The Biological Relationships of Sleep, Stress, Performance, and Productivity

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Summary

This paper explores the biological effects of stress, its impact on sleep, and how both stress and sleep influence performance, emphasizing their interconnected relationships.

Abstract

This paper examines the complex relationships between stress, sleep, and performance. The first section explores the biological effects of stress, including activation of the body's fight-or-flight response through the release of hormones. It explains how this activation can lead to physiological changes and amplify physiological activity like heart rate and alertness, while suppressing other factors, like the function of the immune system. It also emphasizes how these effects can negatively impact overall health, if they're prolonged. The second section focuses on stress's influence on sleep. Stress disrupts the body's natural circadian rhythm, which might cause difficulties falling or staying asleep. Chronic stress can create a vicious cycle, inducing sleep deprivation which further exacerbates stress levels. The third section focuses on how factors like sleep and stress collectively affect performance and productivity. Adequate sleep is essential for cognitive processes such as memory consolidation, problem solving, and emotional regulation. When sleep is disturbed by stress, it could result in reduced focus and impaired decision making, both of which can negatively impact performance. On the other hand, managing stress effectively and maintaining a healthy sleep schedule can enhance productivity, resilience, and overall well being. Overall, by analyzing the interconnected nature of stress, sleep, and productivity, this paper aims to highlight the importance of stress management and positive sleep habits, in order to optimize physical and mental health and performance.

Introduction

In today's fast-paced world, the ultimate goal for many people is to maximize productivity. But at what cost? In an effort to achieve more, we are becoming more stressed (Figure 1) and sleep-deprived (Figure 2). Lack of sufficient sleep can leave us feeling exhausted, which can cause even more stress. Sleep and stress are interconnected, and play a role in both productivity and our health. For example, when our stress levels get too high, it can cause the concentration of certain hormones to be higher than they should, creating health problems. Likewise, insufficient sleep can cause the body to be more stressed, intensify the stress response, and create a sleep deprivation cycle, having an effect on both one's productivity and overall health.

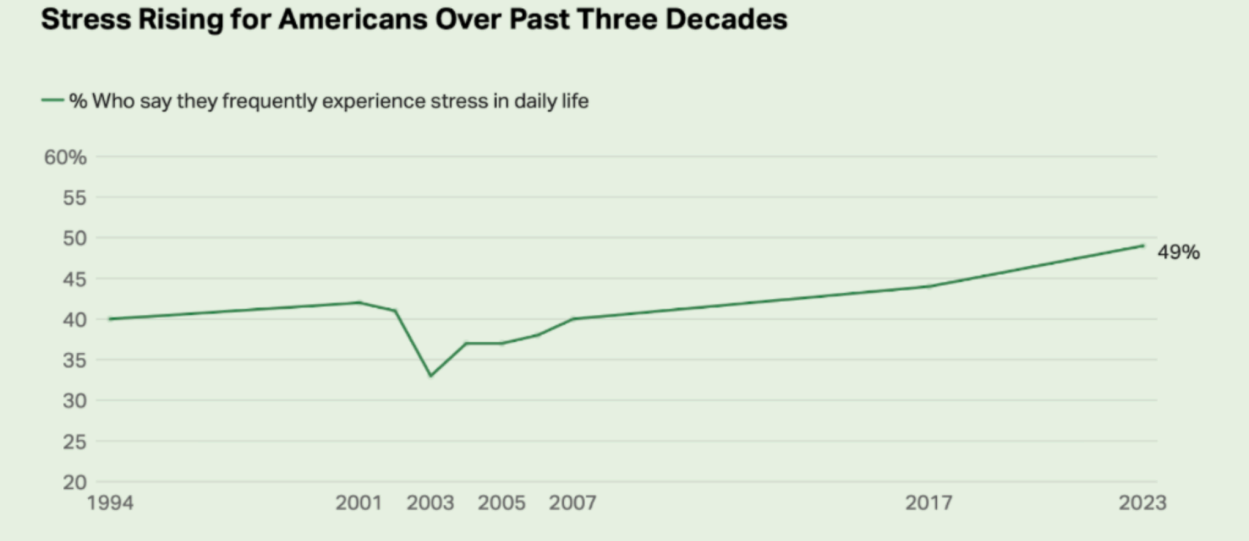

Figure 1. Percentage of Americans reporting frequent stress in daily life over time (Fioroni 2024).

