Self-Regulation of Sleep, Emotion, and Weight during Adolescence: Implications for Translational Research and Practice

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Abstract
Self-regulation—the ability to manage motivations, emotions, physiological sensations, and behavior to meet internal and external demands of the environment—is critical to health and development. Adolescence represents a dynamic period of change in both the demand and capacity for self-regulation. As teens mature and become more autonomous, they are confronted with decisions in determining where they spend their time, what they eat, when they go to bed, and how they prioritize and pursue various social, academic, and recreational goals. We highlight opportunities to improve self-regulatory capacities and related health outcomes during this important developmental window. In particular, we focus on emotion regulation, sleep regulation, and weight regulation as three separate but synergistic self-regulatory systems that may provide unique opportunities for intervention to optimize health outcomes. To this end, we begin by describing developmental changes that occur in emotion, sleep and weight regulatory systems during the transitional period of adolescence, as well as how these changes can lead to profound and enduring health consequences. Last, we end with possible prevention and intervention efforts that capitalize on the interactions among these three regulatory domains.

Introduction
Adolescence
Adolescence is a dynamic period of change with regards to self-regulation. Not only are demands for self-regulation increasing due to changes in autonomy and growing social and academic pressures, but also youth are undergoing a transitional period of maturation across the physiological, social, cognitive, emotional, and motivational systems that underpin the capacity for self-regulation. To further complicate the issue, there is an increase in the degree to which teens are motivated by peer influences—in general, adolescents are motivated to behave in ways that will gain them social acceptance and status (and avoid rejection). Together, these challenges to self-regulation mean that adolescents face a host of competing pressures and motivations (i.e., staying up late to text friends to gain social acceptance compromising their sleep quality and ability to function at school and be physically active) amidst changing capacities and abilities to manage them. Adolescence is therefore a dynamic period for establishing self-regulation of health relevant behaviors, emotions, motivations, and attitudes. Many youth respond positively to this dynamic developmental period as evidenced by new skills, motivations and habits. However, it is also true that many youth struggle. The health consequences can be severe and enduring, as indicated by escalating problems related to managing emotion and behavior (i.e., accidents, emotional disorders, risky sexual behavior, suicide), soaring rates of obesity, and chronic sleep deprivation. Moreover the synergistic interactions across emotion, sleep and weight systems can create negative spirals of functioning and health (see Figure 1). We propose that this spiraling effect also can be used to our advantage in clinical practice by targeting multiple regulatory systems to generate positive spirals of functioning during this developmental window. Preventive and early interventions targeting key aspects of self-regulation are essential to establishing healthy habits, and optimizing a broad set of short- and long-term health outcomes.

Emotion regulation
A key function of emotion is to guide motivation and action to facilitate survival and adaptation. For example, negative emotions such as fear can provide an important signal to the brain to activate immediate motivated behaviors (i.e., fight or flight) that promote safety. However our emotional lives are much more dynamic and complex than this example illustrates. Successfully navigating life requires almost constant regulation (conscious or unconscious) of emotional experience—not only to support short-term goals (flee from danger), but also to pursue long-term goals and aspirations (forego a party to work on homework). Although emotion regulation skills develop and change throughout the lifespan (and particularly during early childhood), adolescence represents an important transitional phase that ushers in new challenges to emotion regulation. The onset of puberty intensifies emotions and some motivational drives, particularly in contexts where social goals and pressures are salient.1 In many ways, these changes are normative and serve adaptive advantages. For example, adolescents are naturally motivated to forge new social relationships and romantic pursuits, and to pursue physical and intellectual goals that support emerging independence from the family system. However, these changes also confer risks as the skills and neural architecture for managing intense emotions and competing motivations are not yet fully realized. Evidence suggests that intensifying emotions and motivational drives (involving striatal and other limbic neural systems) during adolescent maturation can create increasing challenges to the brain systems of cognitive control that help to...
align these emotional responses to balance short and long term risks and rewards, and adjust motivated behavior accordingly (e.g., Crone and Dahl). Too often, these challenges contribute to adolescents making risky or poorly considered decisions with negative long-term health consequences.

