Evidence and Analysis of the Impact of Sleep Quality on Risk-Taking Behavior

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Abstract

The influence of sleep quality on individual risk-taking behavior has been validated and supported by numerous studies. Sleep deprivation not only affects the integrity of prefrontal cortex function, but also influences the activation of brain regions such as the amygdala and striatum, thereby reducing individuals' perception of danger and sensitivity to loss, leading to increased risk-taking propensity and risk-taking behavior. Previous research has predominantly focused on adult populations and has overlooked the interactive influence of individual traits and social environment on the relationship between sleep quality and risk-taking behavior. Given the prevalence of sleep deprivation and high-risk behavior during adolescence, future research should devote greater attention to the relationship between adolescent sleep quality and risk-taking behavior and its underlying mechanisms of influence, particularly the neural mechanisms.

Full Text

The Effects of Sleep Quality on Risk-Taking Behavior: Evidence and Explanation

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Abstract: A growing body of research has confirmed and supported the notion that sleep quality significantly influences individual risk-taking behavior. Sleep loss affects not only the functional integrity of the prefrontal cortex but also the activation of brain regions such as the amygdala and striatum, thereby reducing individuals' perception of danger and sensitivity to loss, ultimately leading to increased risk-taking intentions and behaviors. Previous studies have predominantly focused on adult populations and have overlooked the interactive effects of individual traits and social environments on the relationship between sleep quality and risk-taking behavior. Given the widespread prevalence of sleep deprivation and high-risk behaviors during adolescence, future research should pay greater attention to the relationship between adolescent sleep quality and risk-taking behavior, particularly the underlying mechanisms, especially the neural mechanisms involved.

Keywords: sleep quality; risk-taking behavior; cognitive control system; emotional reward system

1. Introduction

Sleep is intimately connected to numerous aspects of human physiology, psychology, and behavior. Previous research has demonstrated that sleep deprivation triggers a range of risk-taking behaviors, including smoking (Patterson, Grandner, Lozano, Satti, & Ma, 2017; Sivertsen, Skogen, Jakobsen, & Hysing, 2015), alcohol abuse (Park, Lee, & Lee, 2016), drug misuse (Daly et al., 2015), dangerous driving (Hartley et al., 2013), and violent or illegal activities (Backman et al., 2015). Researchers argue that sleep deprivation impairs individuals' risk perception, making them more sensitive to rewards and less sensitive to losses. This diminished capacity to perceive risk strengthens the willingness to engage in risky behaviors, thereby increasing both the probability and frequency of such behaviors (Mullette-Gillman, Kurnianingsih, & Liu, 2015). Beyond sleep loss and sleep deprivation, poor sleep quality or sleep disorders also increase individuals' (negative) risk-taking behaviors (Lei et al., 2016; Wong et al., 2017). Negative risk-taking behaviors threaten and damage physical and mental health, cause accidental injuries, and compromise social safety. As an individual factor closely related to negative risk-taking behaviors, sleep quality warrants attention. Examining the relationship between sleep quality and risk-taking behavior, and investigating the strength and manner of sleep quality' s effects on risk-taking, can help guide and intervene in negative risk-taking behaviors—particularly by emphasizing and improving sleep quality. Such efforts hold significant promise for promoting healthy development in individuals and society.

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2.1 Sleep Quality and Its Measurement

Sleep is a daily necessity for everyone, with most individuals spending more than one-third of their lives sleeping. Sleep enables the body to store energy, facilitates physical and mental recovery, and strengthens immune function. Both timely and adequate sleep form the foundation for maintaining health and physical strength, as well as ensuring high productivity. When sleep problems occur, individuals' restorative processes are compromised, leading to adverse consequences for physical and mental activities. Researchers primarily examine sleep's impact on physiological and psychological health through two dimensions: sleep quality and sleep duration. Currently, there is no precise quantitative standard for measuring sleep quality. Scientific research indicates that sleep duration is the primary indicator for assessing sleep quality, referring to the amount of time an individual sleeps within a 24-hour period (Roehrs, Surilla, Erica, Renee, & Thomas, 2011). Both sleep deprivation and insufficient sleep essentially reflect inadequate sleep duration and poor sleep quality (Dewald, Meijer, Oort, Kerkhof, 2010).

