and “MeSH/Thesaurus” (when available) for best possible search precision. No filters or limitations except for “English language only” were applied to ensure inclusion of pre-indexed materials. A total of 2,162 references were identified through the search and uploaded to the systematic review software Covidence for de-duplication, blinded screening and extraction. A detailed search log

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including all search strings, results and notes is available in Appendix A. This review is registered on Prospero, ID CRD42017068617.

Studies were included if they were primary peer-reviewed journal articles or articles in press, included participants aged 10 to 19 years, as per the World Health Organisation definition of adolescence (24), examined the relationship between sleep duration and mood, and were published in English. Studies that did not report the relationship between sleep and mood in a healthy population (i.e., included clinical population only), or that included pharmacological interventions, were excluded. No exclusion criteria were applied regarding the date of publication to capture all relevant published original research. Data extracted from each study included authors, year of publication, sample size, region (Asia, Australia and New Zealand, Europe, or North America), age range, proportion of male participants, how sleep duration and mood were operationalised, study design, and effect size.

Forty-two, out of the 74 included studies, utilised a cross-sectional design. As such, study quality was assessed for selection bias, information bias, and confounding, which are the three primary sources of bias in these studies (16, 25). Selection bias was assessed using three criteria: Were inclusion criteria given and applied uniformly? Did the sampling strategy achieve a sample representative of the target population? Was the response rate ≥80%? Information bias refers to the reliability and validity of study measures. As subjective measures contain a higher risk of bias due to factors such as social desirability responding and inaccuracy, information bias was assessed using one criterion: Was the IV (sleep duration) measured objectively? Finally, the risk of confounding variables was assessed using one criterion: Did the study assess and statistically adjust for confounding variables?

Statistical Analyses

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The effect sizes were coded to represent the odds of mood deficits with shorter sleep durations; thus, higher values represent worse mood outcomes (for example, greater anger, anxiety, depressed mood and negative affect and/or decreased positive mood affect) with less sleep. Because the selected studies were carried out in different settings and evidence of high level of heterogeneity, random-effects model was employed to calculate the overall effect from effect sizes. Between-study heterogeneity was assessed using I-square (I^2) test (26). A priori subgroup analyses were performed to explore the impact on the effect size. Five subgroup analyses were performed to investigate if the relation between sleep duration and mood was different: 1) Region - Asia, Australia/New Zealand, Europe and North America, 2) Study design – Experimental, longitudinal or cross-sectional, 3) Covariate adjustment – demographics (such as sex or age), others (such as family income or parental years of education, snoring), none, 4) Mood – anger, depressed mood, anxiety, positive effect and negative effect, 5) Sleep operationalisation – actigraphy, sleep diary, questionnaires or PSG. While anger, depressed mood and anxiety could all be classified as aspects of negative affect, because it was possible to include these more specific classifications of negative affect, we chose to do this where possible to allow for a more fine-grained evaluation across different mood states.

Heterogeneity between subgroups was evaluated using random-effect model. Two-sided p-values ≤ 0.05 were considered statistically significant for all tests. To calculate the overall effect size, same studies reporting several mood effects were combined by intrastudy meta-analyses to create independent effect sizes required for the meta-analysis (27). Publication bias was assessed visually using a funnel plot.

RESULTS

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Results of the literature search revealed 74 studies including 361,505 adolescents. The PRISMA flow chart detailing the systematic screening and identification of studies is shown in Figure 1. Studies included mood states such as positive affect (N=10), negative affect (N=11), depressed mood (N=50), anger (N=5), anxiety (N=26), confusion (N=3), irritability (N=3), oppositionality (N=1), stress (N=1), mood (N=1), happiness (N=2), sadness (N=1) and nervousness (N=2). Of the 74 studies, 44 used subjective self-report to measure sleep duration, nine used sleep diaries, 16 used actigraphy, and five used polysomnography (PSG). Examination of study design reveals varied approaches, with 42 cross-sectional, 19 longitudinal and 13 experimental studies identified. The majority of included studies (N=29) were conducted in North America, with 17 studies from Europe, 17 from Asia and 11 from Australia. A summary of the included studies is provided in Table 1.

Insert Figures 1 and 2 here

Meta-analytic results are shown in Figure 2. Overall, results indicated that shorter sleep durations were associated with a 55% increased risk of mood deficits, $OR = 1.55$, $p < .001$. Effects sizes were significantly heterogeneous between studies, $I^2 = 97.9$, $p < .001$. To examine whether the effect of sleep duration on mood varied depending on the type of mood state assessed, study design, geographical region, inclusion of covariates, or how sleep was operationalised, further meta-analyses were conducted. Effect sizes for each subgroup are provided in Table 2.

Effect sizes significantly varied between mood states, Q (4) = 88.23, $p < .001$. Mood states that were examined in fewer than 4 studies were not included as effect size estimates are less reliable when fewer than 4 studies are included. Positive affect showed the largest deficits following shorter sleep, followed by anger, depression, negative affect and anxiety. There was significant heterogeneity among effect sizes according to how sleep was operationalised, Q (3) = 57.01, $p < .001$. Studies measuring sleep using polysomnography

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had the largest effect sizes on mood, followed by questionnaires, actigraphy and sleep diaries. Effect sizes varied according to study design, Q (2) = 144.28, $p < .001$. Experimental and longitudinal studies revealed larger effect sizes between sleep duration and mood than cross-sectional studies. There was significant heterogeneity among effect sizes according to geographical region, Q (3) = 46.98, $p < .001$, with North American studies reporting larger effect sizes, followed by European studies, Australian and New Zealand studies and Asian studies. Effect sizes were not significantly heterogenous according to the covariates included, Q (2) = 5.58, $p = .06$. Results of the risk of bias assessment is shown in Figure 3. A funnel plot of effect sizes is show in Figure 4 and appears symmetrical, indicating no significant publication bias.

Insert Figure 3 and 4 here

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Table 1. Summary of articles identified in the systematic review. Note: S = subjective, O = objective, P = prospective, C = cross-sectional, L = longitudinal, E = experimental, TST = total sleep time, TIB = time in bed.

