Global health insights, social media literacy, and physical activity: a hybrid PLS-SEM-NCA analysis

Alfabetización en redes sociales y actividad física en adolescentes: análisis híbrido de causalidad y necesidad

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Abstract

Background. Adolescence is a critical phase in the formation of lifelong physical activity habits. However, urban teenagers are increasingly trapped in sedentary behavior due to the dominance of digital technology. Even though global health insights are ubiquitous in cyberspace, the cognitive mechanisms that translate this knowledge into physical action, especially the role of social media literacy, remain a paradox rarely explored holistically in the physical education literature.
Purpose and Methods. This research aims to investigate the conventional linear path and the absolute prerequisites (necessary conditions) of Social Media Literacy (SML) and Global Healthy Insights (GHI) towards Physical Activity (PA). Using a cross-sectional design, the study involved junior high school students in Makassar, Indonesia. Data analysis applies a hybrid methodology approach of Partial Least Squares Structural Equation Modeling (PLS-SEM) and Necessary Condition Analysis (NCA).
Results. The PLS-SEM test shows that GHI and SML have a direct positive effect on PA. However, important findings reveal that linear mediation is not supported; GHI did not mediate the relationship between SML and PA. This impasse was overcome by the NCA analysis, which proved beyond a doubt that the SML is an absolute prerequisite (a major bottleneck). Without SML above the minimum threshold, no matter how much health insight a teenager absorbs, it will not be converted into real physical activity.
Conclusion. Rather than acting as a linear bridge, social media literacy operates as a critical cognitive filter that prevents cognitive overload and mental fatigue. The study's implications urge physical education policymakers to eliminate "digital blindness" by integrating algorithm navigation into the sports curriculum to ensure that health insights are translated into active behavior.

Keywords

Physical activity, social media literacy, global health insights, PLS-SEM, necessary condition analysis, cognitive.

Resumen

Antecedentes. La adolescencia es una fase crítica en la formación de hábitos de actividad física para toda la vida. Sin embargo, los adolescentes urbanos están cada vez más atrapados en comportamientos sedentarios debido al dominio de la tecnología digital. Aunque los conocimientos globales sobre salud son ubicuos en el ciberespacio, los mecanismos cognitivos que traducen este conocimiento en acción física, especialmente el papel de la alfabetización en redes sociales, siguen siendo una paradoja raramente explorada de manera holística en la literatura de la educación física.
Objetivo y Métodos. Esta investigación tiene como objetivo investigar la ruta lineal convencional y los prerrequisitos absolutos (condiciones necesarias) de la Alfabetización en Redes Sociales (ARS) y los Conocimientos Globales sobre Salud (CGS) hacia la Actividad Física (AF). Mediante un diseño transversal, el estudio contó con la participación de estudiantes de escuela secundaria en Makassar, Indonesia. El análisis de datos aplica un enfoque metodológico híbrido de Modelado de Ecuaciones Estructurales por Mínimos Cuadrados Parciales (PLS-SEM) y Análisis de Condición Necesaria (NCA).
Resultados. La prueba PLS-SEM muestra que los CGS y la ARS tienen un efecto positivo directo sobre la AF. Sin embargo, hallazgos importantes revelan que la mediación lineal no está respaldada; los CGS no mediaron la relación entre la ARS y la AF. Este callejón sin salida fue superado por el análisis NCA, el cual demostró sin lugar a dudas que la ARS es un prerrequisito absoluto (un cuello de botella principal). Sin una ARS por encima del umbral mínimo, no importa cuántos conocimientos sobre salud absorba un adolescente, estos no se convertirán en una actividad física real.
Conclusión. En lugar de actuar como un puente lineal, la alfabetización en redes sociales opera como un filtro cognitivo crítico que previene la sobrecarga cognitiva y la fatiga mental. Las implicaciones del estudio instan a los responsables de las políticas de educación física a eliminar la "ceguera digital" mediante la integración de la navegación algorítmica en el currículo deportivo para garantizar que los conocimientos sobre salud se traduzcan en un comportamiento activo

Palabras clave

Actividad física, alfabetización en redes sociales, conocimientos globales sobre salud, PLS-SEM, análisis de condición necesaria, carga cognitiva .