For some youth, particularly those who enter adolescence with certain vulnerabilities (i.e., anxiety, proneness to sensation seeking), these new challenges to emotion regulation can lead to significant problems. Adolescence is associated with soaring rates of serious accidents, suicide, homicide, aggression and violence, use of alcohol and illegal drugs, emotional disorders, and health consequences of risky sexual behavior. In fact, by some estimates, despite being one of the physically healthiest periods of the lifespan, adolescence is associated with a 200% increase in death and disability, with the majority of this increase related to problems managing emotion and behavior. Particularly relevant to translational science is that when left untreated, problems that emerge during this maturational period can carry lifelong health consequences. Depression onset during adolescence, for example, is associated with a 70% chance of relapse during adulthood. Likewise, the initiation of risky behavior such as drinking alcohol during adolescence predicts a long-term course of alcohol abuse. In fact, even infrequent binge drinking, when initiated during early adolescence (but not young adulthood), predicts future problems with both alcohol abuse and emotion regulation. It is therefore critical for prevention and early intervention to focus on improving aspects of emotion regulation during adolescence as a way of circumventing risks to health and development.

Sleep regulation
Sleep is essential to basic survival, as evidenced perhaps most strikingly by studies showing that animals deprived of sleep will die. Although the precise links between sleep and survival are not yet clear, we are rapidly gaining clues about the role of sleep for physiological restoration and rest, as well as critical aspects of brain maturation, learning, motivation and emotional functioning. We use the term sleep regulation to refer to maintaining a balance between sleep and waking systems, as these systems are closely intertwined aspects of a larger system of arousal regulation. Adaptive sleep regulation is defined by a balance in sleep and waking systems that permits optimal daytime functioning. Just like emotion regulation, conscious, and unconscious skills (e.g., maintaining a sleep schedule despite competing social pressures) involved in sleep regulation change dynamically throughout the lifespan—adolescence represents one key maturational period when sleep regulation is challenged.

Around the onset of puberty there are important biological and social-contextual changes that profoundly challenge sleep regulation. A biological shift in circadian systems leads to a preference for later bedtimes and later morning rise times (teens are “owls” rather than “larks”). This biological shift is somewhat small, but interacts with a host of modern day social-contextual factors to significantly impact sleep-wake times. That is, a slight owl-like tendency is exacerbated by night-time activity including bright lights, media use, socializing via text or video-gaming, and late-night television. To further amplify these challenges to sleep regulation, school start times force adolescents to be awake very early in the morning. In fact, many adolescents are expected to be at school and functioning at full capacity prior to the time at which their circadian cycle reaches optimal waking arousal levels, with the expectation that teens function at full capacity despite a growing sleep debt from late bedtimes and early rise times. Finally, to make up for this growing sleep debt, many youth report “sleeping in” on the weekends (after staying up even later.
on weekends to hang out with friends), which further perpetuates a circadian shift toward later bedtimes during the school week (a phenomenon termed "social jet lag").

The consequences of these challenges to sleep regulation are significant and pervasive. Put simply, many adolescents are sleep deprived. For example, according to research from the Center for Disease Control in the United States, more than 69% of youth report fewer than 7 hours of sleep on school nights. Importantly, these findings are consistent with studies spanning many continents and cultures. Yet, despite this almost normative pattern of sleep restriction, a series of laboratory studies has shown that adolescents, on average, need approximately 9.5 hours of sleep to function optimally during the day. Although the consequences of this chronic sleep restriction are not yet fully elucidated, there is a growing body of research suggesting impacts on aspects of learning, physical health, motivation, socio-emotional functioning, and brain development. Undoubtedly, these normative challenges to sleep regulation have a stronger impact on certain vulnerable populations, such as those with a preexisting sleep disorder (e.g., sleep apnea) or other health problems (e.g., depression or anxiety or obesity). It is therefore critical to improve sleep regulation to minimize vulnerabilities and promote healthy development in adolescence.

**Weight regulation**

The age-old motto: Calories in = Calories out = Weight maintenance is exemplary of the underlying concept of weight regulation. There are two overarching concepts to discuss surrounding weight regulation: caloric intake and energy expenditure. Eating is perhaps one of the trickiest regulatory processes, as humans need to eat, but regulating food intake (or lack thereof) makes this mandatory process quite challenging. Similarly, physical activity is a regulatory process that requires multiple facets of commitment: motivation to begin physical activity, stamina to engage in exercise, and determination to continue these behaviors to form consistent and variable weight regulatory habits.

There is agreement that with approximately 30% of our adolescents falling into the overweight/obese category, this epidemic is incredibly disconcerting. Adaptive weight regulation for a normal-weight adolescent may be weight maintenance when full growth is achieved; however, weight regulation becomes problematic when adolescents eat more calories than they burn. With a decreased level of physical activity, increased amount of sedentary time, and a plethora of high-fat, high-calorie food options, regulatory systems are imbalanced. While teens need to eat 3,500 fewer calories than they burn to lose one pound, putting weight on is far too easy.

