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The Relationship Between Insomnia, Working Memory, and Inhibition Control with Academic Achievement: A Facial Analysis Study

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ABSTRACT

Sleep deprivation is one of the crucial factors that contribute to the decline in adolescent academic achievement, but objective measurements of this condition are still limited. This study aims to analyze the relationship between physiological insomnia symptoms, executive function (working memory and inhibitory control), and student academic achievement. The method used is a quantitative approach with a cross-sectional design, involving 200 students of Vocational High Schools (SMK) in North Kalimantan. Physiological insomnia symptoms were objectively measured using Computer-Based Facial Analysis via the Eye Aspect Ratio (EAR) and Mouth Aspect Ratio (MAR) indicators, while executive function was measured using the N-Back and Stroop tasks. Data were analyzed using Structural Equation Modeling (SEM) with 5,000 bootstrapping resamples. The results showed that physiological insomnia symptoms had a negative, significant effect on executive function ($\beta = -0.45$; $p < 0.001$), while executive function had a positive, significant effect on academic achievement ($\beta = 0.56$; $p < 0.001$). Mediation analysis showed that working memory and inhibitory control partially mediated the relationship between insomnia and academic achievement (indirect effect = -0.254). The conclusion of this study confirms that insomnia contributes to decreased academic achievement by degrading cognitive function. From the perspective of Islamic educational psychology, these findings reinforce the importance of maintaining sleep quality as part of efforts to maintain reason (hifz al-'aql), as well as encouraging the integration of sleep hygiene education in the school environment to improve students' cognitive readiness.

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1. INTRODUCTION

Sleep is a fundamental biological need that plays an important role in adolescent neurocognitive development, especially during the maturation of the prefrontal cortex,

which supports high-level cognitive functions such as decision-making, emotion regulation, and behavioral control [2]. Nevertheless, sleep deprivation has become an increasingly widespread phenomenon among adolescents, driven by academic pressure, the use of technology, and changes in modern lifestyles [24], [28]. This condition not only affects physical fatigue but also impairs cognitive function, especially executive functions, including working memory and inhibitory control [9].

From an educational psychology perspective, executive functions play a strategic role in determining academic success. This function allows individuals to process information effectively, maintain attention, and control impulses in the learning process. Several studies show that good sleep quality is positively correlated with students' cognitive performance and academic achievement [16], [6]. In contrast, sleep deprivation has been shown to decrease working memory capacity and inhibitory control, with a direct impact on students' ability to understand material and complete academic assignments [27]. Research by Ahmed et al. [2] also confirms that poor sleep quality is an independent predictor of decreased attention skills and complex task management in students.

Although the relationship between sleep quality and academic achievement has been extensively researched, most studies still rely on subjective instruments such as self-report and the Pittsburgh Sleep Quality Index (PSQI) [11], [23]. This approach has limitations because it is susceptible to recall and social desirability biases, potentially failing to reflect the true physiological condition. On the other hand, the development of artificial intelligence-based technologies has enabled objective measurement of sleepiness and fatigue through facial analysis, using parameters such as the Eye Aspect Ratio (EAR) and Mouth Aspect Ratio (MAR) [1], [18]. However, the use of this approach as an objective indicator of the impact of insomnia on cognitive function and academic achievement remains very limited, particularly in the context of education.

Based on the study, there is a significant research gap: the lack of integration between technology-based objective physiological measurements and cognitive function analysis to explain the impact of insomnia on academic achievement. Previous research has tended to separate biological, cognitive, and academic aspects, thereby failing to provide a comprehensive picture of the mechanisms underlying the relationship among the three. Therefore, this study offers an integrative approach by combining computer-based facial analysis, a physiological indicator of insomnia, with executive function as a mediator in predicting academic achievement.

This study aims to analyze the relationship between physiological insomnia symptoms, executive function (working memory and inhibitory control), and student academic achievement. Specifically, this study examined the mediating role of executive function in the relationship between insomnia and academic achievement. Thus, this study not only seeks to identify relationships between variables but also to elucidate the underlying cognitive mechanisms.

The hypotheses proposed in this study are as follows:

- H1: Facial features associated with insomnia are negatively correlated with working memory performance and inhibitory control.

- H2: Deficits in working memory and inhibitory control mediate the relationship between insomnia symptoms and decreased academic performance.

