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Reasons behind Sleep Deprivation among Adolescents: Evidence from Beijing

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ABSTRACT

Although current studies have examined the association between multiple variables and sleep deprivation among adolescents, such as the use of electronic devices and stress, few studies managed to disassociate the variables and examine the impact of each one on sleep individually. The objective of this study is to examine which factor between the use of electronic devices, workload, stress and basic psychological needs of an individual has the most impact on sleep duration and quality of adolescents. 16 participants volunteered for this research measuring their sleep and deep sleep through commercially available smart band provided. They self-reported the sleep data recorded along with the amount of time spent on electronic devices and schoolwork, and a rating of workload and stress on a scale of 1-10 through a period of 38 days. Participants then completed a Pittsburgh Sleep Quality Index questionnaire and a Self-Determination Theory questionnaire. Results show that stress has the most impact on both sleep duration and quality. The fulfillment of an individual's psychological needs highly correlates with sleep: the unmet psychological needs directly influence other variables such as stress level which will affect sleep. This research shows inconsistency during data analysis when different method is applied potentially due to time constrain of this research, future research is needed to prove the validity of the finding.

Introduction & Literature Review

Sleep deprivation is becoming a global phenomenon, especially among adolescents. According to an article from Sleep Foundation written by Eric Suni and medically reviewed by Alex Dimitriu, a psychiatrist, about 70% of high school students are not getting enough sleep (Suni, 2023). Present studies mainly focus on several factors impacting adolescents' sleep. Including stress and usage of electronic devices, increasing workload is included in a few studies as one of the factors impacting sleep in adolescents.

Deep sleep, a crucial part of an individual's sleep schedule, serves as the repairing and restoration function of our body. Another article from Sleep Foundation written by Danielle Pacheco and medically reviewed by Dr. Abhinav Singh, a sleep physician, indicates that an individual should spend about 20% of their regular sleep in deep sleep. During deep sleep, our bodies grow and repair muscle, process information to store memories, and increase immunity (Pacheco, 2023).

Given the phenomenon of sleep deprivation among adolescents, a few factors that have an influence on sleep were widely discussed throughout the past decade.

Stress and Sleep

Stress and sleep are highly interrelated. A paper published by Svetlana Maskevich, along with her colleagues at the Monash Institute of Cognitive and Clinical Neurosciences, highlighted a crucial role sleep plays in balancing stress levels. The level of sleep and stress varies quite a lot for adolescents due to their school curriculum. Maskevich carried out a study on adolescents' sleep and stress during school term and vacation. The result indicated that stress affects sleep quality more than duration. Higher stress level is often linked with longer sleep onset latency, means it takes longer for an individual to fall asleep; this applies both during both school term and vacation. An explanation suggested that higher level of stress is causing adolescents' mental activities to increase before they sleep, resulting in latened sleep (Maskevich et. al, 2019).

Sleep acts as a coping mechanism for adolescents under pressure. Amanda E. Chue, who is from the department of psychology at the American University, Washington D.C., wrote in one of the papers she published with her colleague that investigates the relationship between sleep and stress recovery: "When stress was high, but sleep duration was longer, positive affect bounced back to levels observed following low stress days. When sleep was shorter, adolescents' positive affect remained low the following morning" (Chue et. al, 2018). Maskevich's research indicates that the effect of coping method in her study varies between school term and vacation. Due to the high pressure and sleep restriction at school, the coping method doesn't help much with relieving stress. However, it generates positive effect during vacation, the method has "reduced the indirect effects of stress on both actigraphy and self-reported SOL (sleep onset latency)" (Maskevich et. al, 2019).

Use of Electronic Devices

Ever since the prevalence of electronic devices, there has always been discussion on how severe of an impact it could potentially exert on adolescents. Dr. Philip Baiden, from The Arlington School of Social Work at the University of Texas, with his colleague, Savarra K. Tadeo and Kersley E. Peters, conducted research on the association between the use of electronic devices and insufficient sleep among adolescents. Although multiple studies have been carried out on this relationship, Baiden's study specifically targets the usage of modern devices such as smart phones and tablets. The result indicated that excessive usage of electronic devices can lead to obesity, mental disorders, and poor sleep quality, which can further develop into depression, even suicidal behavior. Hypothesizing that the excessive usage of electronic devices will delay the normal sleep schedule, cause daytime fatigue and disrupt an individual's circadian rhythm, Baiden's team used the YRBS survey in 2017, a school-based survey carried out by the CDC in the United States every two years, as their data. By analyzing the responses related to the use of devices, sleep schedule and other covariates such as race, depression, and suicidal ideation etc., they concluded that adolescents whose screen time is excessive are likely to have insufficient amount of sleep on an average school night. Additionally, adolescents with depression, lack of physical exercise and obesity are more likely to have insufficient sleep (Baiden, Tadeo, and Peters, 2019).