First Author (Year)	N	Country	Sleep	Mood variable	Study design	Summary
Barnes & Meldrum (2014) (28)	563	US	S	Depressed mood	C	Significant negative association between sleep duration and depressed mood
Bauducco et al., (2016) (29)	1,057	Sweden	S	Depressed mood, anger, anxiety	C	Significant dose-dependent effect of sleep duration on depressed mood, anger and anxiety among 12-13yo and 14-16yo
Baum et al., (2014) (30)	50	US	O	Anxiety, depression, anger, fatigue, confusion, vigour	E	Adolescents reported more anxiety, anger, fatigue, confusion and less vigour with sleep restricted to 6.5h TIB for 5 nights compared to 10h TIB for 5 nights. No changes to depression were found
Beebe et al., (2008) (31)	19	US	O	Oppositionality/ irritability	E	Parents, but not adolescents, reported that adolescents were more irritable/oppositional during short vs extended sleep
Bei et al., (2013) (32)	9	Australia	O	Generalized anxiety,	L	The small increase in TST post-intervention was associated with a small increase in general anxiety
Bei et al., (2017) (33)	146	Australia	O	Negative mood (depressed mood and anxiety)	C	No significant association between negative mood (depressed mood and anxiety) and TIB during school holidays
Boergers et al., (2014) (34)	197	US	S	Depressed mood	L	Depressed mood decreased after a 30-minute delay to school start times
Bonnar et al., (2015) (35)	141	Australia	S	Depressed mood	L	Depressed mood decreased following a sleep education program after an increase in school night TST of 27 minutes
Chan et al., (2018) (36)	82	Hong Kong	S	Depression, anxiety, stress	L	Depression, anxiety and stress decreased following a delay in school start time by one hour and increase in TST.
Chue et al., (2018) (37)	89	US	O	Positive affect, negative affect	L	Higher objectively measured TST was associated with better mood recovery following stress for positive and negative affect
Conklin et al., (2018) (38)	3,017	Canada	S	Depressed mood	L	Chronic sleep deprivation was significantly correlated with depression in females but not males
Dewald-Kaufmann et al., (2014) (39)	55	Netherlands	O	Depressed Mood	E	Adolescents in the sleep extension group obtained more sleep and their depressive symptoms diminished significantly compared to controls
Diaz-Morales (2016) (40)	1406	Spain	S	Anxiety	C	There was a significant negative relationship between TIB and anxiety on school nights but not weekends
Doane & Thurston (2014) (41)	78	US	O	Positive affect, negative affect	C	No significant associations were found between TST and positive or negative affect
Doane et al., (2015) (42)	82	US	O	Anxiety, depressed	L	No significant association between sleep duration at Time 1 and depressed

				mood		mood or anxiety one year later
El-Sheikh et al., (2016) (43)	252	US	O	Depressed mood, anxiety	C	No significant associations between sleep duration and depressed mood or anxiety
Fan et al., (2017) (44)	1,573	China	S	Depressed mood (Dichotomised Y/N)	L	After controlling for depression and covariates at Time 1, sleep duration at T1 did not significantly predict depression at T2
Fredrikson et al., (2004) (45)	2,259	US	S	Depressed mood	L	Students who slept less over time experienced more depressed mood
Fuligni et al., (2017) (14)	419	US	P	Depressed mood and anxiety	L	A non-linear association existed between TST and psychological distress the following day, with both too much and too little sleep were associated with next-day distress.
Hall Brown (2008) (46)	35	U.S.	P	General mood	E	Sleep duration, but not general mood, was better on weekdays than weekends
Hasler (2008) (47)	56	U.S.	NS	Anxiety	E	Sleep extended by one hour per night for 3 consecutive nights did not result in decreased anxiety relative to non-extended group
Hyakutake et al., (2016) (48)	409	Japan	S	Depressed mood	C	U-shaped relationship between sleep duration and depressed mood
Itani et al., (2016) (49)	94,777	Japan	S	Anger	C	Adolescents who slept less than 5h per night were significantly more likely to report anger
Josev et al., (2017) (50)	136	Australia	O	Anxiety	C	TST was not significantly associated with anxiety in healthy controls
Kalak et al., (2012) (51)	80	Switzerland	O	Depressed mood	C	No significant association between objective TST and depressed mood
Kang et al., (2014) (52)	4,145	Korea	S	Depressed Mood	C	Participants who slept less than 7h on school nights reported significantly higher levels of depressed mood
Kelly & El-Sheikh, (2014) (53)	113	U.S.	O	Depressed Mood, anxiety	L	Sleep minutes at T2 (10 years) significantly predicted depressed mood at T3 (13 years) but not anxiety at T3
Kuo et al., (2015) (54)	246	U.S.	P	Depressed mood	C*	No relationship between sleep duration and depressed mood
Lazaratou et al., (2013) (55)	696	Greece	S	Anxiety (state and trait)	C	Sleep duration had a small but significant association with state and trait anxiety
Lee et al., (2016) (56)	3,785	Korea	S	Depressed mood	C	Sleep duration on both weekdays (M-F) and weekends (Sa-Su) had small but significant negative associations with depressed mood
Lee et al., (2012) (57)	8,010	Korea	S	Depressed mood	C	Sleep duration on both weekdays and weekends were significantly and negatively associated with depressed mood
Lee (2017) (58)	31,407	Korea	S	Depressed mood	C	TST was negatively correlated with feelings of sadness and hopelessnes
Lehto et al., (2014) (59)	439	Finland	S	Depressed mood	C	Sleep duration on weekdays and weekends showed a small but significant negative association with depressed mood
Lemola et al., (2011) (60)	190	Germany Austria Switzerland	S	Depressed mood	C	No significant association between sleep duration and mood on weekdays not weekends