This research is expected to make a theoretical and practical contribution. Theoretically, this study enriches the study of educational psychology by presenting a multidisciplinary approach that integrates physiological, cognitive, and academic aspects. In practice, the results of this study are expected to serve as a basis for the development of technology-based early screening methods to detect the risk of decreased academic achievement due to sleep disorders. From the perspective of Islamic educational psychology, these findings also underscore the urgency of maintaining sleep quality as part of efforts to preserve reason (hifz al-'aql), one of the main goals of Islamic education.

2. METHOD

Research Design

The study used a quantitative research design that employed a correlational approach to systematically investigate the structural relationships among physiological insomnia symptoms, executive function deficits, and academic achievement [20]. A cross-sectional time frame (cross-section) was adopted, which allowed simultaneous assessment of biological markers (facial features) and measures of cognitive performance in the student population [29]. This approach is appropriate for identifying associations between sleep quality and cognitive variables at one specific point in time.

Location and Subject

The study was conducted at SMKN 1 Tarakan, North Kalimantan, and included a total of around 1,000 high school students in grades X and XI (ages 15–18 years). From this population, a final sample of 200 students was selected using purposive sampling techniques. To ensure that the data accurately reflects the variables of interest, purposive sampling techniques are used. Participants were selected based on specific inclusion criteria: (1) actively registered in the current academic semester [5]; (2) have no history of clinically diagnosed neurological disorders or routine consumption of medications affecting the central nervous system [20]; and (3) willing to give informed consent. Several students were recruited for the final analysis, a sample size calculated to meet the statistical strength requirements for Structural Equation Modeling (SEM) [17].

Instrument

To ensure data robustness, this study uses a multi-method assessment strategy that combines objective physiological analysis, standardized cognitive tasks, and ecological academic records. The specifications for each instrument are detailed in Table 1.

Table 1. Summary of Research Instruments and Measurement Specifications

Category Variable	Variable Name	Instruments / Tools	Parameters / Metric	Reliability / Validity
Independent	Symptoms of Insomnia	Computer-Based Face Analysis (e.g., OpenFace / MediaPipe)	- Eye Aspect Ratio (EAR) - Mouth Aspect Ratio (MAR) - Facial Landmarks (mis., Ptosis)	Validated objective physiological markers for the detection of drowsiness
Mediator	Working Memory (WM)	Digital N-Back Task/Sternberg Test	- Response Accuracy (%) - Reaction Time (ms)	Validated size for working memory capacity
Mediator	Inhibition Control (IC)	Color-Word Stroop Task / Eriksen Flanker Test	- Interference Score - Error Rate	High reliability to assess executive control and inhibition
Dependendency	Academic Achievement	Student Report Card	- Average score of core subjects (Mathematics, Science, Language)	Ecological validity that represents real-world educational outcomes

(1) Facial Analysis (Independent Variables), in contrast to traditional studies that rely on self-reports, this study uses Computer-Based Facial Analysis to quantify insomnia symptoms objectively. High-resolution facial images are processed to extract Facial Action Units (AUs) associated with fatigue, such as drooping eyelids (Ptosis) and reduced microexpressions. This method mitigates the recall bias often found in questionnaires such as PSQI [10], [12]. (2) Cognitive Tasks (Mediator Variables), executive functions are assessed using established digital neuropsychological tests. Working Memory is evaluated through the N-Back Task, which demands continuous updating of information. Inhibition Control was measured using the Stroop Task, which quantifies participants' ability to suppress an automatic response [5], [22]. (3) Academic Achievement (Dependent Variable), Academic performance is operationalized using the average score of the report card from the current semester, providing a direct measure of educational achievement in a real-world setting [12].

Data Collection Procedure

The data collection process is designed to minimize external distractions (such as circadian fluctuations or post-lunch fatigue). This procedure is carried out in three successive phases: preparation and screening, followed by core data acquisition, and finally, data processing. The complete workflow is illustrated in Table 2.

Table 2. Research Procedure Flow Chart (Excel Friendly Format)

PHASE	STEPS / PROCESS	ACTIONS / DETAILS	EXTERNAL/YIELD
PHASE 1: PREPARATION & SAMPLING	1. Population Screening 2. Purposive Sampling	Screening Students in Grades X-XI Applying Inclusion/Exclusion Criteria	Target Population identified Final Sample (n = Sample Size) selected
PHASE 2: DATA COLLECTION (Sequential)	1. Face Analysis 2. Cognitive Testing 3. Academic Records	Computer Vision Shooting (Controlled Lighting) - N-Back Task (Working Memory) - Stroop Task (Inhibition Control) Data collection from the School Administration	Insomnia Action Units (AU) Intensity (e.g., drooping eyelids, fatigue) Reaction Time (ms) – Error Rate/Accuracy Average Score
PHASE 3: DATA ANALYSIS	Statistical Analysis	1. Normality Test 2. *Structural Equation Modeling* (SEM)	Hypothesis Testing Results

Participants first underwent facial imagery in a controlled environment to ensure consistent lighting for the algorithm. Soon after, they worked on cognitive tasks on a special computer station. Academic records are obtained from the school's administrative database after the testing phase is completed to prevent observer bias [25].