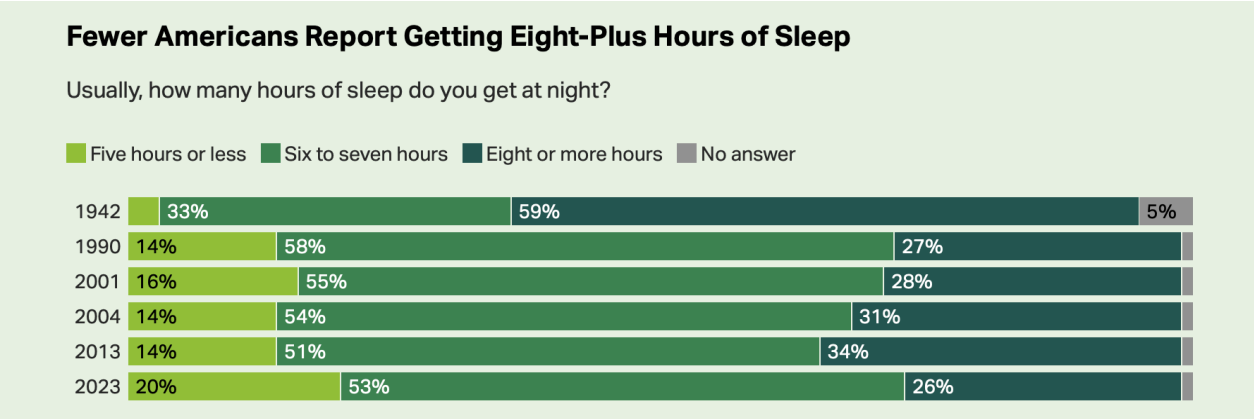

Figure 2. Distribution of how much sleep people get on average a night over time in the US (Fioroni 2024).

The sleep-stress interaction is about more than just how we feel during the day - it has significant consequences on our physical, emotional, and cognitive well-being. Chronic stress and sleep deprivation are linked to several serious health issues, including cardiovascular disease, obesity, and mental health disorders like anxiety and depression (Watson, 2024)(“Chronic Stress”, 2024). Modern culture places a very high value on productivity, which may lead us to undervalue benefits of sleep like rest and recovery.

Therefore, it is critical to understand how the cumulative effects of stress and poor sleep habits can have harmful effects on both our health and our ability to function effectively in our daily

lives, including our performance, productivity, and mental health. In this paper, we focus on both internal and external stressors, and how they affect the body. We also look at the biology behind the sleep-stress relationship and explore how this relationship affects our overall performance and productivity. The aim of this paper is to identify potential stress management interventions and healthy sleep habits.

The Biological Effects of Stress

By definition, stress is “a state of mental or emotional strain or tension resulting from adverse or very demanding circumstances” (Oforeh, 2023). Naturally, there will always be some amount of stress in our lives, but chronic stress is different. Chronic stress is longer lasting and can be debilitating and overwhelming. It can even cause a number of health problems like anxiety, high blood pressure, and a weakened immune system (“How Stress Affects Your Health”, 2013). To recognize how we are affected by stress, we need to look at specific causes of stress and their biological impacts.

When we experience any type of stress, the body releases cortisol, the primary stress hormone (Mayo Clinic, 2023). Cortisol is produced by the adrenal glands, which are on top of each of the kidneys. Our adrenal glands are always producing cortisol, but cortisol levels that are too high or too low can be harmful to our health. Cortisol and other stress-related hormones activate the sympathetic nervous system (SNS), which in turn initiates the fight-or-flight response in our bodies, a physiological reaction that serves as a defense mechanism. The fight-or-flight response prepares the body to either fight back against a threat or run away in an effort to protect the body. In this state, the body prioritizes essential functions, like an increased heart rate, and suppresses processes that would be nonessential in a fight-or-flight situation, like immune responses and digestion (“How Stress Affects Your Health”, 2013). Thus, a person experiencing high levels of stress might find it difficult to sleep, as sleep is nonessential – and in fact, very counterproductive – in a fight-or-flight situation.