In recent years, sleep quality assessment has been conducted through field studies and laboratory research. The most commonly used methods in field studies are sleep diaries and self-report questionnaires. Sleep diary methods enable continuous daily tracking, facilitating the interpretation of individual sleep patterns (Barnes, Lucianetti, Bhave, & Christian, 2015). Among questionnaire-based assessments, the Pittsburgh Sleep Quality Index (PSQI) is most frequently employed by researchers both domestically and internationally due to its simplicity and clarity.

Laboratory research utilizes objective measurement approaches, most notably polysomnography (PSG) and actigraphy. Polysomnography is a technique for exploring brain activity that monitors brain function in real-time through electrode-recorded brain waves, providing insight into the sleep process. Actigraphy, meanwhile, capitalizes on the characteristic that human wrists remain relatively still during sleep, collecting wrist movement intensity and data to determine whether a subject is asleep or awake. Compared to subjective reports, instrument-based recordings offer greater temporal accuracy.

Sleep deprivation refers to a state of sleep loss caused by various factors, leading to a series of physiological and psychological functional changes and resulting in multiple cognitive deficits (Tobaldini et al., 2017). Its practical manifestation is insufficient or short sleep duration. Based on duration, sleep deprivation can be categorized as total or partial (Christian & Ellis, 2011). Total sleep deprivation maintains subjects in a continuous state of wakefulness throughout the deprivation period, typically lasting 24, 36, or 48 hours in research settings. Partial sleep deprivation involves reducing nightly sleep to less than 50% of normal amounts, either continuously or intermittently (Li, Tan, Sun, Xiong, & Pan, 2016). Based on onset speed, sleep deprivation can be acute or chronic (Tobaldini et al., 2017). Acute sleep deprivation involves rapid total or partial sleep loss lasting 24 hours or more, while chronic sleep deprivation is defined as fewer than six hours of sleep per night for two consecutive weeks. With accelerating life rhythms and increasing unhealthy lifestyle patterns, more people are experiencing varying degrees of sleep deprivation. Long-term sleep deprivation can lead to brain dysfunction (Kahn-Greene, Killgore, Kamimori, Balkin, & Killgore, 2007), decreased immunity, and mental irritability (Cardinali & Esquifino, 2012). Consequently, individuals' ability to perceive and identify risky situations declines, manifesting as increased risk-approach behaviors (Ferrara et al., 2015).

2.2 The Concept, Measurement, and Classification of Risk-Taking Behavior

Risk-taking behavior refers to decision-making in uncertain situations, reflecting an individual’ s willingness to choose overtly risky actions. Specifically, when facing approach-avoidance conflicts, individuals may engage in dangerous behaviors to satisfy their needs (Benzur & Zeidner, 2009). Moore and Gullone (1996) defined risk-taking behavior as actions where individuals balance perceived positive outcomes (or gains) against potential negative consequences (or losses) to some degree. Although researchers’ descriptions and definitions vary, most involve behavioral characteristics such as uncertainty, goals and outcomes, risk and reward, and consideration of potential negative consequences from current decisions.

Previous studies have assessed and measured risk-taking behavior through either questionnaire surveys or laboratory risk scenario tasks. The Adolescent Risk-Taking Questionnaire (ARQ) (Gullone, Moore, Moss, & Boyd, 2000; Zhang, Zhang, & Shang, 2011) is among the most commonly used measurement instruments. Additionally, based on the domain-specificity hypothesis of risk-taking, researchers have proposed five domains of risk-taking behavior—economic, health-safety, recreational, ethical, and social—and developed the Domain-Specific Risk-Taking Scale (DOSPERT) (Weber, Blais, & Betz, 2002). Classic risk scenario tasks include the Balloon Analogue Risk Task (BART) (Kessler, Hewig, Weichold, Silbereisen, & Miltner, 2016), the similar Stop-light Task (Telzer, Miernicki, & Rudolph, 2017), the Iowa Gambling Task (IGT) (Almy, Kuskowski, Malone, Myers, & Luciana, 2017; Cosenza, Griffiths, Nigro, & Ciccarelli, 2016), the Delay Discounting Task (DDT) (Hartmann & Slapničar, 2015; Libedinsky et al., 2013), and the Columbia Card Task (CCT) (Łukasz & Elżbieta, 2015).