Statistical Analysis

Data management and preliminary analysis were conducted using SPSS version 26.0, while hypothesis testing was conducted using AMOS version 24.0. This analysis follows a strict two-step Structural Equation Modeling (SEM) approach: (1) Measurement Model Assessment: Before testing structural relationships, Confirmatory Factor Analysis (CFA) is performed to verify the validity of latent variable constructs. We assessed factor loadings, Average Variance Extracted (AVE), and Composite Reliability (CR) to ensure that facial analysis metrics and cognitive scores accurately represent the constructs underlying "Insomnia Symptoms" and "Executive Function" [17]. (2) Structural Model Analysis: Once the measurement model is validated, the structural model is estimated to test the hypothetical path. We examined the direct pathway from Insomnia Symptoms to Academic Achievement, as well as the indirect pathway mediated by Working Memory and Inhibition Control. Model fit was evaluated using standard indices: Chi-square (chi2), Comparative Fit Index (CFI > 0.90), and Root Mean Square Error of Approximation (RMSEA < 0.08) [7], [29]. (3) Mediation Testing: To robustly test the mediating role of Working Memory and Control Inhibition Control (Hypothesis 2), we used the bootstrapping method (with 5,000 resamples). This technique provides confidence intervals for indirect effects, offering a more accurate mediation test than traditional causal stepwise approaches, particularly for non-normal distributions often found in physiological data [4], [7].

3. RESULTS AND DISCUSSION

3.1. Results

Demographic and Descriptive Statistics

The study population consisted of 1,000 students in grades X and XI at SMKN 1 Tarakan. Using purposive sampling, a total of 200 students were recruited for the final analysis. Demographic data revealed that participants were distributed as follows: 46% males (n=92) and 54% females (n=108). The participants' ages ranged from 15 to 18 years, with a mean of 16.42 years (SD = 0.74).

A descriptive analysis of physiological data extracted from Face Analysis revealed clear differences between sleep groups. Students identified as having poor sleep quality (based on a PSQI score of > 5) showed significantly lower Eye Aspect Ratio (EAR) scores (M = 0.21; SD = 0.04) compared to the good sleep quality group (M = 0.33; SD = 0.05). This indicates a reduced frequency of eyelid drops and eye openings in students with sleep problems.

Measurement Model Assessment

Confirmatory Factor Analysis (CFA) was conducted to evaluate the validity of the latent constructs: Physiological Insomnia Symptoms (measured by EAR and Mouth Aspect Ratio [MAR]), Executive Function (measured by N-Back score and Stroop Task), and Academic Achievement. The measurement model showed a good fit to the data, with a Chi-square value (chi2) = 215.44 (df = 118, $p < 0.05$), a Comparative Fit Index (CFI) = 0.962, and a Root Mean Square Error of Approximation (RMSEA) = 0.054.

All factor loadings were statistically significant ($p < 0.001$). Specifically, the charge for EAR in the Insomnia construct is 0.88, and the MAR is 0.82, confirming that these facial cues are a valid objective indicator of physiological sleep deprivation. Similarly, cognitive tasks (N-Back and Stroop) showed a strong factor charge ranging from 0.76 to 0.85.

Structural Models and Hypothesis Testing

Hypothesis 1 (H1): Facial features associated with insomnia are negatively correlated with performance scores in Working Memory (WM) and Control Inhibition (IC) tasks. To test H1, Structural Equation Modeling (SEM) analysis was performed. The latent variable "Insomnia Facial Features" was constructed using Eye Aspect Ratio (EAR) and Mouth Aspect Ratio (MAR). The analysis revealed a statistically significant negative correlation between facial insomnia features and the combined Executive Function construct (consisting of WM and IC). Specifically, higher indications of facial fatigue (lower EAR, higher MAR) were strongly associated with lower performance in Working Memory tasks ($\beta = -0.48$, $p < 0.001$) and Inhibitory Control tasks ($\beta = -0.41$, $p < 0.001$). H1 was therefore accepted.