The lack of sleep appears to be correlated with the excessive usage of devices and attention control difficulties. A similar experiment was carried out by Michael Mireku, along with his colleagues at the Department of Epidemiology and Biostatistics of the University of Lincoln. They examined the baseline data from the Study of Cognition Adolescents and Mobile Phone (SCAMP) by deriving variables to analyze. Their paper indicated that it's quite common for most adolescents to use at least one electronic device within the hour prior to sleep. Moreover, about

one third of the sample students in their study used electronic devices in a dark environment. The usage of electronic devices is highly correlated with insufficient sleep or poor sleep quality, increasing in severity if it's used in darkness (Mireku et. al, 2019).

Student Workload

Among the student population suffering from sleep deprivation, Asian students comprise a significant portion. According to Wen-jun Zhang, who is in school of psychology and cognitive science of East China Normal University, stated in the paper that there has been increasing evidence suggesting that Asian students, especially Chinese students, have a higher chance of suffering from severe sleep problems due to the heavy workload from the curriculum. Since Chinese students experience a higher level of academic stress, the reduction in sleep time caused by workload is inevitable. Under the academic pressure, most students suffer a delay in bedtime as well as experience increased stress levels and depression (Zhang et. al, 2020).

In Maskevich's research, although the initial aim was to examine if stress has been affecting sleep during school days and vacation, the time examined indicated a factor which may be ignored by researchers: The school period which they chose is the end of a given semester, which is usually when most tests take place. Under these circumstances, teachers are more likely to assign review materials, resulting in the increased stress levels and workload of students. If the review materials happen to be online, the use of electronic devices will likely increase as well.

Self-Determination Theory (SDT)

Self-determination theory (SDT) suggests a theoretical framework that could help explain the impact of the factors mentioned earlier, on sleep. It indicated three essential psychological needs that allow an individual to be psychologically and physically well-behaved (Campbell et. al, 2015). According to University of Rochester Medical Center, "SDT is the motivation that has been applied in many life domains such as health, sport, education and work." Motivation is driven by three main factors, which are also the basic psychological needs of an individual: autonomy, competence, and relatedness. Autonomy refers to the control and willingness of one's behavior; it's the recognition of self-endorsement in an individual's action. Competence refers to the feeling of effectiveness of one's activity on their surrounding environment. Relatedness refers to the feeling of connection and belonging between self and others. When those needs are fulfilled, an individual is more likely to experience positive well-being (Mayo et al., 2022; Ntoumanis et al., 2021). In relation to sleep, it's predicted that individuals who feel more motivated are likely to have good sleep, in contrast to a lower sleep quality of those feeling less motivated.

Research Question & Hypothesis

As indicated in the previous literature. Although there have been a variety of research papers that have examined factors which impact adolescents' sleep. Most of them only focus on measuring one of the factors but unaware of other lurking variables that could potentially cause an impact the results. Leading to my research question: What is the main reason behind sleep deprivation among adolescents? The aim of this research is to investigate which factors among the usage of electronic devices, workload, and stress has the most impact on Chinese international high school students. I came up with two null hypotheses for my research.

H_0: Whichever factor that is has the most impact on adolescents' sleep will have the highest correlation and change along with the sleep time. H_1: The better an individual's psychological needs are fulfilled, the better their sleep quality is.

Research Design and Methodology

Participants and Procedure

20 students from School X were volunteered to participate in this study. However, 4 of them were excluded because they failed to report the data, resulting in a final sample of 16 people participating. All participants were given consent form about the study, and it was approved by the Institutional Review Board (IRB) of School X.

Measures & Instruments

Since the goal is to measure which, factor has the most impact on adolescent's sleep. All the variables measured will be converted to a numerical value to analyze the correlation and trend.