Normally, the SNS is dampened by the parasympathetic nervous system (PNS) after the stressful situation has passed, which allows the body to return to normal conditions (Experience Health and Wellness Center). However, in cases of chronic stress, the SNS-PNS balance is disrupted (Won, 2016). Specifically, if the SNS is activated for a long period of time, without being countered by the PNS, cortisol levels may stay elevated. Over time, this can weaken the immune system, and may even cause stress-induced chronic health conditions, such as diabetes, heart disease, obesity, and mental disorders (Bucsek, 2018).

There are many different kinds of stress and each type can have varying effects on the body. One kind of stress is acute stress, which is short-term stress. This type of stress could be caused by situations like taking an exam or having a job interview. In these scenarios, the SNS is acutely activated, which causes a temporary rise in cortisol levels. When the stressor passes,

the PNS activates and allows the body to return to a normal state (“Stress Effects on the Body”, 2018). Another kind of stress is chronic stress, which is prolonged stress (Kandola, 2024). This could be caused by academic pressure, like a heavy workload and constant deadlines, or by a job with consistent overtime work. In these cases, the SNS stays activated, causing cortisol levels to continue to increase, which may eventually lead to a weakened immune system. Since the SNS suppresses non-essential functions, like the immune system and body repair processes, if the SNS stays activated - and it’s forced to in periods of high stress - its function will eventually become impaired. It won’t be able to create a meaningful fight-or-flight response because the body is constantly in that state. This persistent stress could lead to many health issues, like fatigue, anxiety, increased susceptibility to illness, and even stress disorders (Chu, 2024).

In extreme cases of chronic elevated cortisol, one might develop hypercortisolism, or Cushing Syndrome. This disease causes problems like broken bones, reduced metabolism, and high blood pressure because the body is prioritizing functions involved in the stress response. Cortisol’s job is to increase blood pressure, manage blood glucose, and increase muscle tension, all of which are helpful during a stress response. However, in Cushing Syndrome, the body overcompensates with excessive amounts of cortisol, causing health problems. It may take patients with Cushing Syndrome years to figure out why they’re uncomfortable because the symptoms are very minor at first. However, if patients delay diagnosis, the symptoms become more harmful, affecting their daily lives. Cushing Syndrome patients report both “psychological disturbances”, like anxiety or depression, and other symptoms like fatigue (Santos, 2019). In addition, patients report problems with both sleep and stress.

External stressors, like academic or professional pressure, can be significant contributors to stress. For example, students under high academic expectations, or professionals in demanding work environments, often experience high levels of stress. Societal expectations and pressures can further exacerbate this stress and worsen the impact stress has on the body.

Internal factors, like self-perception, also contribute significantly to stress levels. For example, one paper states that “self esteem is regarded as the core and the consequence of mental health” (Liu, 2021). A positive self-image can increase resilience, even in high-stress situations, because individuals with high self-esteem possess the necessary qualities and skills to recover quickly from a mental, physical, or emotional crisis. They naturally have the ability to overcome adversity, fix negative moods, and address psychological challenges, all of which contribute to a greater resilience to stress (Sharma, 2013). On the other hand, a negative self-image could intensify stressful feelings in both acute and chronic stress conditions. Overall, higher self-esteem is linked to lower cortisol levels, decreased stress perceptions, increased confidence, and better work performance (Dandeneau, 2007). The correlation between

self-perception and stress highlights the importance of prioritizing mental well-being, especially in stressful situations.