Lemola et al., (2015) (61)	362	Switzerland	S	Depressed mood	C	Sleep duration was negatively associated with depressed mood
Lin et al., (201 (62)	2,472	Taiwan	S	Emotional wellbeing (Happiness & Depressed mood)	L	Adolescents who slept less than 6h per night were significantly more likely to have low levels of emotional well-being
Liu & Zhou (2002) (63)	1,359	China	S	Anxious/depressed mood subscale	C	Adolescents sleeping less than 8h had significantly higher odds of depressed mood and anxiety than those with 9h or more.
Lo et al., (2017) (64)	57	Singapore	O	Positive affect, negative affect	E	Sleep restriction lead to reduced positive affect but no change to negative affect
Lo et al., (2016) (65)	56	Singapore	O	Positive affect, negative affect	E	Sleep restriction diminished positive affect but not negative affect
Lovato et al., (2017) (66)	138	Australia	S	Depressed mood	L	Sleep duration at T1 did not predict depressed mood 1 year later, however, T1 TST was associated with depressed mood at T1
Maume (2017) (67)	974	U.S.	S	Depressed Mood	L	Sleep duration had a negative correlation with depressive symptoms.
Mazzer et al., (2018) (68)	951	Sweden	S	Depressed mood, anxiety	L	Sleep duration had a negative correlation with psychological distress
McGlinchey et al., (2011) (69)	38	U.S.	O	Computerised and human rated positive and negative emotions	E	Compared to when well-rested, sleep restricted to 2h decreased positive emotional expression but did not affect negative emotion using computer text analysis, and less positive emotional expression and more negative emotion using human raters
McMakin et al., (2016) (70)	64	US	O	Positive affect, negative affect	E	Experimental sleep restriction to 4h TIB led to decreased positive affect and increased negative affect compared to affect following a 10h sleep opportunity
Moore et al., (2009) (71)	247	US	O	Anxiety, depressed mood	C	Sleep duration was not significantly associated with depressed mood or anxiety
Mullin et al., (2017) (72)	17	US	P	Morning Anxiety	L	No significant relationship between sleep duration and anxiety morning
Norell-Clarke & Hagquist (2018) (73)	15,221	Sweden	S	Sadness, nervousness, irritation	C	Individuals sleeping less than 8 hours were more likely to report feeling sad, nervous and irritated than those sleeping more than 8 hours
Nowakowski et al., (2016) (74)	1,042	US	S	Depressed mood	L	After controlling for depressed mood at T1, sleep duration at T2 significantly predicted depressed mood one year later
Nuutinen et al., (2014) (75)	4,985	Denmark, Finland, France	S	Negative affect (feeling low, irritable, nervous)	C	Significant negative associations were found between sleep duration and negative affect among all adolescents except for Danish males.
Oginska & Pokorski, (2006) (76)	191	Poland	S	Negative mood	C	No association between TIB on school nights and negative mood
Ojio t al., (2016) (13)	15,637	Japan	S	Depression and	C	Depression/anxiety symptoms were the lowest in males and females who

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				anxiety (above/below cut-off)		slept 8.5–9.5 h and 7.5–8.5 h, respectively and worse for both shorter and longer sleepers
Owens et al., (2010) (77)	201	US	S	% reporting being at least somewhat unhappy or depressed, % reporting feeling irritated or annoyed, Depressed mood	E	A 30m delay to school start time led to a 45m increase in TST on school nights, less depressed mood, and a significantly lower proportion of adolescents who reported feeling at least somewhat unhappy or depressed or feeling irritated or annoyed
Pallesen et al., (2010) (78)	1,279	Norway	S	Anxiety, Depression	C	Short sleepers (<7h) had significantly higher depressed mood but not anxiety when compared to normal sleepers (≥7h)
Pasch et al., (2010) (79)	242	US	S	Depressed mood	C	Depressed mood was negatively associated with depressed mood and school night sleep duration, but not weekend sleep duration
Randler & Weber, (2015) (80)	219	Germany	S	Positive affect, Negative affect	C	Negative, but not positive, affect was significantly associated with TST the prior night. Neither positive or negative affect were related to habitual sleep duration
Raniti et al., (2017) (81)	695	Australia	S	Depressed mood	C	School night sleep duration was negatively associated with depressed mood
Reddy et al., (2017) (82)	42	US	O	Positive affect Negative affect State Anxiety Trait Anxiety	E	Adolescents whose sleep was restricted to 4h TIB for one night reported significantly less positive affect and greater state and trait anxiety, but not negative affect, than adolescents who had 9.5h TIB
Roberts & Duong (2014) (83)	3,134	US	S	Depression symptoms	L	Short sleep was a much larger predictor of major depression than depression symptoms.
Sarchiapone et al., (2014) (84)	11,788	Austria Estonia France Germany Hungary Ireland Israel Italy Romania Slovenia Spain	S	Anxiety	C	School night sleep duration showed a small negative relationship with anxiety
Seo et al., (2017) (85)	26,395	Korea	S	Depressed mood	C	School night sleep duration had a small but significant negative association with depressed mood
Shen et al., (2018) (86)	4,582	Australia	S	Happiness, positive	C	Short sleep was associated with lower happiness and positive affect, and

				affect, negative affect		higher negative affect.
Short & Louca (2015) (87)	12	Australia	O	Depressed mood, anger, confusion, anxiety	E	Depressed mood, anger, confusion and anxiety all significantly increased following one night without sleep
Short et al., (2013a) (88)	385	Australia	P	Depressed mood	C	Significant negative relationship between sleep duration and depressed mood
Short et al., (2013b) (21)	258^	Australia	P	Anxiety	C	Significant negative relationship between sleep duration and anxiety
Singh et al., (2018) (89)	501	India	S	Depressed mood	C	TST was not significantly correlated with depressed mood
Stheneur et al., (2017) (90)	855	France	P	Depressed mood	C	TST was negatively correlated with depressed mood
Suzuki et al., (2011) (91)	99,668	Japan	S	Depression/ anxiety, loss of positive emotion	C	Sleep duration of less than 7h, but not 8h or more, was associated with increased depression/anxiety and loss of positive emotion, while sleep of 8 h or more was associated with greater loss of positive emotion
Van Dyk et al., (2017) (92)	54	US	O	Anxiety, Depressed mood, anger, confusion	E	Extended sleep (average of 72 minutes) resulted in lower anger and confusion.
Wahlstrom et al., (2017) (93)	8,261	US	S	Feeling unhappy, sad, or depressed, and feeling nervous or tense	C	Adolescents who slept longer on school nights were significantly less likely to report feeling unhappy, sad or depressed or nervous or tense
Warner et al., (2008) (94)	307	Australia	S	Depressed mood	C	Significant association between school night TST and depressed mood, with less sleep associated with worse mood
Watson & Brickson, (2018) (95)	65	UK	P	Mood	L	TST negatively correlated with mood
Wolfson & Carskadon, (1998) (22)	2,166	US	S	Depressed mood	C	Adolescents sleeping ≥8h15m had significantly lower levels of depressed mood than those sleeping ≤6h45m
Yang & Cha (2018) (96)	421	Korea	S	Depressed mood	C	TST negatively correlated with depressed mood
Yip (2015) (97)	146	US	P	Depressed mood, anxiety	C	No significant associations between weekly sleep duration and depressed mood or anxiety