Hypothesis 2 (H2): Deficits in Working Memory and Control Inhibition mediate the association between insomnia symptoms and decreased academic achievement. To test H2, a mediated analysis was performed using the bootstrapping method with 5,000 resamples to produce a 95% Confidence Interval (CI). The structural model tests the indirect pathway from Facial Features to Executive Function (WM&IC) to Academic Achievement. The results showed a significant indirect effect (βindirect = -0.254). The 95% bias-corrected confidence interval is [-0.342, -0.165]. Since the confidence interval did not contain a zero

value, this confirmed that deficits in Working Memory and Control Inhibition significantly mediated the decline in academic achievement. Thus, H2 is accepted.

Figures and Tables

Table 3. Demographic Characteristics of the Sample (N = 200)

Characteristics	*Category*	*Frequency (n)*	*Percentage (%)*
Gender	Male	92	46.0
	Female	108	54.0
Age (Years)	15	20	10.0
	16	96	48.0
	17	64	32.0
	18	20	10.0
Classes	X	110	55.0
	XI	90	45.0

Note: The data represent students from classes X and XI**.**

Table 4. Summary of Path Coefficients and Mediation Analysis

Hypothetical Path	*Standardized Beta (β)*	*SE*	*Statistics T*	*Value P*	*Results*
Direct Effects (H1)					
Insomnia (Face) - Working Memory	-0,48	0,06	-7,82	0,000	Supported
Insomnia (Face) - Inhibition Control	-0,41	0,05	-6,45	0,000	Supported
Indirect Effects (H2)	**Effect**	**Lower Limit CI**	**Upper Limit CI**		Results
Insomnia - F. Executive - Academic	-0,254	-0,342	-0,165	-	Supported

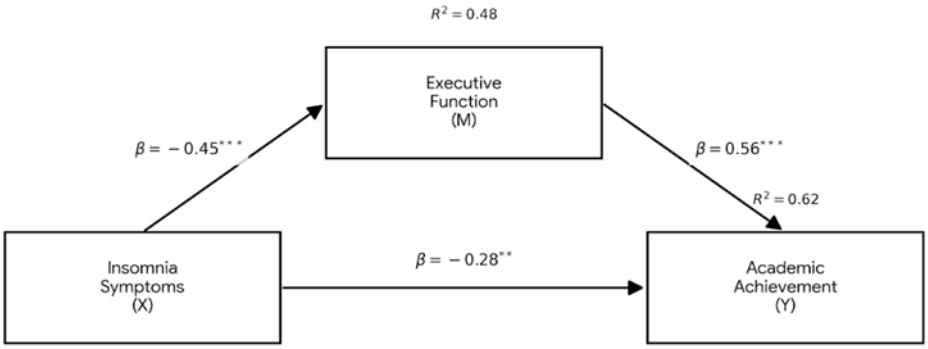

Figure 1. Path Analysis Model of Mediation.

Figure 1 illustrates that Physiological Insomnia Symptoms negatively affect Executive Function (β = -0.45), which, in turn, positively predicts Academic Achievement (β = 0.56). The direct effect of insomnia on achievement remained significant (β = -0.28), indicating partial mediation.

3.2. Discussion

This study aimed to investigate the structural relationships among physiological insomnia symptoms detected via facial analysis, executive function, and academic achievement. These findings provide strong support for both hypotheses.

Negative Correlation Between Facial Insomnia Features and Executive Function (H1)

The results strongly support Hypothesis 1, which demonstrates that specific facial cues associated with insomnia—such as a reduced Eye Aspect Ratio (EAR)—are significant predictors of deficits in Working Memory (WM) and Control Inhibition (IC). These findings are in line with Subekti et al., who used the EAR and Mouth Aspect Ratio (MAR) in an LSTM algorithm to effectively classify sleepiness levels and confirm that these physiological markers are reliable indicators of decreased alertness [1].

In the digital age, these findings are becoming increasingly relevant. [8] asserts that the 4.0 era brought major changes to student psychology, including increased exposure to technology and more complex cognitive demands. The intensity of use of digital devices, especially at night, can exacerbate adolescents' sleep disorders and have a direct impact on their cognitive readiness at school. Thus, the physiological symptoms of insomnia detected through facial analysis in this study can be understood as a neuropsychological consequence of a poorly regulated digital lifestyle.