Some researchers classify risk-taking behaviors from a positive/negative perspective into socially approved risks and problem risks, also termed recreational risks and problem risks or positive and negative risks (Özmen & Sümer, 2011). Clearly, negative risk-taking behaviors threaten physical health and adversely affect others and society. Research shows that compared to individuals with normal sleep, sleep-deprived individuals often engage more frequently in negative risk-taking behaviors such as smoking, alcohol abuse, and gambling, disregarding harmful consequences (Chein, Albert, O’ Brien, Uckert, & Steinberg, 2011; Foley & Weinraub, 2017; Weigard, Chein, Albert, Smith, & Steinberg, 2014). Consequently, researchers have consistently focused on the relationship between sleep quality and risk-taking behavior, providing direct and indirect evidence of sleep quality’ s impact on risk-taking, particularly negative risk-taking. With advances in cognitive neuroscience in recent years, researchers have offered not only psychological and behavioral explanations but also neural mechanism accounts for how sleep quality affects negative risk-taking behavior.

3. The Effects of Sleep Quality on Individual Risk-Taking Behavior: Evidence from Behavioral, ERP, and Brain Imaging Studies

Currently, many researchers have employed behavioral measurements, event-related potentials (ERP) technology, and functional magnetic resonance imaging (fMRI) technology to explore how sleep quality affects individual risk-taking behavior, providing multi-angle, extensive, and in-depth explanations for the occurrence and mechanisms of risk-taking behavior.

3.1 Behavioral Research Evidence

Behavioral research typically uses self-reports and artificially designed laboratory risk-taking tasks to examine sleep quality' s effects on risk-taking behavior. In specific studies, researchers selectively employ appropriate methods based on sample characteristics: studies on sleep' s impact on adolescent risk-taking behavior mostly use large-sample subjective report methods (e.g., Ayres, Pontes, & Pontes, 2016; Meldrum & Restivo, 2014), while studies on sleep' s impact on adult risk-taking behavior utilize both subjective reports and laboratory tasks (e.g., Maric et al., 2017; Wilhelm et al., 2014). Numerous large-sample surveys have found that sleep deprivation leads to more negative risk-taking behaviors in adolescents. A longitudinal study examining the relationship between sleep duration and binge eating, illegal drug use, and smoking among 6,504 adolescents found that sleep duration at T1 significantly negatively predicted alcohol abuse and binge eating at T2 and T3, with insufficient sleep being an important predictor of subsequent increased risk-taking behavior (Wong, Robertson, & Dyson, 2015). Another study surveyed 10,718 middle school students in 2010 and 11,240 in 2012, examining the relationship between sleep quality and risk-taking behavior. Using a 7-point self-report scale to assess average nightly sleep duration (1 = less than 4 hours/night; 7 = more than 10 hours/night) and measuring risk-taking through rebelliousness, early initiation of drug use, early antisocial behavior, attitudes favorable to antisocial behavior, attitudes favorable to drug use, perceived risk of drug use, sensation seeking, and gang involvement, the study found that after controlling for gender, race, and socioeconomic status, middle school students averaging less than 7 hours of sleep per night showed significantly higher risk-taking scores compared to those averaging 9 hours, with those averaging less than 5 hours showing the highest scores across all risk-taking dimensions. This study relatively directly demonstrated the relationship between adolescent risk-taking behavior and insufficient sleep, showing that adolescents with less nightly sleep are more likely to exhibit risk-taking behaviors in daily life (Owens, Wang, Lewin, Skora, & Baylor, 2017). Another survey of 12,154 middle school students found that the insufficient sleep group (less than 8 hours per night) reported significantly higher frequencies of smoking, alcohol consumption, marijuana use, and unsafe sexual behavior than the adequate sleep group (8 hours or more per night), with decreasing nightly sleep associated with higher proportions of these risk-taking behaviors (Mcknight-Eily et al., 2011).

Adolescence is a period of rapid yet unbalanced physical and psychological development, characterized by emotional sensitivity, instability, and poor self-control. Simultaneously, the brain undergoes crucial development of neural fine structures, and immature neural structures and functions may lead to dysregulated behavior patterns (Blakemore, 2008; Romer, 2010). Specifically, adolescents'cognitive control systems are still developing, and immature systems are insufficient to control impulses toward risk-taking behavior. Sleep problems exacerbate the lag and immaturity of cognitive control system development, causing adolescents with sleep problems to show higher risk-taking tendencies and more risk-taking behaviors compared to those with better sleep (Telzer, Fuligni, Lieberman, & Galvan, 2013).