*Cross-sectional data drawn from a longitudinal study; ^Subsample of above study

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Table 2. Meta-analyses of studies examining the relationship between sleep duration and mood in adolescents. The number of studies for mood states category equal more than (Total N of studies) as some studies included more than one mood state.

	k	*OR*	*Lower limit*	*Upper limit*	*p*
Overall	**73**	**1.55**	**1.44**	**1.67**	**<.001**
Mood State					
Depressed Mood	43	1.62	1.38	1.85	<.001
Anxiety	22	1.41	1.29	1.54	<.001
Anger	9	1.83	1.51	2.15	<.001
Negative Affect	20	1.60	1.49	1.71	<.001
Positive Affect	9	2.02	1.62	2.42	<.001
Sleep Measurement					
Questionnaires	45	1.55	1.44	1.67	<.001
Sleep Diary	9	1.30	1.11	1.49	<.001
Actigraphy	14	1.45	1.28	1.62	<.001
PSG	5	1.70	1.20	2.20	<.001
Region					
Asia	16	1.34	1.19	1.50	<.001
Australia and New Zealand	11	1.42	1.22	1.62	<.001
Europe	17	1.47	1.34	1.60	<.001
North America	29	1.70	1.43	1.98	<.001
Study design					
Experimental	13	1.72	1.48	1.97	<.001
Longitudinal	19	1.71	1.31	2.10	<.001
Cross-sectional	41	1.42	1.31	1.53	<.001
Covariates					
None	45	1.67	1.48	1.85	<.001
Demographics	12	1.44	1.27	1.60	<.001
Others	16	1.28	1.18	1.38	<.001

Note. k = no. of studies; OR = Odds Ratio; PSG=polysomnography

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DISCUSSION

The present systematic review and meta-analysis identified 74 original studies, including over 360,000 adolescents, that examined the effect of sleep duration on mood. Of these, 73 studies were suitable for meta-analysis. Shorter sleep duration significantly increased the odds of adolescents experiencing mood deficits by 55%. Mood deficits due to shorter sleep were observed across mood states including depression, anxiety, anger, positive affect and negative affect, indicating that short sleep can lead to a range of mood deficits in otherwise healthy, non-clinical samples of adolescents. While strong research evidence exists to support the casual role of sleep in mood, the important task of estimating the sleep duration for optimal mood is only just emerging (13, 14). Fuligni and colleagues used two weeks of daily estimates of sleep duration and mood to determine the average amount of sleep needed for the lowest levels of next-day depressed mood and anxiety. Estimates revealed that 9-hours sleep per night was needed for optimal mood and that this optimum tended to be greater among younger adolescents and among those with higher levels of psychopathology (14). These estimates concur with estimates of sleep durations for optimal cognitive functioning and with current sleep recommendations (19, 20, 98).

There was significant heterogeneity in effect sizes according to the mood state measured. Shorter sleep durations doubled the odds of adolescents experiencing reduced positive affect, and increased the odds of anger by 83%, depressed mood by 62%, negative affect by 60% and anxiety by 41%. The finding that positive mood is most affected by sleep loss is consistent with recent research (65, 86). For example, Shen and colleagues examined the associations between sleep duration and mood in 4,582 adolescents. They found that the association between sleep loss and mood was stronger for happiness and positive affect than it was for negative affect. Anhedonia, or the reduced ability to experience pleasure from normally pleasurable activities, is a clinically significant symptom and diminishes quality of

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life among those experiencing it. These results highlight an important potential mechanism between short sleep and mood disorders through reduced enjoyment or pleasure and elucidates the importance of measuring moods beyond common measures of depression and anxiety (99).

While anhedonia is one mechanism through which sleep loss may affect mood, there are many additional pathways and mechanisms posited to account for this relationship. Sleep loss is known to effect brain regions implicated in mood and emotion regulation. Sleep loss reduced prefrontal activity and reduced functional connectivity between the prefrontal cortex and limbic regions (100). Sleep loss also reduces rapid eye movement (REM) sleep, which is implicated in the processing of emotional memories (101). Finally, sleep loss negatively effects cognitive functioning, many of which processes are needed for affective monitoring, reasoning and emotion regulation (12, 20, 102). For example, the repetitive negative thinking that is a transdiagnostic risk factor for various mental health conditions is argued to be maintained by sleep loss as sleep loss diminishes a person's ability to shift attention away from their repetitive negative thoughts (103).

In addition to differences between mood states, results indicated that effect sizes varied according to the way sleep was operationalised, the design of the study, and geographical region. Studies that utilised an experimental design to manipulate sleep reported the largest effects between sleep duration and mood. This finding is likely to be due, at least in part, to the observation that experimental studies include meaningful manipulations of sleep duration and by having a control condition that included sleep durations within the recommended range. Given the universality of insufficient sleep among adolescents worldwide, cross-sectional and longitudinal studies are likely to include a more restricted rang of sleep durations and contain a paucity of adolescents whose sleep falls within the recommended range, thus masking the true effect of sleep duration on mood (104). Effect

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sizes from experimental studies are also less likely to be impacted by extraneous variables that are likely confounded with naturalistic sleep loss, such as academic pressure, parental regulation of sleep, and socioeconomic status. Studies using polysomnography to measure sleep duration and mood reported largest effect sizes than those utilising sleep diaries, actigraphy and questionnaires. This may be due to the superior validity of polysomnography and also the improved temporal association between sleep measurement and mood assessment in these studies. Studies using polysomnography typically assessed mood immediately following the objectively measured sleep period, whereas questionnaires ask about "typical" sleep and not the sleep immediately prior to mood assessment. It is important to note, however, that sleep measurement tends to be confounded with study design, as all studies using polysomnography were experimental. Small differences in effect size estimates were observed according to region, with North American studies reporting the largest effect sizes. It is unclear whether these larger effects are due to methodological differences or differences in vulnerability to sleep loss. Cross-cultural studies that directly compare regons using the same methodology are needed to tease apart this finding. Of greater importance was the observation that none of the geographical regions included were spared the negative impacts of shorter sleep durations on mood, with Asia, Europe, North America and Australia and New Zealand studies uniformly similarly finding this relationship. Further studies examining the relationship between sleep and mood in understudied South American, African and Middle eastern countries are needed to understand any potential differences in risk of shorter sleep between countries and/or geographical regions.