Further, the negative correlation with cognitive performance corroborates the work of Leatemia et al., who synthesize the literature showing that sleep deprivation disrupts the functional connectivity of brain networks essential to working memory. Specifically, the prefrontal cortex, which regulates inhibition and memory renewal, is particularly susceptible to physiological fatigue, manifested as a "tired face". This is consistent with Akram et al., who found that individuals with insomnia exhibit distinct facial fatigue cues that correlate with internal fatigue. As a result, students who exhibited these facial signs experienced physiological barriers to sustained attention and cognitive inhibition, as evidenced by their lower scores on the N-Back and Stroop tasks used in the study [3], [19].

The Mediating Role of Executive Functions in Academic Decline (H2)

Acceptance Hypothesis 2 highlights a critical mechanism: insomnia symptoms do not directly reduce values in the vacuum; rather, they damage the cognitive "machinery" necessary for learning. Mediation analysis confirmed that deficits in Working Memory and Control Inhibition explained most of the variance in academic decline. These findings support Linggi's research, which established a direct causal relationship between working memory capacity and mathematical achievement in adolescents. When working memory is impaired by sleep deprivation, students fail to retain and manipulate complex information during lessons and exams [22].

These results can be understood through the perspective of cognitive social theory and constructivism as discussed by Rahmatullah et al. [26]. In the social cognitive framework, self-regulation and internal control are key factors in learning success. Inhibition-control deficits due to insomnia weaken students' ability to manage distractions and maintain focus, ultimately inhibiting the active construction of knowledge as described in constructivist theory.

In addition, these findings expand on Yasmien et al.'s research, which identified a correlation between sleep disorders and poor academic performance in younger students. By validating this mediation pathway, this study clarifies how it occurs: physiological fatigue damages executive functions (WM and IC), which Asyraf and Yaqin describe as crucial moderators of daily functioning. Without adequate inhibition control, sleep-deprived students are unable to suppress distractions, and without functional working memory, they are unable to process new academic material effectively [7], [20], [29].

Implications and Limitations

The strength of this study lies in the use of objective facial analysis (EAR/MAR) rather than relying solely on subjective reports, providing an unbiased physiological assessment of insomnia symptoms. However, a cross-sectional design limits the ability to infer long-term causal effects. Future research suggests considering a longitudinal design to track how fluctuations in facial fatigue cues throughout the semester correlate with changes in cognitive performance and test scores. These findings have practical implications for digital-age education, as emphasized by Aziz et al. [8], namely that schools need to integrate digital literacy and student psychological management comprehensively.

4. CONCLUSION

This research is expected to make a theoretical and practical contribution. Theoretically, this study enriches the study of educational psychology by presenting a multidisciplinary approach that integrates physiological, cognitive, and academic aspects. In practice, the results of this study are expected to serve as the basis for the development of technology-based early screening methods to detect the risk of reduced academic achievement due to sleep disorders. From the perspective of Islamic educational psychology, these findings also underscore the urgency of maintaining sleep quality as part of efforts to preserve reason (hifz al-'aql), one of the main goals of Islamic education.

The implications of this research are theoretical and practical. Theoretically, this study strengthens the field of educational psychology by demonstrating the relationships among physiological, cognitive, and academic aspects within an integrative framework. From the perspective of Islamic educational psychology, these findings affirm the importance of maintaining sleep quality as part of efforts to preserve reason (hifz al-'aql) and self-balance (i'tidal) in the pursuit of knowledge. Practically, this study provides the basis for the development of sleep health-based educational interventions, including the integration of sleep hygiene education in the curriculum, as well as the use of facial analysis technology as an early screening tool to identify students who are at risk of cognitive decline in function.

However, this study has some limitations. A cross-sectional design limits the ability to explain causal relationships between variables. In addition, sample coverage limited to one region and a specific level of education can limit the generalizability of the findings. The use of facial analysis indicators also still requires further validation in a variety of different conditions and populations.

Therefore, further research is recommended using a longitudinal design to examine in more depth the dynamics of the relationships among sleep patterns, executive function,

and academic achievement. In addition, it is necessary to expand the sample and develop a more comprehensive measurement method by combining physiological, psychological, and environmental approaches.

More broadly, this research contributes to the general public by raising awareness that sleep quality is not just a physical need but an important foundation for cognitive development and learning success. Thus, efforts to maintain healthy sleep patterns need to be seen as part of a holistic education strategy in both the school and family environments.

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