Introduction

Adolescent health has evolved into a crucial global public health priority, given the significance of this period as a time of physical, cognitive, and psychosocial transition that determines long-term quality of life. Over the past four decades, monumental initiatives such as the Health Behavior in School-aged Children (HBSC) study under the auspices of WHO have provided a unique cross-country data infrastructure, covering more than 1.6 million students in 50 countries to explain persistent health disparities between regions (Alshahrani et al., 2025). Global data show that the world is facing a physical activity crisis: only approximately 20% to 28% of school-age adolescents meet daily physical activity recommendations, with a drastic decline as they enter early adolescence (Watkins, Goss, Schigur, et al., 2025). In developed countries such as Sweden, integrated national policies can maintain physical activity levels at 24%. In contrast, in resource-limited regions such as Haiti, this figure drops to 10% due to structural barriers and the absence of public recreation facilities (Alshahrani et al., 2025). This phenomenon is exacerbated by sedentary behavior, which is now recognized as an independent biological risk factor; the risk of cardiometabolic disease remains significantly increased in adolescents who spend long periods in front of screens, even if they regularly exercise (Castro et al., 2023).

At the regional level in Southeast Asia, these challenges are increasingly complex amid the rapid pace of digital urbanization. Countries such as Malaysia, Vietnam, and Thailand report similar trends, in which increasing internet penetration is negatively correlated with the duration of students' physical movement (Peltzer & Pengpid, 2016). Indonesia, as one of the largest digital markets in ASEAN, faces a very sharp paradox, especially in metropolitan growth centers such as Makassar. As an economic hub in Eastern Indonesia, Makassar represents the characteristics of Emerging Urban Centers, where access to Global Healthy Insights is readily available to teenagers but fails to be internalized into real action. The penetration of social media among junior high school (SMP) students is rapid, but cellphone screens more often function as movement inhibitors than activity drivers. This condition creates a sedentary cycle that is difficult to break due to cell phone dependence (nomophobia) which triggers depression, anxiety disorders, and low self-esteem diri (Shawon et al., 2025; Wu et al., 2025) (The behavior of sitting still for more than three hours a day outside of school hours has become a new norm that endangers the mental and physical health of middle school students, who are developmentally in a critical period of searching for identity (Zhang et al., 2025).

Social media has become a major platform for promoting healthy lifestyles, with influencers playing a significant role in spreading messages about exercise and healthy eating. Several studies show that promotion of physical activity by influencers can encourage audiences to participate more actively in sports (Moreno et al., 2023). The importance of social media literacy is also emphasized to help audiences, especially young people, critically evaluate the information they receive and avoid negative influences from inaccurate or unhealthy content (Duplaga, 2020).

On the other hand, the use of wearable technology such as Fitbit, combined with social media, shows the potential to increase teenagers' motivation to exercise. Nonetheless, challenges such as difficulty using technology and preferences for certain social media platforms may influence the effectiveness of these interventions (Drehlich et al., 2020). High social media literacy allows individuals to make better use of existing information, thereby improving the quality of the physical activity they undertake (Watkins, Goss, Kercher, et al., 2025)

Social media-based interventions designed with social media literacy in mind may help increase physical activity, especially among young women. However, further research is needed to explore more effective technology designs (Malloy et al., 2024). Social media use can increase social support and accountability for physical activity, but it can also exacerbate social comparisons and spread misinformation. Therefore, good digital literacy is needed to maximize benefits and minimize risks (AlNamlah et al., 2026). Influencers on platforms like Instagram play an important role in motivating their audiences to lead active lifestyles. They use digital marketing strategies to promote physical exercise, healthy eating habits, and individual training programs. However, the importance of social media literacy is emphasized to enable people to evaluate the information they receive and avoid negative influences critically (Moreno et al., 2023). Theoretically, the failure to internalize global health insight by students can be dissected comprehensively through the integration of three main theoretical frameworks: Self-Determination Theory (SDT) (Ryan & Deci, 2023), Basic Psychological Need Theory (BPNT),