The methodological and theoretical implications discussed above provide direction for future research. Firstly, dose-response experimental protocols are required to examine causal relationships between sleep duration and mood. Most of the studies were cross-sectional. Cross-sectional designs are unable to determine the direction of the relationship

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between sleep and mood. This is of central importance as research highlights the bi-directional relationship between these variables (13, 99). In addition, cross-sectional studies cannot determine the degree to which confounding factors, such as diet, long-term habitual sleep loss or varying home environments, influence participants' mood. Secondly, an overwhelming emphasis is placed on negative mood states in reviewed studies which is indicative of a research field that has largely focussed on the relationship between sleep loss and the negative mood states of depression and anxiety. The few studies measuring positive mood states, such as positive affect, happiness and vigour derived findings worthy of further investigation as consistent reductions across positive mood states following short sleep were found.

Finally, mood is often conflated with emotion and emotion regulation in reviewed literature and separation of these concepts will be beneficial in future research (12). As all these factors play a key part in the development and perpetuation of clinical disorders such as depression, obsessive-compulsive disorder, anxiety disorders and posttraumatic stress disorder (12), examining explicit links between sleep duration and emotion and emotion regulation, as well as mood, will allow for more accurate prediction of how short sleep may contribute to mood deficits and dysfunction. Similarly, there are multiple aspects of affective functioning that remain underexplored in relation to sleep, including anhedonia, specific types of emotion regulation strategies, and rumination. It is recommended that psychological disorder-specific models be utilised to further examine how sleep loss contributes to the development of mental health disorders among healthy adolescents and how sleep loss maintains these disorders.

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Conclusion

Sleep duration significantly predicted mood deficits on all mood states, including increased depression, anxiety, anger, negative affect and reduced positive affect. This effect was observed across geographical regions, demonstrating that short sleep is truly a universal risk-factor for mood deficits. Fortunately, sleep loss is an inherently *modifiable* risk-factor, providing a target for intervention at individual, family, community and public policy levels. Interventions to increase sleep duration include increasing parental regulation of sleep and technology use, delayed school start times, ensuring academic pressure and out of school hours tutoring does not impede sleep, and maintaining regular sleep and wake times across school nights and weekends. Targeting sleep in this at-risk population will reduce the likelihood of mood deficits transitioning to clinically significant problems and mood disorders.

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Practice points

1. This systematic review examined the association between sleep duration and mood in 361,505 adolescents from 74 identified studies, 73 of which were suitable for meta-analysis.

2. Pooled results indicated that shorter sleep was associated with a 55% increased risk of mood deficits across mood states.

3. The effect that short sleep had on mood varied according to which mood state was assessed, the study design, the operationalisation of sleep and geographical region.

4. Short sleep has a significant deleterious effect on a range of positive and negative mood states among healthy, non-clinical samples of adolescents. It is imperative that greater focus is given to sleep as for prevention and early intervention for mood deficits.

Research agenda

1. While positive affect showed the largest impact from short sleep, research has largely focussed on negative affect and mood states. Future research would profit by including a range of positive mood states.

2. Dose-response studies of the effect of sleep on a range of mood states are needed to determine the degree of sleep loss at which mood deficits occur, whether they accumulate over time, and the optimal duration of sleep needed for mood.

3. Disorder-specific models of psychiatric conditions include valuable information on those aspects of affective and cognitive-affective functioning that precipitate and maintain mental ill-health. Research is needed that examines mood from a much broader framework to test whether sleep affects mental health through these disorder-specific mechanisms.

4. Research would benefit by including broader aspects of sleep in addition to sleep duration, such as sleep quality, sleep timing, sleep efficiency, sleep regularity and chronotype, as they may all have a unique impact on mood.

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Appendix A

Literature Search

Source	Search string	Result	Notes
Source: PubMed **Coverage:** 1809- **Search Date:** 2018-12-17	(("Adolescent"[Mesh] OR adolescen*[Title/Abstract] OR youth*[Title/Abstract] OR teenager*[Title/Abstract] OR teen[Title/Abstract] OR teens[Title/Abstract]) AND ("sleep duration"[Title/Abstract] OR "sleep deprivation"[Title/Abstract] OR "Sleep Deprivation"[Mesh] OR "sleep loss"[Title/Abstract] OR "total sleep"[Title/Abstract] OR "sleep restriction"[Title/Abstract]) AND ("Confusion"[Mesh] OR happiness[Title/Abstract] OR suicidal[Title/Abstract] OR "Suicidal Ideation"[Mesh] OR antagonism[Title/Abstract] OR apathy[Title/Abstract] OR "Apathy"[Mesh] OR oppositionality [Title/Abstract] OR euphori* [Title/Abstract] OR "Euphoria"[Mesh] OR "Depression"[Mesh] OR depress*[Title/Abstract] OR tense*[Title/Abstract] OR tension[Title/Abstract] OR irrita*[Title/Abstract] OR annoyed[Title/Abstract] OR hostil*[Title/Abstract] OR "Hate"[Mesh] OR "Happiness"[Mesh] OR hate*[Title/Abstract] OR "Hostility"[Mesh] OR frustrat*[Title/Abstract] OR "Frustration"[Mesh] OR "Anxiety"[Mesh] OR rage[Title/Abstract] OR "Anger"[Mesh] OR "Rage"[Mesh] OR "Irritable Mood"[Mesh] OR moods[Title/Abstract] OR mood[Title/Abstract] OR moody[Title/Abstract] OR anxious*[Title/Abstract] OR emotion*[Title/Abstract] OR temper[Title/Abstract] OR anxiety*[Title/Abstract] OR distress*[Title/Abstract] OR anger*[Title/Abstract] OR angry[Title/Abstract] OR happy*[Title/Abstract] OR sad[Title/Abstract] OR sadness[Title/Abstract] OR confus*[Title/Abstract] OR upset[Title/Abstract]) AND (English[lang]))	**781**	All terms searched in the fields "Title/Abstract" and in "MeSH" when available **Filters applied:** English Language