Risk simulation tasks have confirmed these findings. Using the Iowa Gambling Task to examine risk choices in college students under varying degrees of sleep deprivation, research found that sleep deprivation altered risk perception abilities, biasing individuals toward risk-seeking and resulting in more selections of advantageous decks. Specifically, when facing high rewards, 24-hour sleep-deprived college students already began to show less concern for negative consequences and tended toward risk-seeking compared to normal sleep groups, while 48-hour and 72-hour sleep-deprived students selected high-risk advantageous decks even more frequently, showing more pronounced risk-taking tendencies (Varsha, 2013). The relationship between sleep and risk-taking has also been confirmed in impulsivity-related behavioral risk tasks. Stop-light Task research found that after partial sleep deprivation, subjects' risk perception abilities declined, showing more impulsive and reckless behavior, demonstrated by more crash outcomes (risk behavior indicators) in the experimental task (Banks, Catcheside, Lack, Grunstein, & Mcevoy, 2004). Balloon Analogue Risk Task studies have also found that college students with poorer sleep quality scored significantly higher than normal sleep groups on two risk-seeking indicators: average number of pumps and number of balloon explosions (Hisler & Krizan, 2017). Additionally, a within-subjects experimental design comparing subjects' performance in a virtual reality pedestrian environment under 8.5 hours versus 4 hours of nightly sleep found that when sleep was reduced to 4 hours, subjects made riskier choices, including allowing smaller distances between themselves and oncoming cars when crossing streets, experiencing more virtual collisions, and showing more head-turning behaviors (Davis, Avis, & Schwebel, 2013). This may occur because sleep deprivation reduces attention allocation and self-control abilities, impairing the capacity to process rapidly changing information, thereby manifesting as enhanced risk willingness and increased risk-taking frequency (Mullette-Gillman et al., 2015).

3.2 ERP Research Evidence

Event-related potentials reflect brain electrical changes associated with specific psychological activities (events) and offer real-time advantages. Research directly revealing sleep quality' s impact on risk-taking behavior using ERP technology remains relatively scarce. Current studies on the relationship between sleep quality and risk-taking behavior have been indirectly inferred through sleep' s effects on response inhibition ability. Response inhibition refers to the ability to suppress responses that do not meet current needs or to inhibit inappropriate behavioral reactions (Johnstone, Barry, Markovska, Dimoska, & Clarke, 2009). The most commonly used laboratory tasks for studying response inhibition are the Go/No-Go task and the Stop-Signal task. The Go/No-Go task typically includes high-frequency stimuli (Go stimuli) and low-frequency stimuli (No-Go stimuli), requiring subjects to respond to high-frequency stimuli and withhold responses to low-frequency stimuli, thereby examining inhibition of dominant responses (Friedman & Akira, 2004). The Stop-Signal task includes Go stimuli and Stop stimuli, with Stop trials appearing after several Go trials. When subjects detect the Stop signal, they must immediately cease their key-press response to the target stimulus. This task requires individuals to stop an ongoing selected response. Since the Stop stimulus appears temporally after the response stimulus, individuals must inhibit already-initiated or ongoing behaviors. This process demands reasonable attention allocation and control of conflicts between behavioral responses during motor execution. The Go/No-Go task requires individuals to judge whether to respond based on presented stimuli and then perform corresponding operations, involving stimulus discrimination, response selection, and inhibition of response activation states. Therefore, the Stop-Signal task presents greater behavioral inhibition difficulty than the Go/No-Go task, as it requires stopping already-initiated behaviors and includes online control and conflict control, while the latter focuses more on examining individuals' behavioral selection at the cognitive level.