and Cognitive Load Theory (CLT). Through the lens of BPNT as a mini-theory in SDT, it is emphasized that basic psychological needs, which include autonomy, competence, and relatedness, are critical resources that underlie individuals' natural tendencies towards self-organization and well-being (Vansteenkiste et al., 2020). In a digital context, when a toxic social media environment hinders the fulfillment of these needs, global health information often remains external regulation that fails to become intrinsic motivation (Collie, 2022). Students' low perceptions of autonomy and social-emotional competence are directly related to failure to internalize information, in which the disappointment of unmet needs actually increases their vulnerability to maladjustment and to ignoring health messages (Vansteenkiste et al., 2020).

This condition is exacerbated by the information overload phenomenon described in Cognitive Load Theory (CLT). Social media algorithms designed to retain user attention create a tremendous cognitive load by presenting complex, contradictory, and ambiguous information. This encourages individuals to engage in motivated cognition, namely, selective attention to information that aligns with existing beliefs, or even giving up on understanding new information altogether (Fox & Rey, 2024). Limited working memory capacity is a fundamental obstacle for adolescents in processing the flood of health information, which often does not lead to knowledge but rather to analysis paralysis (Andersen & Makransky, 2021).

This is where Social Media Literacy (SML) comes in as a cognitive and strategic variable. SML is not simply a technical skill of digital navigation, but rather a psychological filtering and cognitive filtering mechanism that allows adolescents to critically evaluate distorted health messages, body image, and nutritional information (Pfender et al., 2022; Watkins, Goss, Kercher, et al., 2025). The integration of these three theories explains that without strengthening SML to manage cognitive load and support the fulfillment of basic psychological needs, global health information cannot be transformed into meaningful physical activity. Recent research even revealed that fulfilling psychological needs, such as high body appreciation, is positively correlated with physical literacy, while social media addiction without a strong SML filter is a major predictor of clinical anxiety and body image dissatisfaction in students (Watkins, Goss, Schigur, et al., 2025).

Although digital literacy has been widely explored in the education domain in Indonesia (Suryawati et al., 2024), the current empirical literature is still trapped in a linear methodological orthodoxy. The majority of previous studies tend to rely on traditional causality analysis based on Partial Least Squares Structural Equation Modeling (PLS-SEM), which is only able to test 'sufficiency' factors, but fundamentally fails to identify critical points (bottlenecks) of 'necessity' for the internalization of health behavior (Zahrai et al., 2022). As a result, a digital paradox has emerged: massive access to global health insights in Indonesia actually triggers analysis paralysis and extreme cognitive load in teenagers, rather than increasing physical activity (Alduosari et al., 2025; Fox & Rey, 2024).

This research is here to break this deadlock by repositioning Social Media Literacy (SML) not just as a complementary variable, but as a cognitive-psychological filter that is necessary to bridge global information into the local reality of junior high school students at their critical transition period (Alshahrani et al., 2025; Helvacı & Tayhan, 2025). By applying the pioneering hybrid approach of PLS-SEM and Necessary Condition Analysis (NCA), this study goes beyond conventional causality analysis to identify essential literacy thresholds. This initiative not only addresses the uncertainty of mediating mechanisms by self-efficacy variables and information trust in Indonesia's unique digital ecosystem (Sondak et al., 2025) but also offers theoretical and methodological contributions that have been neglected in global adolescent digital health discourse (Joseph & Fleary, 2024; Zhao et al., 2024).

The novelty and contribution of this research lie in its very comprehensive "Triple-Analysis" approach. First, conceptually, this study integrates SML as a cognitive-strategic bridge that transforms information load into movement energy. Second, methodologically, this study applies a hybrid approach combining PLS-SEM and Necessary Condition Analysis (NCA) to identify the absolute prerequisites for adolescent healthy behavior. The use of NCA enables researchers to provide threshold-based recommendations, which are crucial for curriculum policymakers. Third, this study goes further by integrating the PLSpredict procedure to evaluate out-of-sample predictive power. This was done to ensure that the model built did not overfit and had high accuracy in predicting adolescent physical activity behavior in a broader population context.