Source: Scopus **Coverage:** 1996- **Search Date:** 2018-12-14	((TITLE ("sleep duration" OR "sleep deprivation" OR "sleep loss" OR "total sleep" OR "sleep restriction") OR ABS ("sleep duration" OR "sleep deprivation" OR "sleep loss" OR "total sleep" OR "sleep restriction"))) AND ((TITLE (adolescen* OR youth* OR teenager* OR teen OR teens) OR ABS (adolescen* OR youth* OR teenager* OR teen OR teens))) AND ((TITLE (happiness OR suicidal OR antagonism OR apathy OR oppositionality OR euphori* OR depress* OR tense* OR tension OR irrita* OR annoyed OR hostil* OR hate* OR frustrat* OR rage OR moods OR mood OR moody) OR ABS (happiness OR suicidal OR antagonism OR apathy OR oppositionality OR euphori* OR depress* OR tense* OR tension OR irrita* OR annoyed OR hostil* OR hate* OR frustrat* OR rage OR moods OR mood OR moody) OR ABS (anxious* OR emotion* OR temper OR anxiety* OR distress* OR anger* OR angry OR happy* OR sad OR sadness OR confus* OR upset) OR TITLE (anxious* OR emotion* OR temper OR anxiety* OR distress* OR anger* OR angry OR happy* OR sad OR sadness OR confus* OR upset))) AND (LIMIT-TO (LANGUAGE , "English"))	**344**	All terms searched in the fields "TITLE" and "ABS" (Abstract). No thesaurus available. **Filters applied:** English Language
Source: PsychInfo (EBSCO) **Coverage:** 1987-	((TI (happiness OR suicidal OR antagonism OR apathy OR oppositionality OR euphori* OR depress* OR tense* OR tension OR irrita* OR annoyed OR hostil* OR hate* OR frustrat* OR rage OR moods OR mood OR moody OR anxious* OR temper OR emotion* OR anxiety OR distress* OR anger* OR angry OR happy* OR sad OR sadness OR confus* OR upset) OR AB (happiness OR suicidal OR antagonism OR apathy OR oppositionality OR euphori* OR depress* OR tense* OR tension OR irrita* OR annoyed OR hostil* OR hate* OR frustrat* OR rage OR moods OR mood OR moody OR anxious* OR temper OR emotion* OR anxiety OR distress* OR anger* OR	**292**	All terms searched in the fields "Title" (TI) and "Abstract" (AB) and in the thesaurus (DE) when available. **Filters applied:** English Language

Search Date: 2018-12-14	angry OR happy* OR sad OR sadness OR confus* OR upset) OR (DE ("Mental Confusion" OR "Happiness" OR "Suicidal Ideation" OR "Hostility" OR "Apathy" OR "Euphoria" OR "Major Depression" OR "Depression Emotion" OR "Irritability" OR "Hate" OR "Frustration" OR "Anger" OR "Moodiness" OR "anxiety" OR "distress" OR "sadness") AND (TI ("sleep duration" OR "sleep deprivation" OR "sleep loss" OR "total sleep" OR "sleep restriction") OR AB ("sleep duration" OR "sleep deprivation" OR "sleep loss" OR "total sleep" OR "sleep restriction") OR DE ("Sleep Deprivation") AND (TI (adolescen* OR youth* OR teenager* OR teen OR teens) OR AB (adolescen* OR youth* OR teenager* OR teen OR teens))		
Source: Embase (Elsevier) **Coverage:** 1947- **All sources included** **Search Date:**	(('sleep duration':ab,ti OR 'sleep deprivation':ab,ti OR 'sleep loss':ab,ti OR 'total sleep':ab,ti OR 'sleep restriction':ab,ti OR 'sleep time'/de OR 'sleep deprivation'/de) AND (adolescen*:ab,ti OR youth*:ab,ti OR teenager*:ab,ti OR teen:ab,ti OR teens:ab,ti OR 'adolescence'/de) AND (happiness:ab,ti OR suicidal:ab,ti OR antagonism:ab,ti OR apathy:ab,ti OR oppositionality:ab,ti OR euphori*:ab,ti OR depress*:ab,ti OR tense*:ab,ti OR tension:ab,ti OR irrita*:ab,ti OR annoyed:ab,ti OR hostil*:ab,ti OR hate*:ab,ti OR frustrat*:ab,ti OR rage:ab,ti OR moods:ab,ti OR mood:ab,ti OR moody:ab,ti OR anxious*:ab,ti OR temper:ab,ti OR emotion*:ab,ti OR anxiety:ab,ti OR distress*:ab,ti OR anger*:ab,ti OR angry:ab,ti OR happy*:ab,ti OR sad:ab,ti OR sadness:ab,ti OR confus*:ab,ti OR upset:ab,ti OR 'suicidal ideation'/de OR 'apathy'/de OR 'euphoria'/de OR 'depression'/de OR 'irritability'/de OR 'hostility'/de OR 'hate'/de OR 'frustration'/de OR 'sadness'/de OR 'happiness'/de OR 'anger'/de OR 'anxiety'/de OR 'mood'/de OR 'rage'/de OR 'confusion'/de) AND	**745**	All terms searched in the fields Title" and "Abstract" (ab,ti) and in "MeSH" (/de) when available **Filters applied:** English Language

Journal Pre-proof

2018-12-14	([english]/lim))		
Total no. of references located		**2162**	
Total no. of references after de- duplication		**1532**	