Both Go/No-Go and Stop-Signal tasks assess individual response inhibition abilities by analyzing N2 and P3 component changes in ERP data, with researchers showing no strict differentiation in task selection. For example, Wang et al. (2010) used a Go/No-Go task to examine changes in response inhibition abilities in 14 college students before and after total sleep deprivation. Compared to baseline ERP amplitudes, N2 amplitude began decreasing after 12 hours of sleep deprivation, with more significant decreases at 36 hours. P3 amplitude and latency changed after 24 hours of sleep deprivation, showing reduced amplitude and prolonged latency, with more pronounced changes at 36 hours, though latency showed significant changes later than amplitude. Meanwhile, a Stop-Signal ERP study on response inhibition deficits in insomnia patients revealed that insomnia patients showed significantly longer reaction times than healthy controls in Stop trials, with ERP data analysis showing reduced P3 component amplitude and prolonged latency in successful inhibition trials, possibly explaining the inefficient response inhibition in insomnia populations (Zhao et al., 2018). Thus, Go/No-Go and Stop-Signal tasks show similar brainwave patterns in populations with poor sleep conditions. The N2 waveform represents subjects' perception patterns of cognitive control processes (Falkenstein, Hoormann, & Hohnsbein, 1999), while P3 represents the processing of behavioral inhibition control, with latency reflecting individuals' evaluation time for corresponding stimuli (Debener et al., 2005). These studies confirm the progressive impairment of executive control functions during prolonged wakefulness. Previous research has demonstrated that sleep-deprived subjects show decreased abilities in stimulus classification and evaluation and in discriminating target stimuli (Drummond, Brown, Salamat, & Christian, 2004), leading to weakened executive control abilities manifested as abnormal brainwave patterns, with poorer sleep quality and longer sleep deprivation duration causing more severe inhibition control impairments. We speculate that sleep-deprived subjects' increased impulsivity due to executive function impairment leads to reduced response inhibition function, consequently increasing risk-taking behavior. This may represent a neural mechanism through which sleep quality affects risk-taking behavior, though this inference requires further research confirmation.

3.3 Brain Imaging Research Evidence

With the rise of cognitive neuroscience, researchers have begun using functional magnetic resonance imaging (fMRI) with its high spatial resolution advantages to explore the neural mechanisms underlying sleep' s effects on risk-taking behavior in classic risk decision-making tasks. Over the past two decades, fMRI studies have confirmed the relationship between sleep quality and brain centers. Research has found that as sleep deprivation duration increases, activation intensity decreases in relevant brain regions including bilateral prefrontal cortex (PFC), inferior frontal gyrus (IFG), and supplementary motor area (SMA) (Mccoy & Strecker, 2011). These brain regions constitute core components of the inhibition control process network; dysfunction in the prefrontal cortex causes individuals to lose or reduce inhibitory capacity (Wiers et al., 2015). The inferior frontal gyrus, particularly the right IFG, is a more advanced cortical region regulating response inhibition function. Reduced IFG activation may be related to response inhibition capacity, with lower response inhibition associated with weaker activation in this region (Stramaccia et al., 2015). Sleep deprivation reduces individuals' response inhibition capacity, thereby increasing impulsive responses to inflate balloons (number of inflations) in the Balloon Analogue Risk Task (Rao, Korczykowski, Pluta, Hoang, & Detre, 2008). The prefrontal cortex and inferior frontal gyrus may represent important brain markers currently identified for sleep' s influence on risk-taking behavior.

Additionally, research has found that long-term sleep deprivation significantly increases activation in the thalamus and striatum—brain regions related to reward—while activation intensity positively correlates with the likelihood of individuals engaging in risk-taking behavior (Figner, Mackinlay, Wilkening, &

Weber, 2009). Sleep deprivation also enhances functional connectivity between the amygdala and the insula, which is responsible for emotional processing (Pace-Schott et al., 2017). This enhancement of brain emotional circuit function may cause sleep-deprived individuals to process and manage emotions, particularly negative emotions, more extensively, leaving them unable to escape negative emotional distress. Individuals in negative emotional states often choose risk-taking behaviors to obtain greater benefits, hoping to change their current negative emotional state (Berger, Miller, Seifer, Cares, & Lebourgeois, 2012). Neuroimaging research on the relationship between sleep quality and cortex function has confirmed that sleep deprivation, as a physiological process of self-regulatory depletion, severely consumes glucose—the energy substance required by the prefrontal cortex—thereby reducing the metabolic rate of activity in this region. Consequently, cognitive functions related to self-control and executive function controlled by this region are hindered (Christian & Ellis, 2011), and decreased self-control capacity in sleep-deprived individuals inevitably leads to increased impulsivity and risk-taking tendencies.