Given this urgency, the main aim of this research is to evaluate the explanatory power, identify absolute requirements (NCA), and test the accuracy of predictions (PLSpredict) from Social Media Literacy and Global Healthy Insights on Physical Activity among junior high school students in Makassar. Through the synergy of causal analysis, prerequisite identification, and predictive validation, this research is projected to make a significant contribution to the development of a holistic healthy lifestyle curriculum. Preventive health interventions for adolescents from urban communities must combine structured physical activity with cognitive agency to navigate digital environments healthily. It is hoped that the results of this study will serve as a global reference model for integrating digital literacy into contemporary physical education, ensuring that technological advances in Indonesia do not become a cardiometabolic burden but rather a catalyst for the sustainable health of future generations.

The research hypothesis consists of a Linear Sufficiency Logic (PLS-SEM) hypothesis, including H1: Global Healthy Insights (GHI) positively and significantly predicts the level of Physical Activity (PA) among Junior High School (SMP) students in the Makassar urban area. H2: Social Media Literacy (SML) has a positive and significant effect on increasing Physical Activity (PA) of junior high school students in Makassar. H3: Global Healthy Insights (GHI) mediates the linear relationship between Social Media Literacy (SML) and Physical Activity (PA) in junior high school students in Makassar. The Necessity Logic Hypothesis (NCA Hypothesis) consists of H4: Social Media Literacy (SML) is an absolute requirement (necessary condition) to achieve a high level of Physical Activity (PA). H5: Global Healthy Insights (GHI) is an absolute requirement (necessary condition) to achieve a high level of Physical Activity (PA).

Method

Research design, location, population and sample

This research employed a non-experimental, cross-sectional quantitative approach to explore behavioral and cognitive phenomena among urban adolescents in Makassar, Indonesia, a metropolis characterized by high digital penetration and a deficit of public spaces for physical activity. A two-stage cluster sampling technique was used to recruit the participants. In the first stage, 10 public junior high schools across Makassar's urban areas were randomly selected as the primary clusters. In the second stage, classrooms within these 10 selected public schools were purposively sampled based on specific inclusion criteria: respondents must be active students aged 13–15 years, possess a personal smartphone, and be active social media users. Based on these strict inclusion and exclusion criteria, a final sample of 446 junior high school students was successfully recruited for this hybrid analysis. To ensure the protection of human subjects, the data collection process conducted from August 14 to October 15, 2025, fully complied with institutional guidelines and officially received ethical clearance from the Institute for Research and Community Service at the State University of Makassar (LPPM UNM) under formal approval decree number 3429/UN36.11/TU/2025.

This sample configuration is rigorously designed to ensure the validity of partial least squares structural modeling (PLS-SEM) (Hair et al., 2021; Sarstedt et al., 2019), which is synergistically integrated with Necessary Condition Analysis (NCA) (Dul, 2016). This integration revolutionizes the conventional linear paradigm through identifying cognitive-structural bottlenecks and mapping absolute 'performance ceilings'. By outlining absolute requirements at the upstream level before allocating resources to supporting variables, this imperative logic ensures the efficiency of tactical interventions while positioning this study as a strategic roadmap for urban adolescent health transformation in Eastern Indonesia.