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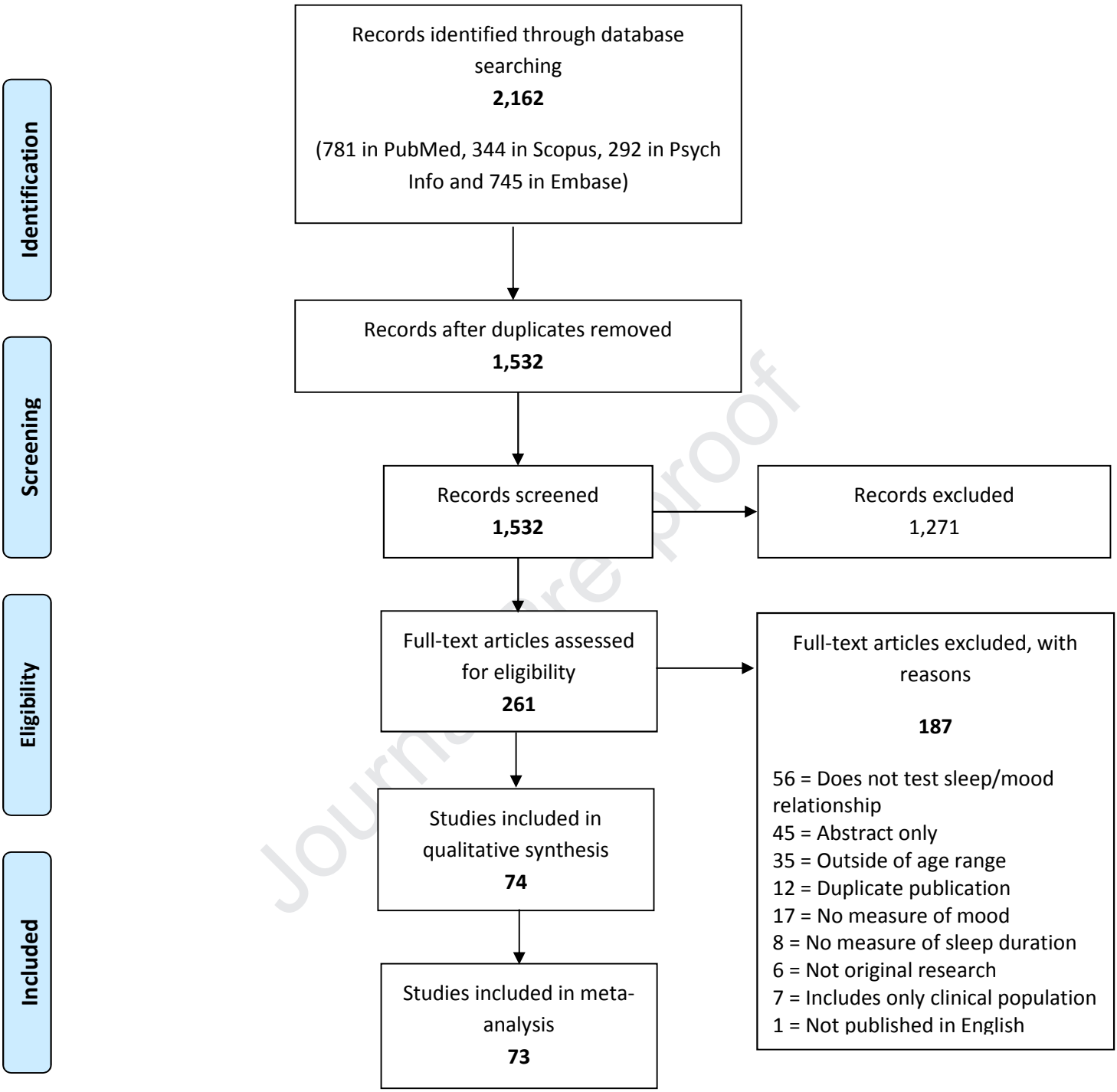

Figure 1. PRISMA diagram showing the results of the literature search.

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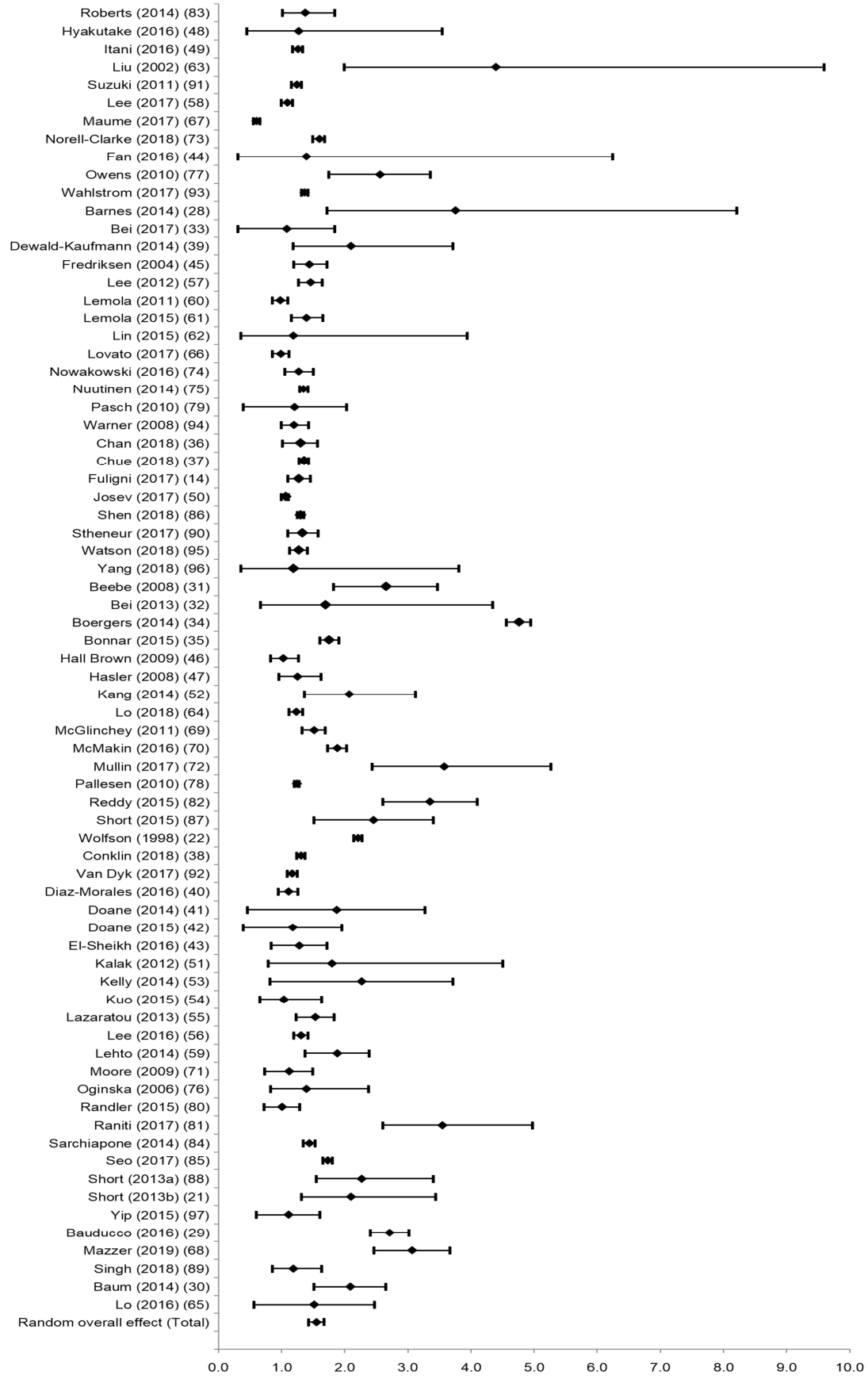