Sleep

The sleep quality is assessed using Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989) (See **Appendix A**). PSQI contains 19 items and will generate seven components: subjective poor sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of hypnotics, and daytime dysfunction (Buysse et al., 1989). A few input values for calculation using PSQI require the participants to estimate a value in the amount of time spent on sleeping for the past one month. To maintain the accuracy of the measurement of time slept instead of asking them to simply give an estimate, participants were given smart bands that have the function to measure sleep time. Considering that the smart bands only measure sleep between 9PM to 9AM on the next day, only Sunday night to Thursday nights' sleep data were recorded so the school schedule helps to control the time awake (school starts at 8AM). Due to budgetary constraints, the quality of the smart bands wasn't guaranteed, and it occasionally failed to capture the correct measurement due to technical issues. Thus, participants were asked to check if the time recorded is accurate or not, if the smart band over-measured the time slept, participants were asked to indicate the length of time over-measured, and number was deducted. If the error is too large, then the average of that participants' sleep time will be used to fill the gap. After the data collection that lasted for 38 days, participants were given the PSQI questionnaire to fill which I used to calculate a PSQI Score for them which would reflect their sleep quality. Their average sleeping time will be used to fill the question regarding how much they have slept on the questionnaire.

Usage of Electronic Devices

Participants were asked to report how long they spent using electronic devices within 4 hours before sleep. This method is inspired by a similar study conducted by Michael Mireku, whose method included asking the participants to report how often they use electronic devices 1 hour prior to bed (Mireku et. al, 2019). Considering that the use of electronic devices is prevailing in the current education system, most teachers assign tasks and materials on websites, it's hard to distinguish whether a positive response given is due to workload or gaming. Thus, in the study, the time is extended to four hours.

Workload

Chinese international high school students have a comparatively different curriculum from the ones in public high school, so workload is one variable which is collected. Since workload is a subjective measurement which varies by person. It's difficult to make comparisons based on how much work was done or how many words were written, so a rating scale is chosen as the method to measure workload. In this study, participants were asked to rate their workload everyday based on a scale of 1 (no work at all) to 10 (extremely heavy workload).

Stress

Like workload, stress is hard to describe by words, so it needed to be converted into a measurement which is easier to calculate. There are questionnaires examining stress that are available, but those questionnaires require the participants to fill out the survey based on their experiences in the past few months while this study only lasted for two months, creating potential lurking variable that I can't control. Additionally, the measurement is collected daily, using a long-term evaluation questionnaire would not show effective changes. This study adopted the rating method used by Amanda Chue and her group to collect stress levels from adolescents, in which the participants were asked to rate their stress levels on a scale of 1 (not at all) to 7 (extremely) daily (Chue et. al, 2018). To keep the scale consistent with the one used to measure workload; stress will also be reported by participants daily based on a scale of 1 (no stress) to 10 (extremely stressful).

Time Spent on School Work

After a few days of data collecting, I found that the workload reported by a few participants was either untruthful or highly exaggerated. I introduced a new measurement to keep the balance: time spent on schoolwork. Participants will self-report the amount of time spent on schoolwork at home. This measurement helps to double check if the workload rates are reasonable, and it provides a comparison between use of device and workload. If the time spent on schoolwork is a large number that almost covers the entire period between school ends and their bedtime, we can assume that most of the usage of electronic devices before bed is a result of studying, and vice versa.

SDT Questionnaire

The SDT questionnaire (Deci & Ryan, 2000; Gagné, 2003) (See **Appendix B**) was given to the participants after data collecting, they were asked to complete it and the final score for autonomy, competence, and relatedness was calculated by me.

Data Collection

Since I collected primary data for an extended period of 38 days during my research, my data set fits the definition of a panel data. The aim of this study is to examine which of the explanatory variables has the most impact on sleep. **Table 1** is about descriptive statistics of the data of all the variables I collected. It has shown, the student sample has an average of 423 minutes (7 hours) of sleep every night, which is significantly lower than the 9-hour recommended sleep for adolescents. **Table 2** is the correlation coefficient matrix between the variables measured. Since the study has last for 38 days, we must consider that the sleep quality from yesterday can potentially influence the measurement of other explanatory variables today and vice versa. Thus, we added variables "lag-stress", "lead-stress", "lag-stress 2", and "lag-sleep" to increase accuracy of data analysis as time series data is often an autoregressive (AR)

process. “Lag-” indicates the effect from one variable today is partially influenced by the leftover-effect from one of the variables yesterday while “lead-” indicates the result of today would contribute to the measurement in the future. Those variables will be included and analyzed in more detail in Results section.