The impact of age on stress is unclear. While it is clear that all people, both young and old, experience stress and are impacted by it, it is not clear if different age groups are impacted differently. One study states that “only by understanding the context of daily life can we predict when and how age is related to affective well-being,” emphasizing how age alone does not directly affect stress; rather, it is affected by the unique circumstances of an individual’s life (Charles, 2009). In other words, age is not a determining factor of stress, even though nonexistent correlations might seem to occur with individuals of the same age group and circumstances. For example, two 16-year-old individuals whose parents might be going through divorces might be experiencing similar levels of stress, leading one to conclude that their age is a responsible factor in their similar stress levels. However, according to current research, it would be more accurate to say that they’re stress levels are similar because they are going through similar events in their lives (Charles, 2009).

Along that same idea, cultural expectations can also have an impact on stress levels. For example, in individualistic cultures - like in the United States, Germany, Ireland, South Africa, and Australia - people are expected to be independent and self-sufficient. If an individual cannot meet that expectation, they might feel an increased stress burden than other individuals in their community.

Lastly, biological sex and gender differences can impact an individual’s experience and response to stress. Females have higher levels of oxytocin and estrogen, so when they get stressed, they are more likely to seek out social bonding as a response. Males, on the other hand, with higher levels of testosterone, lean toward the fight-or-flight response when in a stressful situation (Verma, 2011).

All of these factors - the biological responses, external stressors, and self-perception - can interact, creating a cycle of stress. For example, if you have had a stressful day at work or school, you might take the stress out on family members, which increases your overall stress level and increases the significance of the impact the stress has on your body.

Stress is an inevitable part of life, but it doesn’t always have to be negative. Stress is one of the main components that determines how someone will perform and how productive they will be. We need a little bit of stress to stay motivated - it is only when it is too much that it becomes a problem and will hinder our performance. Finding ways to cope when needed is essential to maintaining positive overall well-being. To effectively identify and manage stress we need to understand the biological implications and recognize the differences between acute and chronic

stress to effectively cope or seek out help if necessary. Creating a healthy balance for ourselves is key in making sure stress mainly helps us, instead of hurting us.

The Biological Effects of Sleep Disturbances Due to Stress

Sleep disturbances are commonly reported during periods of chronic stress. An elevated cortisol level “suppresses melatonin and dilutes adenosine”, which contributes to quality sleep (Mikkelsen, 2022). Elevated levels of stress and cortisol activate the SNS and suppress key chemicals responsible for regulating sleep, which can interfere with a restful night of sleep. Additionally, although it’s possible to fall asleep while the SNS is activated, this kind of sleep is not considered good quality. Furthermore, the lack of restorative sleep can cause even more stress. This creates a vicious cycle that can be difficult to break - if left unchecked, it can have detrimental effects on both physical and mental health. Overall, chronically elevated stress levels have a negative impact on our ability to obtain rejuvenating sleep.

Sleep affects almost every tissue and system in the body, which makes it essential for survival; however, not all kinds of sleep are the same. There are four stages to the sleep cycle, each serving a different role: The light sleeping stages, or non-rapid eye movement (non-REM) sleep stages, are N1 and N2, the deep sleeping stage is N3, and the vivid dreaming stage is called rapid eye movement (REM) sleep (Patel, 2024). Each stage plays an important part in making sure your body and brain feel refreshed in the morning.

Sleep quality also affects resilience to stress. A person who regularly gets good quality sleep will experience increased resilience to stress, while a person who regularly gets poor quality sleep has an increased risk of developing a mental health disorder. In fact, students who regularly get poor quality sleep are 4.7 times more likely to have higher stress levels than students who get good quality sleep (Herawati, 2019).

The amount of time required for sleep quality can differ for everyone, and is dependent on many factors. For example, babies spend about 16 hours a day sleeping, and spend about half of that time in REM sleep (Figure 3). Children and adults sleep much less, and spend less of the time they do sleep in REM sleep (“Genetics, Aging and Sleep: Sleep and Aging”). However, both groups may still get a good quality of sleep, as long as they get the amount of sleep that their age group requires. Sleep guidelines for each age group are listed in Table 1.

Age Group	Recommended Hours of Sleep/Day
Infants (4 months-12 months)	12-16 hours/day (including naps)
1-2 Years	11-14 hours/day (including naps)
3-5 Years	10-13 hours/day (including naps)

6-12 Years	9-12 hours/day
13-18 Years	8-10 hours/day
Adults (18+ Years)	7-8 hours/day

Table 1. Sleep guidelines for each age group ("Recommended Amounts of Sleep by Age Group", 2021).