These findings collectively support, to varying degrees, the view that sleep quality affects risk-taking behavior.

4. A Dual-Systems Model Analysis of Sleep Quality' s Effects on Individual Risk-Taking Behavior

Steinberg' s (2010) dual-systems model of risk-taking behavior has gained widespread acceptance. This model posits that two primary systems in the brain guide and support daily activities: the cognitive control system, an analytical rational decision-making system, and the emotional reward system, an automated experiential decision-making system. The former requires conscious participation, primarily relies on logical rules and probability calculations to make decisions, and represents a relatively slow cognitive decision-making process. The latter requires less conscious participation, mainly relies on experience or associations between things to make relatively rapid decisions, with emotion playing a primary role (Steinberg, 2010). Previous research has found that sleep loss affects both the functional integrity of the prefrontal cortex and enhances activation in reward-related brain regions such as the amygdala and striatum, thereby reducing individuals' perception of danger and sensitivity to loss, leading to increased risk-taking intentions and behaviors (Liu & Zhou, 2016). The following sections explain how sleep quality affects individual risk-taking behavior from the dual-systems model perspective.

4.1 Sleep Quality's Effects on the Cognitive Control System

The brain regions of the cognitive control system are primarily located in the prefrontal cortex, including the dorsolateral prefrontal cortex (DLPFC), ventromedial prefrontal cortex (VMPFC), and orbitofrontal cortex (OFC). Research has found that risk-taking behavior particularly depends on the functional integrity of prefrontal cortex function (Mccoy & Strecker, 2011), while spontaneous functional activity in brain regions responsible for higher cognitive processing significantly weakens after sleep deprivation (Wu et al., 2006). Studies show that after 24 hours of sleep deprivation, individuals experience attentional dispersion, narrowed attentional focus, and reduced perceptual sensitivity to danger in situations, consequently increasing risk-taking behavior (Jugovac & Cavallero, 2012).

The dorsolateral prefrontal cortex (DLPFC) is closely related to impulse control (Duncan & Owen, 2000). Research indicates that patients with right DLPFC damage show obvious risk choices on the Iowa Gambling Task, suggesting that DLPFC damage may cause abnormal activity in neural networks related to attention organization, preventing individuals from effectively organizing attentional resources to meet task-related brain region needs (Seeley, Smith, Macdonald, & Beninger, 2016). Positron emission tomography (PET) studies have found that glucose metabolism levels in subjects' DLPFC significantly decrease after 24 hours of sleep deprivation, with continued decreases after 48 and 72 hours of deprivation. Moreover, the longer the sleep deprivation duration, the lower the DLPFC activation level (Thomas et al., 2003). These studies confirm that sleep deprivation reduces DLPFC activation, thereby decreasing individuals' ability to inhibit impulses and leading to increased risk-taking behavior.

The ventromedial prefrontal cortex (VMPFC) is a core brain region responsible for self-control, decision-making, and value judgment. Sleep-deprived subjects and VMPFC-damaged patients show similar behavioral characteristics, tending to make high-risk choices (Bechara & Damasio, 2002). Research has found that under sleep deprivation conditions, VMPFC functional connectivity density (FCD), regional homogeneity (ReHo), and amplitude of low-frequency fluctuations (ALFF) all significantly decrease, potentially leading to reduced self-control capacity and increased risk-taking tendencies in sleep-deprived individuals (Libedinsky et al., 2011). Another fMRI study examining sleep-deprived subjects' performance on the Balloon Analogue Risk Task found that the sleep deprivation group showed significantly lower VMPFC activation than the control group, correspondingly showing more impulsive performance on the task—specifically, more balloon clicks and explosions (Spoormaker, Gvozdanovic, Sämann, & Czisch, 2014).

The orbitofrontal cortex (OFC) primarily functions to encode expected outcomes and control impulsivity. OFC damage leads to impaired danger perception and abnormal social behavior, with OFC-damaged individuals tending to choose immediate rewards regardless of future negative consequences (Bechara, 2004). Research has found that sleep-deprived subjects show weakened OFC activation compared to normal sleep subjects, specifically manifested as lower OFC activation levels and poorer emotional learning abilities when experiencing losses (Mccoy & Strecker, 2011). Previous research confirms that OFC damage prevents individuals from obtaining appropriate emotional markers (e.g., disappointment or regret) from negative risk-taking behavior outcomes, thereby preventing them from using feedback to guide subsequent risk behaviors. This reduces risk perception and loss sensitivity, consequently increasing risk-taking willingness and frequency (Cela-Conde et al., 2013). Therefore, OFC functional decline may be one mechanism through which sleep-deprived individuals exhibit more risk-taking behavior.