Table 1. Descriptive Statistics of the explanatory variables.

Variable	Mean	SD	Min	Max
Time Slept	423.030	38.108	186	682
Deep Sleep	173.000	42.379	52	443
Times Awake	0.690	0.956	0	5
Electronic	178.11	54.170	30	240
Workload	5.094	2.006	1	10
Stress	5.280	2.134	1	10
Schoolwork	138.631	86.462	0	660
Autonomy	4.098	0.964	2.43	6.29
Competence	4.106	1.315	1.2	6.67
Relatedness	4.835	1.028	2.25	6.625
PSQI Score	5.437	1.837	2	9

Table 2. Correlations Coefficient Matrix.

	Time slept	Deep Sleep	Times Awake	Electronic	Workload	Stress	Schoolwork
Time Slept	1.000						
Deep Sleep	0.303***	1.000					
	0.000						
Times Awake	0.048	-0.015	1.000				
	0.234	0.706					
Electronic	-0.055	-0.147***	-0.011	1.000			
	0.178	0.000	0.784				
Workload	-0.091**	-0.052	-0.033	0.180***	1.000		
	0.025	0.201	0.419	0.000			
Stress	-0.106***	-0.116***	0.013	0.299***	0.708***	1.000	
	0.0095	0.004	0.742	0.000	0.000		
Schoolwork	-0.161***	-0.036	-0.009	0.281***	0.683***	0.588***	1.000
	0.0004	0.426	0.834	0.000	0.000	0.000	

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. The table indicates Pearson correlations between time slept, deep sleep, times awake, electronic, workload, stress, and time spent on schoolwork.

Data Analysis & Results

Since my data set is counted as panel data, I'll be running time series regression on them to test which of the explanatory factors is contributing the most to adolescent's sleep. All data analysis was done through STATA (StataCorp, 2019). Variables added (lead-stress, lag-stress, lag-stress 2, lag-sleep) will be included when a time series regression has been conducted.

Table 3. Time Series Regression: The Relationship between Explanatory Variables Measured and Time Slept.

$$Time\ Slept = \beta_0 + \beta_1 deep\ sleep + [\beta_x Variable_x] + \epsilon_t$$

Time Slept	Coefficient	Standard Error	*p-value*
Deep Sleep	0.553	0.044	**0.000*****
Times Awake	0.524	1.986	0.792
Electronic	0.061	0.040	0.125
Workload	-0.245	1.477	0.868
Stress	-1.921	1.097	**0.081***
Schoolwork	-0.060	0.031	**0.060***
Lag-Stress	0.085	0.894	0.924
Lead-Stress	1.665	0.874	**0.058***
Lag-Stress[n − 2]	-1.405	0.875	0.109
Lag-Sleep	-0.082	0.044	**0.067***
Constant	346.675	15.188	**0.000*****

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. Significant values are marked **bold**.

As shown in **Table 3**, by using the time series regression, the data analysis states that a longer time slept is highly correlated with longer deep sleep ($r = 0.553$), lower stress ($r = -1.921$), and lower schoolwork ($r = -0.060$). Additionally, lead-stress shows a positive correlation ($r = 1.665$) and lag-sleep shows a negative correlation ($r = -0.082$) with the amount of time slept. Indicating that higher level of stress today will result in a longer sleep time tomorrow while the longer an individual slept yesterday, the shorter they will be sleeping today, and vice versa.

Table 4. Simple Regression: The Relationship between Explanatory Variables Measured and Time Slept.

$Time\ Slept = \beta_0 + \beta_1 Deep\ Sleep + [\beta_x Variable_x] + \epsilon$			
Time Slept	**Coefficient**	**Standard Error**	***p-value***
Deep Sleep	0.412	0.042	0.835
Times Awake	0.336	1.617	**0.000*****
Electronic	0.034	0.031	0.278
Workload	2.060	1.296	0.113
Stress	-1.783	1.194	0.136
Schoolwork	-0.107	0.025	**0.000*****
Lag-Stress	1.091	1.013	0.282
Lead-Stress	2.317	0.982	**0.019****
Lag-Stress[n − 2]	-0.191	0.969	0.844
Lag-Sleep	-0.217	0.042	**0.000*****
Constant	378.976	11.238	**0.000*****

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. Significant values are marked bold.