Figure 2. Forest plot showing effect sizes for individual studies, together with the random overall effect size in odds ratios.

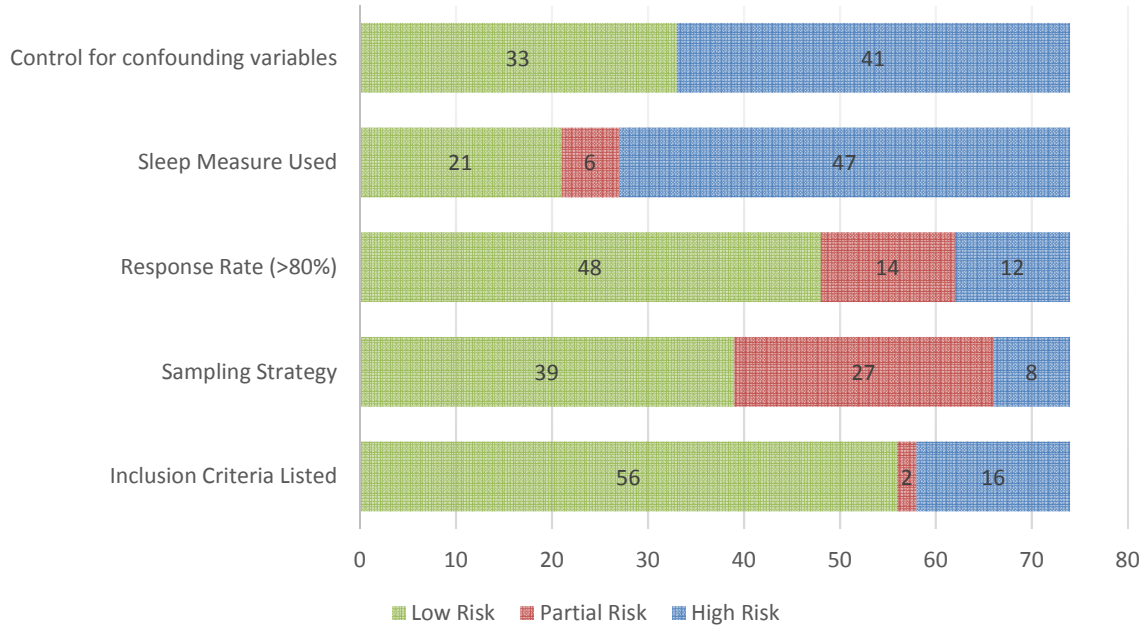

Figure 3. Risk of bias assessment. A study was deemed as having partial risk of bias for an indicator if information was not provided regarding that indicator.

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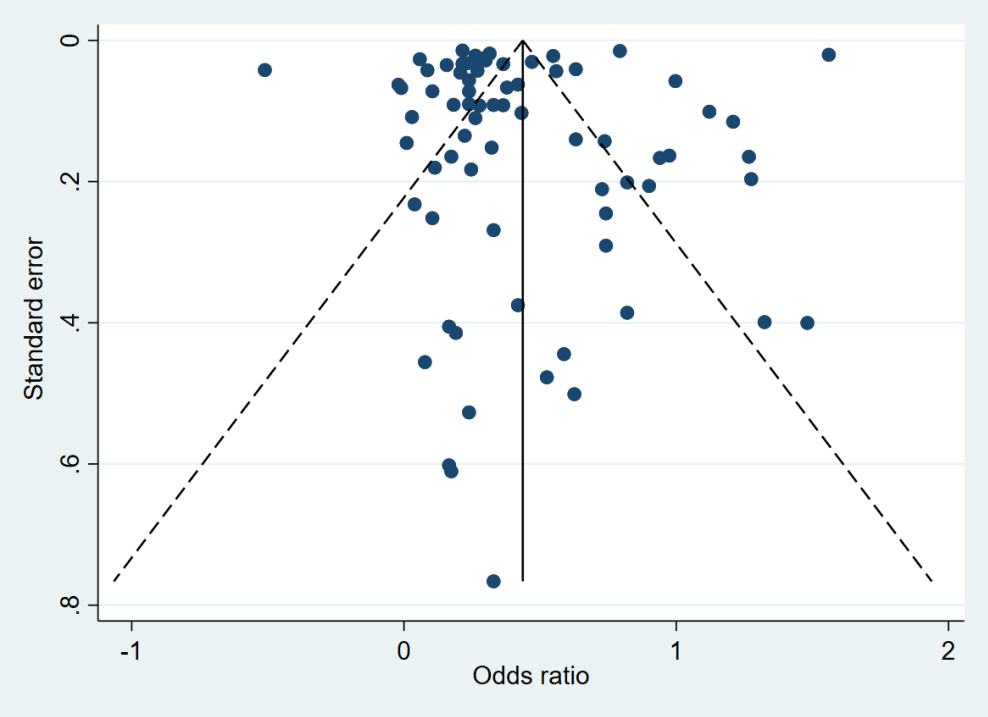

Figure 4. Funnel plot of effect sizes and their standard error.

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