Moreover, the International Consensus Conference on PA Guidelines for Adolescents recommends that "all adolescents … be physically active daily, or nearly every day, as part of play, games, sports, work, transportation, recreation, physical education, or planned exercise … three or more sessions per week of 20 minutes or more." Although adolescents are more physically active than adults, according to the Center for Disease Control, many young people do not engage in moderate or vigorous physical activity at least 3 days a week. Physical activity among both girls and boys tends to decline steadily during adolescence. For example, 69% of young people age 12–13 years exercised vigorously on at least 3 of the preceding 7 days. However, for those 14 years old and above, this rate dropped to 38%. Moreover, adolescents stop growing, but data show that most people continue gaining weight throughout the lifetime. Exertion during adolescence has also been shown to shift away from extracurricular activities and move to toward social opportunities.

The consequences of these challenges to weight regulation are significant, and adolescents are becoming more obese. Despite the myriad of efforts to decrease childhood obesity, statistics are still showing an increase in obesity until 2012. Although the consequences of obesity are not yet fully understood, research suggests impacts on aspects of cognitive functioning, cardiovascular disease, and brain development. Undoubtedly, these normative challenges to weight regulation have a stronger impact on certain vulnerable populations (i.e., those with a preexisting family history of diabetes, obstructive sleep apnea, and emotional disorders such as depression). It is therefore critical to improve weight management services to minimize vulnerabilities and promote healthy development in adolescence.

**Synergy in self-regulatory systems**

It is a common human observation that sleep, emotion, and weight can impact one another—just ask a sleep-deprived parent of a newborn about the consequences of chronic sleep loss on their daily mood, physical activity, and eating habits. Or consider the tendency to toss and turn at night when feeling worried about a relationship or impending deadline, which makes it even more difficult to deal with these problems the following day. But what is the evidence for these common notions? Moreover, do the developmental changes and related health consequences within emotion, sleep and weight systems put adolescents at unique risk for a negative spiral of functioning across these systems? Here, we briefly describe five lines of converging evidence that emotion, sleep, and weight regulatory systems interact and cascade during adolescence to impact health and development.

1. **Youth with emotional disorders exhibit high rates of problems related to sleep and weight regulation.** Sleep problems are a central feature of almost all psychiatric conditions involving emotional disturbance. Data suggest, for example, that as many as 90% of depressed and anxious youth report sleep problems. Also decades of research support that teens experiencing emotional problems (i.e., depression) frequently show sedentary behavior and struggle with weight-related issues. Moreover, a series of recent studies note a positive predictive relationship between depressive symptoms during adolescence and increasing body mass index and risk of obesity in adulthood.

2. **Sleep problems are not simply a consequence of emotional disorders, but they can also impact emotional functioning.** For example, longitudinal studies demonstrate that sleep problems during childhood often precede the onset of emotional disorders, such as depression, during adolescence. Moreover, experimental sleep restriction paradigms demonstrate an immediate impact of sleep loss on the ability to manage and modulate emotions the next day, leading to low frustration tolerance and irritability.

3. **Developmental changes in sleep and emotional systems at puberty increase vulnerabilities for problems with sleep and emotional functioning during adolescence.** Although sleep and emotion systems are separable, the fact that both of these self-regulatory systems undergo dramatic changes that are at least partly driven by biological changes associated with puberty suggests that there may be some common underlying mechanisms driving these changes, leading to vulnerabilities across systems.
(4) Sleep problems can impact weight regulation. For example, in obese children, longer sleep duration is associated with decreased physical activity the following day, regardless of gender. Moreover, experimental sleep restriction studies have demonstrated that physical activity is decreased following acute sleep loss. Finally, overall activity is exerted at a lower intensity than activity preceded by a full night of sleep.

(5) Physical activity levels typically drop-off dramatically during adolescence (as described in the above section), and there is evidence that physical activity impacts emotional functioning. For example, endorphins have long been theorized to improve mood. Endorphins are neurotransmitters produced in response to physical activity, which can help to create feelings of pleasure and satisfaction. Evidence supporting interactions across regulatory systems is also important for understanding how these regulatory systems develop and interact during the dynamic period of adolescence, it is apparent that both separately and together, they confer substantial vulnerability and risk for a range of poor health outcomes. However, as we describe in the following section, the developmental changes and interactions among regulatory systems that can lead to negative spirals of functioning also create opportunities for synergistic behavioral interventions with potential for strong and enduring impact.