As shown in **Table 4**, by using the simple regression, the data analysis states that a longer period of sleep is highly, negatively associated with time spent on schoolwork ($r = -0.107$), positively associated with lead-stress ($r = 2.317$), and negatively associated with lag-sleep ($r = -0.217$).

Table 5. Time Series Regression: The Relationship between Explanatory Variables Measured and Deep Sleep.

$Deep\ Sleep = \beta_0 + \beta_1 Times\ Awake + [\beta_x Variable_x] + \epsilon_t$			
Deep Sleep	**Coefficient**	**Standard Error**	***p-value***
Times Awake	-3.008	2.118	0.156
Electronic	-0.035	0.042	0.402
Workload	-1.303	1.578	0.409
Stress	-0.825	1.171	0.482
Schoolwork	-0.016	0.034	0.626
Lag-Stress	1.797	0.952	**0.060***
Lead-Stress	-0.851	0.934	0.362
Lag-Stress[n − 2]	-0.014	0.936	0.988
Lag-Sleep	-0.090	0.047	**0.057***
Constant	207.045	12.947	**0.000*****

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. Significant values are marked **bold**.

Unlike total time slept, which is simply an indicator of whether one has got enough rest. Deep sleep reflects the quality of an individual's sleep. As shown in **Table 5**, surprisingly, a longer deep sleep is highly associated with only a greater lag-stress ($r = 1.797$) and a shorter lag-sleep ($r = -0.090$), indicating that a higher level of stress, a shorter length of sleep yesterday will lead to a longer period of deep sleep today.

Table 6. Simple Regression: The Relationship between Explanatory Variables Measured and Deep Sleep.

$$Deep\ Sleep = \beta_0 + \beta_1 Times\ Awake + [\beta_x Variable_x] + \epsilon$$

Deep Sleep	**Coefficient**	**Standard Error**	***p-value***
Times Awake	-0.925	1.775	0.603
Electronic	-0.077	0.034	**0.025****
Workload	-1.253	1.422	0.379
Stress	-1.005	1.310	0.443
Schoolwork	0.034	0.028	0.222
Lag-Stress	2.427	1.106	**0.029****
Lead-Stress	-1.085	1.077	0.314
Lag-Stress[n − 2]	-1.355	1.063	0.203
Lag-Sleep	0.443	0.041	**0.000*****
Constant	118.575	11.039	**0.000*****

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. Significant values are marked **bold**.

As shown in **Table 6**, by using simple regression, the data analysis states that a longer period of deep sleep is highly, negatively associated with the amount of time spent on electronic devices within four hours prior to bedtime ($r = -0.077$), positively associated with lag-stress ($r = 2.427$), and positively associated with lag-sleep ($r = 0.443$).

Table 7. Simple Regression: The Relationship between Time Slept and PSQI Score, Relatedness, Competence, and Autonomy.

$$Time\ Slept = \beta_0 + \beta_1 PSQI\ Score + [\beta_x Variable_x] + \epsilon$$

Time Slept	**Coefficient**	**Standard Error**	***p-value***
PSQI Score	-2.133	0.899	**0.018****
Relatedness	0.703	2.533	0.781
Competence	-3.950	2.120	**0.063***
Autonomy	0.031	2.153	0.988
Constant	447.321	11.254	**0.000*****

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. Significant values are marked **bold**.

Since PSQI Score and the SDT questionnaire were given to participants after data collection, they weren't continuous data that was collected on a regular basis, so I ran the simple regression on the relationship between time slept and PSQI Score, relatedness, competence, and autonomy instead of a time series regression. As shown in **Table 7**, the time slept is highly correlated with the PSQI Score ($r = -2.133$), further proving the effectiveness of how PSQI reflects the participants' sleep. However, only competence is negatively correlated with time slept ($r = -3.950$) out of the three psychological needs.

Table 8. Simple Regression: The Relationship between the PSQI Score, Relatedness, Competence, and Autonomy.

$$PSQI\ Score = \beta_0 + \beta_1 Autonomy + [\beta_x Variable_x] + \epsilon$$

PSQI Score	**Coefficient**	**Standard Error**	***p-value***
Autonomy	-0.273	0.098	**0.005*****
Competence	-0.203	0.096	**0.036****
Relatedness	-0.153	0.116	0.187
Constant	8.135	0.392	**0.000*****

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. Significant values are marked **bold**.