Research variables and measurements

To ensure the accuracy of measuring cognitive and behavioral phenomena in this research, a 5-point Likert scale instrument was developed, ranging from 1 (strongly disagree) to 5 (strongly agree). The choice of a 5-point scale was intended to reduce cognitive load and prevent frustration among early adolescent respondents during questionnaire completion. Furthermore, it optimized visual readability on digital devices by providing an objective midpoint to mitigate forced-choice bias. Recent methodological evidence indicates that in measurements of self-reported health perception and subjective cognitive load among youth, shorter response scales (e.g., 5 points instead of 7) significantly reduce mental fatigue and processing overload. This optimizes construct validity and prevents response bias, thereby

ensuring that adolescents evaluate their cognitive and behavioral states with greater accuracy and stability (Coombes et al., 2021; Schuessler et al., 2025). This configuration is proven to produce reliable, stable and high-precision data variance for optimal execution in hybrid PLS-SEM and NCA analysis

The measurement of the Social Media Literacy (SML) construct in this research was adapted from The Youth Social Media Literacy Inventory developed by (Purington Drake et al., 2023; Wendt et al., 2023). The Physical Activity (PA) variable was adopted from the International Physical Activity Questionnaire for Adolescents (IPAQ-A) (Hagströmer et al., 2006), a global instrument for measuring physical activity related to public health consisting of 5 items. The Global Healthy Insights (GHI) variable was adapted from (Sørensen et al., 2012) and Global Healthy Insights was operationalized by integrating the Global Citizenship Education framework (Education, 2015) with the health literacy dimension with 5 items

Data Collection and Analysis Methods

The data collection procedure began with official permission from the Makassar City Education Office and tactical coordination with school authorities, during which instruments were distributed digitally via Google Forms to students who had provided informed consent, with full anonymity. To mitigate response bias, the questionnaire was completed in the presence of the class teacher to ensure an objective understanding without intervention. Next, the structural interrelations and bridging mechanisms among Global Healthy Insights (GHI), Social Media Literacy (SML), and Physical Activity (PA) were explored using Variance-Based Structural Equation Modeling (VB-SEM) in SmartPLS 4.0. This non-parametric approach was chosen because it is robust to anomalous distributions of adolescent behavior research data, and is equipped with the PLSpredict algorithm to validate out-of-sample predictive power (Hair et al., 2021; Shmueli et al., 2019). To go beyond conventional linear logic, this analysis is hybridly synergized with Necessary Condition Analysis (NCA) (Bokrantz & Dul, 2023; Dul et al., 2023). This methodological integration not only unravels the serial mediation effects of how SML bridges GHI to PA, but also revolutionarily maps 'ceiling lines' and identifies cognitive-literacy bottlenecks at the upstream level to determine the necessary thresholds (necessary conditions) for realizing peak physical activity performance among junior high school students in Indonesia.

Results

Respondent Demographic Data

This data provides an overview of respondents as additional information to enhance the research's credibility and to support further analysis and the application of research results to populations with similar characteristics. The demographic profile of the 446 respondents in this study is presented in detail in Table 1. This table presents the distribution of sample characteristics to provide a representative picture of the population under study.

Table 1. Demographic and Digital Characteristics of Respondents

Category	Frequency	Percentage
Student's Gender		
Male	234	52%
Female	212	48%
Father's Occupation		
Civil Servant/Military/Police	81	18%
Entrepreneur	61	14%
State-Owned Enterprise Employee	70	16%
Trader	38	9%
Others	196	44%
Mother's Occupation		
Civil Servant/Military/Police	34	8%
Entrepreneur	9	2%
State-Owned Enterprise Employee	15	3%
Trader (Pedagang)	29	7%
Others (Housewife/IRT)	359	80%
Father's Education		
Junior High School	10	2%
Senior High School	230	52%
Higher Education	206	46%
Mother's education		

Junior High School	21	5%
Senior High School	300	67%
Higher Education	125	28%
Social Media Platforms		
Instagram	89	20%
Facebook	3	1%
TikTok	150	34%
ChatGPT	20	4%
Google	30	7%
YouTube	33	7%
WhatsApp	121	27%
Daily Social Media Usage		
0 – 1 hours/day	40	9%
1 – 2 hours/day	90	20%
3 – 4 hours/day	115	26%
4 – 6 hours/day	120	27%
≥ 6 hours/day	81	18%
Total	446	100%

Table 1 presents the demographic profile, the parents' socio-economic background, and the digital characteristics of the 446 respondents. The gender distribution of students is nearly equal, with men representing 52% and women 48%. Most parents have formal educational backgrounds at the upper-secondary level (SMA) or higher. Urban employment is diversified: mothers mainly work in the non formal/domestic sector (80%), while fathers are concentrated in the formal sector or are self-employed.