4.2 Sleep Quality's Effects on the Emotional Reward System

Sleep deprivation not only affects risk sensitivity by influencing the DLPFC, VMPFC, and OFC but also impacts risk perception and risk assessment by affecting emotional and emotional processing functions, ultimately leading to increased risk-taking behavior (Minkel et al., 2012). Research confirms that the amygdala, striatum, and nucleus accumbens (NAcc) (Dolcos, Iordan, & Dolcos, 2011) are primary reward-related brain regions. These regions are closely interconnected, forming an integrated neural network that primarily processes emotional stimuli and is called the emotional reward system (Albert & Steinberg, 2011). Studies have found that activation in reward-related brain regions increases after sleep deprivation, causing substantial increases in sensation seeking in sleep-deprived individuals and resulting in heightened reward sensitivity and decreased impulse control (Vermeulen, van der Heijden, Benjamins, Swaab, & van Someren, 2017). Additionally, enhanced activation of the emotional reward system makes individuals less sensitive to probability and more sensitive to possible outcomes, potentially causing them to ignore high risks and focus on high rewards, thereby exhibiting risk approach.

The amygdala is the primary brain region responsible for emotional processing, particularly negative emotion processing (Horacek et al., 2015), and participates in regulating various emotional activities including anxiety, mania, and irritability (Davis, 1992). More negative emotions produce stronger amygdala activation (Spohrs et al., 2018; Weber, Morrow, Rizer, Kangas, & Carlson, 2016). Sleep deprivation increases individuals' negative emotions including anger (Keenan, Tiplady, Priestley, & Rogers, 2014), anxiety (Baum et al., 2014), irritability (Demos et al., 2016), depression (Tkachenko et al., 2014), and hostility (Welsh, Ellis, Christian, & Mai, 2014) while also suppressing positive emotions (Baglioni et al., 2012). Therefore, sleep deprivation causes stronger amygdala activation (Killgore, Balkin, Yarnell, & Ii, 2017). Excessive negative emotional experiences increase individuals' risk-taking behavior (Reynolds et al., 2013) because individuals in negative states tend toward risk choices to obtain benefits and change their current negative emotional experiences (Berger et al., 2012). In other words, heightened amygdala activation after sleep deprivation occurs because sleep deprivation increases negative emotional experiences, leading sleep-deprived subjects to seek positive emotions from rewards to regulate sleep-induced negative emotional states, consequently resulting in more risk-taking behavior.

The striatum is a core brain region in the reward network, playing important roles in reward expectation evaluation, reward magnitude perception, and reward outcome experience (Liu, Hairston, Schrier, & Fan, 2011). Research has found that striatum activation intensity significantly positively correlates with risk-taking behavior (Figner et al., 2009), with high-risk seekers showing stronger striatum activation than low-risk seekers when obtaining reward outcomes (Chein et al., 2011). Studies on sleep and risk-taking behavior have found that after sleep deprivation, healthy subjects show significantly enhanced striatum activation when facing reward outcomes, demonstrating high reward expectation and high risk-taking behavior (Gujar, Yoo, Hu, & Walker, 2011). Based on these findings, we can infer that sleep deprivation causes significant striatum activation, increasing individuals' reward sensitivity and consequently increasing risk-taking behavior.