Implications and future directions for translational research
Although adolescent health and development can negatively spiral across regulatory systems, the inter-connectedness among systems modulating sleep, emotion, and weight may offer a unique opportunity for effective, broad-based prevention and intervention efforts. First, there are empirically supported interventions available to address each of these domains. For example, cognitive behavioral therapy—identifying how thoughts, emotions, and behaviors interact positively and negatively—has been empirically validated across emotion (e.g., challenging negative automatic thoughts that drive negative mood), sleep (establishing a regular sleep/wake schedule), and weight (identifying negative self-thoughts that lead to aberrant eating). These approaches can be broadly disseminated during the developmental window of adolescence to minimize vulnerabilities, and establish adaptive self-regulation of health relevant behaviors, emotions and motivations. Second, given evidence supporting interactions across regulatory systems during adolescence, we suggest that there may be opportunities to create positive spirals of functioning by combining the active facets of these empirically supported intervention approaches. For example, increasing daytime activity can contribute to better sleep at night; good sleep can enhance daytime mood and motivation; healthy eating can improve mood and sleep; and good exercise and sleep habits are positive elements for emotion regulation (see Figure 1 above). Implementing such an integrated approach could be especially salient during the transitional period of adolescence, generating long-term impacts on health and development. Further translational research is needed to fully explore the value of such synergistic approaches, as well as how, where and when these approaches might best be delivered. To this end, we propose three areas for continued translational research in the context of (1) efficacy trials, (2) effectiveness and dissemination research, and (3) basic science—focusing on opportunities within the field of developmental neuroscience.

First, we propose a call for efficacy trials that both assess and target multiple regulatory systems and domains of health. “Efficacy trials” refer to controlled experimental research trials that aim to ensure that the proposed intervention yields positive results in highly constrained conditions before being disseminated to the community. Alternatively, “effectiveness trials” ascertain the effect of the intervention in a usual or routine care condition. For decades, efficacy trials have excluded youth who exhibit overlapping disruptions across emotion, sleep, and weight as a strategy for controlling the intervention target of interest. For example, in most pediatric obesity treatment programs, youth who have major depressive disorder are excluded from randomization. While this does make sense for some scientific questions, it precludes us from a full understanding of how change in one regulatory system impacts others. We propose that research teams conducting efficacy trials relevant to emotion, sleep and weight consider employing strong assessments of functioning across regulatory systems and health domains, and clearly state a priori hypotheses about how targeted intervention in one system may affect another. Assessing multiple regulatory domains in this way also may help to clarify why some participants fail to respond, or only respond partially, to efficacious treatments. As one example, in several clinical efficacy trials of treatment for adolescent depression, sleep problems appear to impede adequate response (for review, see Clarke and Harvey). In addition to assessing outcomes across regulatory systems in intervention trials with a singular target (i.e., weight regulation) we propose there may be value added by combining approaches for targeting sleep, emotion and weight regulation. It will be important for these trials to be designed and controlled in ways that allow for a careful examination of how targeting multiple regulatory systems, as opposed to focusing on one set of systems, may improve both short- and long-term health outcomes. Finally, as described throughout this commentary, there is a strong rationale to conduct these trials during the dynamic developmental window of adolescence when self-regulation of health relevant behaviors, emotions, and motivations are being established. Several trials in line with this agenda are ongoing, including intervention trials targeting sleep and emotion in depressed or anxious adolescents (Dahl), prevention trials targeting sleep, emotion and weight (Shaw & Dahl), and another targeting emotion and weight in adolescents. These interventions also intervene at varying levels of patients’ presenting problems and stages of development. For example, Health Promotion (Shaw & Dahl) targets high-risk children at the transition to adolescence through a prevention model. These families are “offered” modules on emotion regulation, sleep regulation, and weight regulation and can opt into any or all of these proposed treatment trials. There remain numerous areas of inquiry and opportunities for innovation in developing interventions that target multiple regulatory systems in adolescence.