A simple regression was done on the few discrete variables to justify the effectiveness of the theoretical framework behind the study. As shown in **Table 8**, within the three elements from the SDT questionnaire, two of them show a high correlation with the PSQI score: autonomy ($r = -0.273$) and relatedness ($r = -0.153$), which justified the theoretical framework that SDT helps to explain the length and quality of sleep of adolescents.

Table 9. Simple Regression: The Relationship between Stress, Autonomy, Competence, Relatedness, and PSQI Score.

$$Stress = \beta_0 + \beta_1 Autonomy + [\beta_x Variable_x] + \epsilon$$

Stress	**Coefficient**	**Standard Error**	***p-value***
Autonomy	-0.912	0.109	**0.000*****
Competence	-0.308	0.107	**0.004*****
Relatedness	1.204	0.128	**0.000*****
PSQI Score	0.020	0.045	0.648
Constant	4.350	0.571	**0.000*****

Note: ***, **, and * represent statistically significant outcomes at the 1%, 5%, and 10% level respectively. Significant values are marked **bold**.

As shown in **Table 9**, by using simple regression, the data analysis states that a higher level of stress is highly, negatively associated with both autonomy and competence level ($r = -0.912$,$r = -0.308$ respectively) and positively associated with relatedness ($r = 1.204$). Indicating an individual's stress level is significantly associated with the level which their basic psychological needs are fulfilled.

Discussion

This study conducts an experimental study which generates primary data set along with survey data to investigate which factor among the use of electronic devices, workload, and stress would most impact adolescents' sleep. First, based on the results, most students have not met the recommended 9 hours of sleep. The factors which are influencing their length of sleep the most is stress, same when it comes to influencing the length of deep sleep. Unexpectedly, the result varies depending on which test is carried out on the data, which will be explained later in discussion.

Factors Influencing Time Slept

First, I did a time series regression on the panel data set collected from the sample group. Based on the result from **Table 3**, stress has the most impact on the amount of time slept by having a negative correlation with it ($r = -1.921$), followed by the use of electronic devices before bed, which also has a negative correlation ($r = -0.060$). The result makes intuitive sense, higher workload delays bedtime which reduces the amount of time slept while increasing stress caused sleep difficulties, disrupting normal sleep schedule and as well as sleep quality, this finding was consistent with Maskevich's research on stress and sleep (Maskevich et. al, 2019). Surprisingly, a positive correlation with lead-stress ($r = 1.665$) and a negative correlation with lag-sleep ($r = -0.082$) show a significant correlation with time slept. The negative correlation with lag-sleep can be explained by indicating that our body is able to balance and regulate the amount of sleep needed, the more you slept yesterday the less amount of sleep is needed today. The positive correlation with lead-stress is an unexpected result: it states that the longer you sleep today, the higher stress it will lead to.

Although workload and stress were indicated to have a significant relationship with time slept when a time series regression is carried out. When I ran a simple regression on the data, the results varied. As shown in **Table 4**, schoolwork, lead-stress, and lag-sleep still present as having significant correlation ($p < 0.01$,$p < 0.05$ and $p < 0.01$ respectively), stress level, however, was not found to have a significant correlation with the amount of time slept ($p > 0.1$).

Factors Influencing Deep Sleep

Similar with how I examined the correlation between explanatory variables and the amount of time slept. I ran both the time series regression and simple regression to test which variable influences deep sleep more. When a time series regression is run between the explanatory variables and deep sleep, none of the explanatory variables measured directly correlated with deep sleep. Lag-stress and lag-sleep became the only two factors that presented a significant correlation with deep sleep. As shown in **Table 5**, a positive correlation between lag-stress and deep sleep presents, higher stress from yesterday will result a longer period of deep sleep today, which is consistent with Maskevich's research again where she states that compared to the length of sleep, stress is more correlated with the quality of sleep, which in my study is reflected through the length of deep sleep (Maskevich et. al, 2019). This phenomenon can be explained by the mediating role of sleep, our brains grab more deep sleep to refresh itself under high level of stress. Lag-sleep has a negative correlation with deep sleep, which means the more an individual slept yesterday, the less deep sleep they will get the following day because they already got enough rest from the day before. Similar with how **Table 3** and **Table 4** slightly differ from each other, when I ran a simple regression on this data, the amount of

time spent on electronic devices within four hours prior to bed had a significant negative correlation with deep sleep ($p < 0.05$), as shown in **Table 6**. The more electronic devices used before bed, the shorter the deep sleep is, this finding is similar with Mireku's finding on their paper, nighttime electronic device usage results in adverse sleep outcome (Mireku et. al, 2019). Overall, I can conclude that stress is the factor having most impact on adolescents' sleep regarding both sleep duration and quality. Although the result matches with similar studies done, difference presents in results received from two regression tests. A potential reason behind this is the time constrain, the experiment only lasted for 38 days so the data set isn't large or stable enough for a time series regression, leading to the difference in result produced.