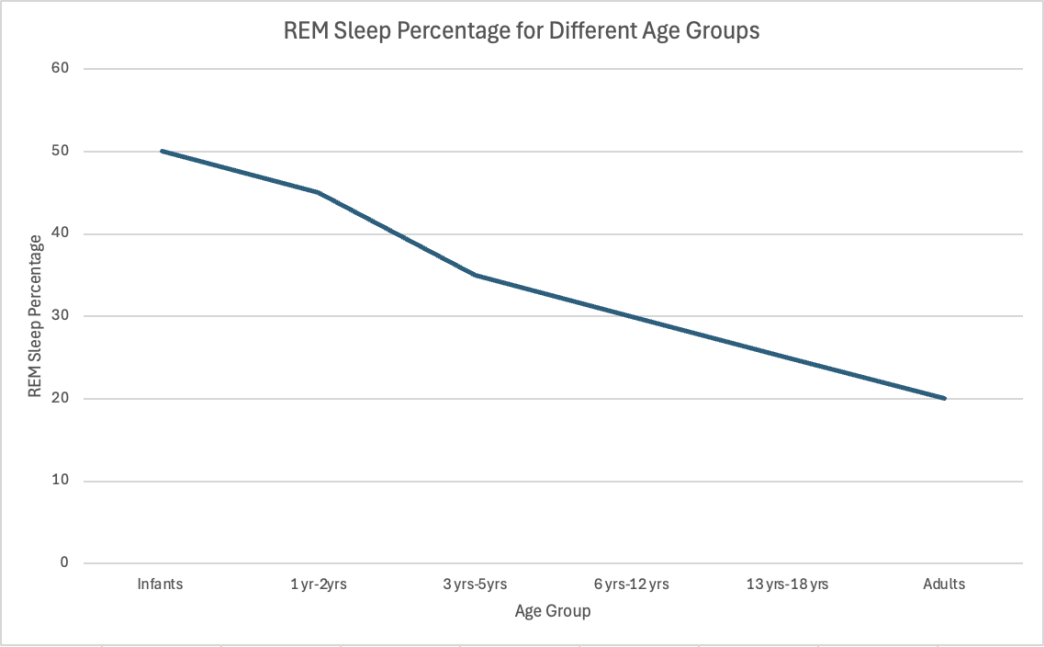

Figure 3. Average percentage of sleep time that people spend in REM sleep based on age. REM sleep declines as people get older. A steady decrease in the percentage of REM sleep is observed from infancy to adulthood (Pacheco, 2023).

Babies spend about twice as much of their sleeping time in REM sleep compared to older children and adults because, than older children and adults because REM sleep plays an important role in brain development and forming neural connections. Since their brains are growing a lot more than older children and adults, they need to spend more time in REM sleep to account for that.

There are also differences in sleep quality between genders. Men are generally able to fall asleep faster than women can. Men tend to spend more time in the first two stages of sleep, while women tend to get more deep sleep. Furthermore, men have even less deep sleep as they get older (Burgard, 2013). Men typically spend more time in REM sleep, but older women get more REM sleep than older men do.

There's certainly a correlation between sleep deprivation and stress, but studies show that some stress might indeed be the result of sleep deprivation, showing us that sleep loss and stress aren't just correlated - they directly affect each other (Nollet, 2020). Sleep disturbances may be caused by a variety of factors such as work, school, or even living next to a highway. All sleep disruptions will have some kind of negative effect on the body, but the extent will vary depending on the severity of the disruption. An acute sleep disruption, such as from pulling an all-nighter, can lead to increased stress the next day. The individual might experience short-term effects like fatigue, metabolic changes, and reduced immune responses (Thompson, 2022). In comparison, chronic sleep disruptions, such as consistently getting less than 8 hours of sleep, can cause chronic stress. Over time, this can result in chronic health issues and reduced cognitive function ("Sleep Disorders and Sleep Deprivation", 2006).
If these unhealthy habits continue, they may lead to sleep disorders like insomnia, or mental health disorders like depression (Franzen, 2008). These disorders are becoming increasingly prevalent, for several reasons such as increased obesity, an older aging population, and more blue light exposure (Tubbs, 2020; Miner, 2017; Shechter, 2017). Depression affects more than 8% of American adults and more than 15% of American youth, and chronic insomnia affects about 30% of the general population (Roth, 2019). Of course, depression isn't entirely caused by sleep, but sleep is an important factor.