At the level of effectiveness and dissemination research, we propose a need to identify optimal healthcare platforms for the delivery of behavioral interventions that target sleep, emotion and weight individually and synergistically. A starting point may
be to disseminate empirically validated approaches focusing on each domain alone outside of academic treatment facilities (i.e., community-based care). A more long-term goal may be to identify opportunities for targeting multiple domains of regulatory functioning. A major problem in intervention science is that even when interventions are deemed “efficacious” in the context of efficacy trials, they often fail when they reach the stage of effectiveness trials. There are numerous reasons that this can occur, and two are particularly pertinent to this discussion. First, as described above, there is a tendency in efficacy trials to exclude youth with problems across multiple health domains. This approach is intended to improve the ability to examine intervention effects on the targeted domain, but it also means that some of these “efficacious” treatments ultimately may be nongeneralizable to a broader health community. Second, since efficacy trials are often conducted in university-based clinics, issues arise in effectiveness trials due to limits on the dissemination of interventions to the broader community. For example, a critical issue in developing interventions that aim to influence multiple regulatory systems during the maturational transition to adolescence lies in the fact that each of these domains (sleep, emotion, and weight) is historically treated in different settings (i.e., psychiatry practice vs. pulmonology specialty clinic vs. endocrinology specialty clinic). In future work aimed at solving these problems, one promising line of research at the level of effectiveness and dissemination is the Chronic Care Model. This model offers a framework in line with rolling treatment out to patients in primary care settings. The delivery of prevention and intervention services in primary care and the use of nonphysician specialists (e.g., social workers, dieticians, and mental health coaches); (2) decision support (efficient/automated use of on-site visits, training of primary care providers); (3) delivery system design (trained coach coordinates services with specialists, and health coaches); (2) decision support (efficient/automated screening and diagnostic feedback reports); (3) delivery system design (trained coach coordinates services with specialists, use of on-site visits, training of primary care providers); (4) clinical information systems (technology, communication); (5) self-management support (help family understand options and treatment); and (6) community resources (outside services to assist patients). This approach permits attention to a patient’s individual need (e.g., stepped care approach), and allows for flexible use of health coaches as educators, consultants, and clinicians working collaboratively.23–31 The interdisciplinary approach of the Chronic Care model could ultimately accommodate the dissemination of behavioral interventions that target sleep, emotion and weight both individually and synergistically. However, it is important to acknowledge that for extreme cases (emotion—suicidality; sleep—obstructive sleep apnea; and weight—extreme obesity), specialty care clinics will continue to be instrumental in optimal care. Moreover, within these specialty clinics, it may be advantageous to embed services that cast a wider net in treating these synergistic, albeit sub-clinical symptoms (e.g., a teen having bariatric surgery may also receive psychological services for preoperative depressive symptomatology).

Finally, we propose that ongoing translational work in developmental neuroscience can help to illuminate mechanistic links between emotion, sleep, and weight to identify targets for early intervention or prevention. One example includes recent experimental work showing that acute sleep restriction impacts functioning in brain circuits underpinning emotion regulation.32 This finding, when considered from a developmental framework, carries important clinical implications. That is, the same brain circuits involved in emotion regulation that are disrupted by sleep are also going through tremendous maturational change around puberty, and appear involved with the increase in emotional problems during adolescence.33 This developmental framework offers a testable model suggesting that treating emerging sleep problems among pre or early adolescents may be one way to prevent the onset of disorders characterized by problems with emotion regulation, such as depression. One aspect of this framework that is particularly appealing is that it highlights opportunities to alter key interactions among developing regulatory systems before the onset of clinically significant symptoms. Identifying developmental markers of vulnerability in early adolescence (e.g., sleep problems in anxious youth who are at increased risk for developing depression during adolescence) may lead to high impact prevention and intervention. Second, developmental neuroscience models can highlight optimal timing of certain strategies for shaping maturational changes in the brain systems that underpin self-regulation. For example, responsiveness to reward and the capacity for motivational learning is enhanced during adolescence.34 These changes may promote new self-regulatory capacities—such as the ability to pursue rewarding goals despite challenges and frustrations—that can facilitate certain intervention approaches. Fostering healthy habits and better regulatory skills in domains of sleep, emotion and weight during key windows of adolescent development may shape brain maturation in enduring ways.

Conclusions
In conclusion, we argue the following overarching points: (1) Given the clear scientific and clinical links among emotion, sleep, and weight, there are a multitude of opportunities to develop and test prevention and treatment approaches that cut across these self-regulatory systems. (2) There is compelling evidence that focusing on inclusive treatment trials and maximizing services for youth experiencing multiple problems across the aforementioned 3 domains is warranted. (3) At the level of dissemination, these youth may receive broad-based care in their “home” settings such as pediatric offices and/or school settings.

Acknowledgments

References