SDT, PSQI Score and Sleep

Table 7 was a regression between time slept, three variables derived from SDT questionnaire, and the PSQI score. As expected, the PSQI is highly correlated with time slept ($p < 0.05$) in a negative relationship. A higher PSQI score indicates a worse sleep length and sleep quality. However, out of the three derived categories from SDT questionnaire, only competence shows a significant negative correlation with time-slept ($p < 0.1$), indicating a higher competence level is leading to shorter period of sleep. I did another regression between PSQI and the three SDT categories to test the correlation between them. As shown in **Table 8**, both autonomy and competence are highly correlated with PSQI ($p < 0.01$ and $p < 0.05$ respectively) in a negative relationship, the higher the autonomy and competence of an individual, the lower their PSQI score will likely be and an improved quality of sleep. This conclusion supports my hypothesis: the better an individual's psychological needs are satisfied, the better quality their sleep is. The regression analysis further justified the theoretical framework of this research where one's psychological needs influence their sleep length and quality.

STD, SPQI Score and Stress

Given that previous data analysis indicate stress as the variable which has the highest correlation with sleep, I decided to run a regression to see the relationship between autonomy, competence, relatedness, PSQI Score and stress. As shown in **Table 9**, all three basic psychological needs were found to have a significant correlation with stress. Suggesting that the fulfillment of psychological needs is correlated with stress, and stress correlates with sleep, forming a potential logic chain behind the results.

Limitations and Implications

Several limitations were present in this study that needs to be addressed. First, as shown in the discussion section, variables that were indicated to be highly associated with sleep length or sleep quality varies when different tests were carried out. Although this can be explained by the time constraints, future research needs to be done to confirm whether the association found in this study is significant or not. Second, all participants volunteered themselves for this study, creating a potential selection bias. It cannot be guaranteed whether students who volunteered for this study a representative enough. Third, this study only lasted for about two month with data collection date reduced down to 38 days since all weekends and holidays weren't included, the time period is relatively short with days that weren't recorded being potential lurking variables. Lastly, due to the quality of the smart band, participants were asked to

double-check whether the numbers recorded were accurate or not and then report to me whether there were portions/values which needed to be subtracted or added. I won't know if there is any untruthful response present when they report to me the portion that needs to be modified, so the time recorded can vary. Further research is needed to prove the association found in my research as well as making students aware of how their sleep is affected by both internal and external variables. The finding from this research is beneficial for the communities' social institutions such as schools to modify their curriculum to provide students with longer and higher quality of sleep. It also proves the possibility of conducting experimental research using commercially available equipment under budget constraints.

Conclusion

Overall, my findings suggest that stress has the most impact on adolescents' sleep by having the largest correlation coefficient with both the amount of time slept and deep sleep regardless of whether a simple regression or a time series regression is run on the data. The higher stress levels an adolescent experienced, the shorter their sleep duration is, which contributes to their stress level tomorrow and the cycle continues. Its correlation with deep sleep is similar with time slept, indicating stress influences both sleep quality and sleep duration. Moreover, stress leaves lag effect on deep sleep, stress from previous days influences deep sleep on a larger magnitude than stress during that day.

The SDT and PSQI proved that fulfillment of an individual's basic psychological needs do influence sleep. The higher an individual's capacity and self-rule is, the more likely that they'll have good sleep quality. Psychological needs are found to correlate with stress levels which still lead to the change in sleep. Without a doubt, stress is the most crucial factor that contributes to sleep by having an extended impact. Stress during the day, lag-stress, and lead-stress all have a significant impact on adolescents' sleep. However, potentially due to time constrain, in data analysis the variables found to have connections with sleep varies based on the type of regression ran on data. Future research is needed to test and reinforce the findings in this research as well as applying it to real life circumstances for adolescents to obtain the length and quality of sleep they need.

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