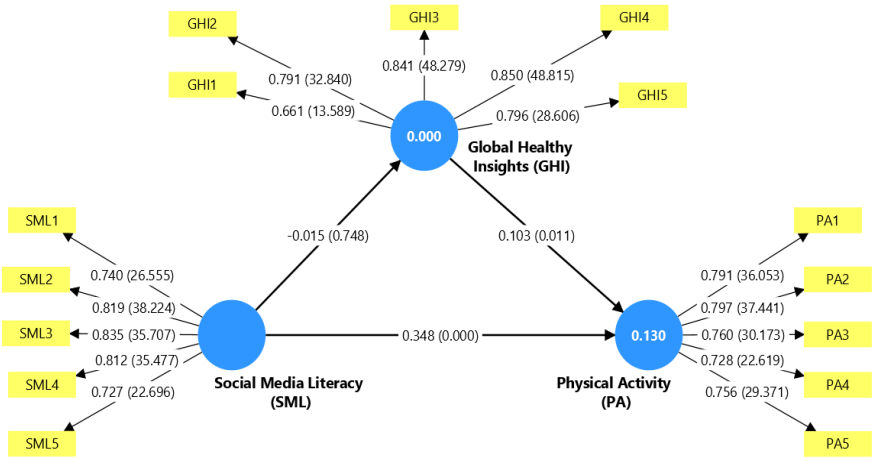
The digital landscape of early teens in Table 1 reveals crucial findings: TikTok leads as the most dominant platform (34%), followed by WhatsApp (27%) and Instagram (20%), confirming their strong preference for vertical, algorithm-based consumption of short audiovisual content. The intensity of daily gadget exposure was very high, with the majority of students allocating 3–4 hours (26%) or 4–6 hours (27%) per day. In fact, 18% of respondents were active on social media for more than 6 hours a day. This extensive access duration pattern provides strong empirical justification for the urgency of testing their Social Media Literacy (SML) capacity to mitigate the impact of digital engagement on Physical Activity (PA) performance

Measurement Model Evaluation

Evaluation of the measurement model (outer model) was executed rigorously through testing internal consistency reliability, convergent validity and discriminant validity of all latent constructs, where indicators with factor loading values (outer loadings) below 0.70 were excluded in order to maintain the psychometric integrity of the model (Hair et al., 2021), Internal consistency is confirmed by Cronbach's Alpha and Composite Reliability (CR) values that exceed the 0.70 threshold. At the same time, convergent validity is supported by Average Variance Extracted (AVE) values above the minimum standard of 0.50. In order to guarantee orthogonality between variables, discriminant validity is verified comprehensively through two comparative approaches: the Heterotrait-Monotrait Ratio (HTMT) matrix with a strict limit below 0.90 which is ideal for behavioral and educational research (Hair et al., 2021), as well as the Fornell-Larcker criterion which ensures that the square root value of the AVE of each construct exceeds the correlation coefficient between other constructs (Fornell & Larcker, 1981).

The transition to a structural model (inner model) uses a bootstrapping procedure with 10,000 subsamples to produce robust parameter estimates (β, t-value, p-value) (Hair et al., 2021). Explanatory power (R^2) as well as the magnitude of specific contributions between variables measured through effect size (f2) were evaluated strictly based on criteria (Cohen, 2013), and out-of-sample predictive relevance (Q^2) was then validated via the PLSpredict algorithm to guarantee the generalizability of the model (Shmueli et al., 2019), providing a solid confirmatory foundation in proving the role of SML as an empirical bridging mechanism from GHI towards improving the PA performance of urban adolescents. The comprehensive research design model is depicted in Figure 1, which integrates the evaluation results of the outer model (measurement model) and inner model (structural model).