Sleep and stress are interrelated as demonstrated by a lack of sleep or a low quality of sleep causing stress, and increased stress in turn causing a lack or low quality of sleep. Chronic stress leads to chronic sleep problems, which creates more stress. The cycle continues, and it gets harder and harder to break as time goes on.

Short-term treatments for sleep and stress issues can include medications (Table 2). Benzodiazepines are commonly used to treat sleep problems, but there might be withdrawal symptoms with REM rebound. Hence, drugs like zolpidem and zaleplon, which are newer benzodiazepine-like agents, are often prescribed because they result in fewer side effects. They work by acting as receptors of the neurotransmitter GABA, a chemical that plays a role in regulating sleep cycles. By doing so, they help ensure a more restful night of sleep. In terms of treating stress problems, Paxil and Lexapro are commonly prescribed. They both belong to a class of antidepressants called selective serotonin reuptake inhibitors (SSRIs), and they increase the concentration of the neurotransmitter serotonin - which is responsible for regulating mood - available in the brain by preventing its reuptake. However, even though these drugs can be effective in improving sleep and stress, they often come with side effects.

Drug	Treatment Target	Mechanism of Action	Side Effects

Zolpidem	Increase sleep	GABA receptor agents	Idiosyncratic daytime sleepiness or anterograde amnesia
Zaleplon			
Paroxetine	Decrease stress	Increasing serotonin	Dizziness, nausea, headaches, drowsiness
Escitalopram			

Table 2. Comparison of side effects associated with drugs used to treat problems with sleep and stress (Pagel, 2001; “Paroxetine”, 2022; “Escitalopram”, 2023).

It’s clear that although effective, these medications might not be the best long-term solutions.

Medications can provide short-term symptom relief, but they might result in dependence or other health effects (Fitzgerald, 2015; Von Moltke, 2003). Treatments like lifestyle changes and psychotherapy,where coping strategies can be learned, may help break the cycle more effectively (Gabbard, 2007).

Adequate sleep and stress management are not two separate issues, but rather one interconnected problem. Solving the problem may seem extremely difficult, but it is required to maintain our overall health. It may seem like there’s not enough time for sleep, but that means that there’s not enough time to prioritize health, which is one of the most important things that one can prioritize. Everyone needs different amounts of sleep, but it is important to prioritize sleep enough to get the amount of sleep each of our bodies need.

The Impact Sleep and Stress Have on Productivity

Before we look further into impacts performance and productivity, it is important to define these terms. For the purposes of this paper, we will define academic performance as “grade point average, standardized test scores, and educational aspirations and attainment” (Farb, 2012). We will define academic productivity as progress and improvements that a student makes. Put simply, when we are looking at academic productivity, we are looking at the quality of studying that a student is doing and the focus they are able to maintain while doing it.

Another term that is important to define is the Maslow Hierarchy of Needs, which describes our needs based on priority. At the base of the pyramid are immediate psychological needs, followed by safety, love/belonging, esteem, and self-actualization (Kenrick, 2010). It’s important to note that if one or more of these needs are not met, they can contribute to performance inhibiting stress (Lomas, 2013). Making sure that these needs are met can help us reach peak performance levels.

Now that we realize that some stress is helpful and that many factors can contribute to performance, we can start to focus on what ideal stress should look like. To do this, we can refer to the Yerkes-Dodson law, which states that moderate stress levels enhance performance, but excessive levels of stress can inhibit it (Yerkes, 1908). It is also important to recognize that stress levels can be different for everyone depending on their current personal circumstances and their overall resilience.