The nucleus accumbens contains sleep-related neurotransmitters and receptors and has fiber connections with sleep-wake nuclei (Basar et al., 2010). Over 95% of neurons in this nucleus are gamma-aminobutyric acid (GABA), which primarily inhibits dopamine cells and affects other structures such as the pedunculopontine tegmental nucleus and glutamatergic neurons. Sleep deficiency or sleep loss affects dopamine (DA) release or inhibits GABAergic neurons, ultimately leading to sustained enhancement of dopamine release from ventral tegmental area inputs to the nucleus accumbens (Sardi, Tobaldini, Morais, & Fischer, 2018). Dopamine is a multifaceted neurotransmitter involved in attention adjustment, cognitive function regulation, and reward and motivation modulation (Baler, Ruben, Volkow, & Nora, 2007). Long-term sleep deficiency enhances dopamine transmission in the brain' s reward system, reducing individuals' reward thresholds and causing them to show preference for small rewards that can be obtained immediately (Uy & Galvan, 2017). Therefore, increased preference for immediate rewards and decreased interest in delayed large rewards after sleep deprivation constitute important reasons for increased risk-taking behavior in sleep-deprived individuals.

5. Research Outlook

In summary, numerous researchers have directly or indirectly investigated the relationship between sleep quality and risk-taking behavior from behavioral and neural mechanism perspectives, discovering and revealing some patterns and trends. However, several issues require further exploration, and future research directions may focus on the following aspects:

First, adolescence is a critical period of transition from immaturity to maturity and represents the period of greatest physiological and psychological turbulence in an individual' s life. Therefore, adult research results cannot be generalized to adolescents, as adolescents require more sleep than adults to achieve optimal functional states. Moreover, adolescence involves exposure to many new risk-taking behaviors, but their brain development is incomplete, with brain regions related to intense sensation seeking and risk-taking developing faster than those crucial for decision-making and inhibiting risk-taking behavior (Hirshkowitz et al., 2015). Existing studies examining the relationship between adolescent sleep quality and risk-taking behavior have used large-sample subjective report methods for both measures, but subjective report methods carry inherent risks including inaccuracy and response biases, which may similarly affect sleep and risk-taking measurements. Consequently, the relationship between sleep and risk-taking in adolescent populations may be exaggerated by subjective reports, and such methods cannot yield strong causal conclusions. Therefore, future research should consider the particularities of adolescent populations and employ combined subjective and objective methods to explore the relationship between sleep quality and risk-taking behavior.

Second, sleep measurement methods require further improvement. Although several methods for measuring sleep quality have been developed, each has advantages and disadvantages due to sleep' s complexity and unique characteristics and requires supplementation and refinement. Polysomnography has objective characteristics and provides the most detailed and accurate data but is costly, requires a clinical environment, and may interfere with subjects' normal sleep to some extent. Actigraphy, another objective measure, offers advantages of portability and ability to measure sleep data under natural conditions but is not as comprehensive or precise as polysomnography. Questionnaire measures, though simple and convenient for large-scale implementation, provide relatively coarse data that is less precise than the two objective methods. Some researchers have noted that subjective and objective methods yield substantially different results when studying the relationship between sleep quality and risk-taking behavior (Mccall & Mccall, 2012). Therefore, future research needs technological breakthroughs to develop efficient and convenient methods that neither affect subjects' normal sleep nor compromise comprehensive reflection of sleep indicators, thereby improving and enhancing research techniques to better serve research purposes.

Third, based on Bronfenbrenner' s social-ecological systems theory, future research should deeply explore the mechanisms through which sleep quality affects adolescent risk-taking behavior across various systemic environments and through interactions between systems, thereby enhancing the applied value of research in this field. Studies have found that individuals' risk-taking behavior is closely related to sociocultural background and personality traits influenced by cultural background (Mcghee, Ehrler, Buckhalt, & Phillips, 2012). Compared to adults, the influence of social environments on adolescent risk-taking behavior is amplified. Research has found that neural mechanisms underlying adolescent risk-taking behavior change under conditions such as peer accompaniment, family relationships, and social exclusion. For example, one study found that peer accompaniment significantly activates adolescents' reward-related brain regions, and this activation can predict the phenomenon of adolescents' risk-taking behavior being exacerbated by peer presence (Chein et al., 2011). Long-term positive family relationships can reduce activity in adolescents' socio-emotional systems while strengthening cognitive control system activity, thereby reducing risk-taking behavior (Telzer et al., 2013). Therefore, when exploring sleep quality' s effects on risk-taking behavior, researchers should further investigate the roles of various factors and their interactive effects, particularly the influences of cognition, emotion, personality, and social environments on risk-taking behavior. Based on such research, reasonable intervention programs can be developed to reduce and mitigate the adverse effects of negative risk-taking behaviors resulting from sleep quality issues.

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