For example, one study found that children with high anxiety levels performed worse than children with low anxiety levels, but children with medium anxiety levels outperformed both of the other groups (Wood, 2016). In this study, they evaluated childrens' performances on a standardized reading comprehension test on children with varying degrees of anxiety. These results suggest that some amount of anxiety is necessary in order to have a positive learning outcome.

However, it is important to recognize that high-anxiety children were outperformed by low-anxiety children. This shows that excessive stress might impair focus and memory recall, which are claims supported by another study on stress and long-term memory retrieval (Klier, 2020). As a student myself, I'm able to see all of these things in action at school. For example, when I am stressed before a test, I have trouble remembering what I've studied, which reduces my performance. I also feel worse during the test because feeling like I don't know the content makes me completely lose motivation, which creates even more stress. Another thing to consider would be the quality of studying. Research shows that study strategies, especially time management, play a critical role in student stress levels (Gallardo-Lolandes, 2020).

The last thing to consider is a big one, and it is probably a question we have all asked ourselves at some point: why do some people perform better under pressure than others? According to one study, a possible explanation is that people with high memory capacity can perform better under normal pressure, but when the stakes get too high, they can't perform as well (Ötting, 2020). Another article explains how resilience is the one trait all people who perform well under pressure share (Steel, 2024). The more resilient personality type that a person has and the stronger support system they have the more likely that a person's stress will be helpful, and not negatively impact, their productivity.

While stress is a big part of productivity, it isn't the only thing that impacts it. Goal setting can also play an essential role in increasing productivity by creating a specific focus to work towards. However, it's important to set goals appropriately, because unrealistic goals could have the opposite effect, causing more stress and hindering performance.

It's also important to consider how effective goal setting methods are. One method, called the SMART goal, involves creating goals that are Specific, Measurable, Attainable, Relevant, and Time-Bound. A survey of more than 16,000 people found that "SMART goal setting is actually leading to lower performance, less inspiration and may even impede career success" ("Are SMART Goals Dumb?"). As an alternative to SMART goals, they proposed using visuals to describe goals, which seems to be more effective. Another study focused on the impact goal setting has on motivation and self-efficacy, finding that although goal setting can benefit academic achievement, it has no effect on motivation and self-efficacy (Sides, 2020). These findings emphasize how although goals can help guide us in the right direction, the exact "formula" of a perfect goal is not something that can be set in stone.

Conclusion/Discussion

Overall, there are three main things we need to reach maximum performance. Firstly, we need to have our basic needs met. Secondly, we need to have a moderate amount of stress. And lastly, we need to have realistic and manageable goals. It is important to note that all three of these things impact and are impacted by stress. Thus, stress impacts productivity, and lower productivity can increase stress, creating yet another vicious cycle that needs to be broken. In order to break it, we can start by setting reasonable goals and practicing coping strategies.

As we continue to prioritize productivity and achievement, it's important to keep the intricate connections between sleep, stress, and overall well-being in mind. Stress can disrupt sleep, and likewise, inadequate sleep creates stress. This loop can negatively impact physical health, mental well being, and academic performance. At the same time, performance and productivity are influenced not only by stress and sleep, but also by factors like effective goal setting and the attainment of basic psychological needs. Maintaining a balance is essential - a moderate stress level is a necessity for productivity and resilience, but excessive stress can impact focus and memory, decreasing overall productivity.

These findings emphasize the importance of addressing stress and sleep issues holistically. Better time management, effective goal setting, and effective coping mechanisms all play an important role in breaking the cycle. Recognizing that stress doesn't have to be harmful, but requires careful management, can help individuals use stress positively to achieve their goals. Likewise, making sleep a priority is essential for both physical and mental health, in addition to its role in personal and academic achievement.

It's critical that we find ways to manage our stress and get adequate sleep in order to achieve our ultimate goal of peak productivity. By spreading awareness of the issue and focusing on our individual needs, we can all thrive under pressure, while still maintaining our health and well-being.

Now that we understand the cycle and are armed with practical strategies to combat it, we can turn the vicious cycles of stress and sleep deprivation into virtuous ones, leading to greater productivity, resilience, and life satisfaction.

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