Figure 1. Structural Model Assessment (Path Coefficients and p-values)



Before conducting structural testing, a comprehensive evaluation of the measurement model was conducted to ensure the psychometric robustness of the research instrument. As presented in Table 2, testing includes measures of convergent validity, internal consistency, model stability (VIF), and model fit.

Table 2. Construct Validity and Model Fit

Variable	Code	Indicator	LF	CA	CR	AVE	VIF	SRMR
Global Healthy Insights (GHI)	GHI1	Global Guideline Awareness	0,661	0,848	0,856	0,625	1,381	0.060
	GHI2	Nutritional Global Trends	0,791				1,796	
	GHI3	Health Risk Perception	0,841				2,129	
	GHI4	Cross-Cultural Health Values	0,850				2,328	
	GHI5	Digital Health Reliability	0,796				1,957	
Physical Activity (PA)	PA1	Vigorous Activity Frequency	0,791	0,824	0,826	0,588	1,826	
	PA2	Moderate Activity Duration	0,797				1,846	
	PA3	Sedentary Behavior Reduction	0,760				1,632	
	PA4	Walking Consistency	0,728				1,519	
	PA5	Leisure-Time Exercise	0,756				1,586	
Social Media Literacy (SML)	SML1	Digital Health Agency	0,740	0,846	0,850	0,621	1,583	
	SML2	Algorithmic Navigation	0,819				1,960	
	SML3	Critical Appearance Filter	0,835				2,106	
	SML4	Global Insight Integration	0,812				2,004	
	SML5	Cognitive Resource Management	0,727				1,517	

The evaluation results for the measurement model in Table 2 were conducted comprehensively to ensure the psychometric robustness of the instrument used before structural testing. Based on the data presented in Table 2, all indicators show Loading Factor (LF) values that exceed the conservative threshold of 0.60, ranging from 0.661 to 0.850. This confirms that each item has a significant absolute contribution in representing the latent construct. The internal consistency of the model is very satisfactory, with Cronbach's Alpha (CA) and Composite Reliability (CR) values for all variables (GHI, PA, and SML) consistently above 0.80. These results confirm that the research instrument has high reliability and is free from random measurement bias.

Convergent validity is also supported empirically by Average Variance Extracted (AVE) values, which are all above 0.50 (range 0.588–0.625), indicating that the construct explains more than 50% of the variance of its indicators. Apart from that, testing the stability of the model through the Variance Inflation Factor (VIF) showed a value below 2.5 (highest 2.328), which indicates there is no multicollinearity problem between indicators in one construct. Finally, the model fit is supported by an SRMR of 0.060, which is below the critical value of 0.08. Overall, this statistical evidence indicates that the measurement model in this study has robust validity and reliability, thereby providing a solid foundation for inferential analysis and generalization of findings in the context of physical education and digital health literacy.

Evaluation of the measurement model continues by ensuring discriminant validity to ensure that each construct is empirically unique. As presented in Table 3, the test was conducted using a dual approach: the classic Fornell-Larcker criteria and the modern Heterotrait-Monotrait Ratio (HTMT) for more sensitive detection.

Table 3. Fornell-Larcker dan HTMT

Variable	Global Healthy Insights	Physical Activity	Social Media Literacy
Global Healthy Insights (GHI)	0,791	0,121	0,043
Physical Activity	0,097	0,767	0,416
Social Media Literacy	-0,015	0,346	0,788

The results of the classic Fornell-Larcker test and the modern Heterotrait-Monotrait Ratio (HTMT) approach are in Table 3. The Fornell-Larcker criterion, the square root value of the Average Variance Extracted, which is located on the diagonal of the table (GHI: 0.791; PA: 0.767; SML: 0.788), is consistently greater than the correlation value between constructs in the same row and column. This indicates that each variable in this model shares more variance with its constituent indicators than with other variables in the structural model. To overcome the limited sensitivity of classical criteria, this study also reports the HTMT value, which is considered the latest gold standard. The results of the analysis show that all HTMT values are well below the conservative threshold of 0.85 (the highest value was 0.416 in the relationship between PA and SML). This low ratio provides very strong statistical evidence that there is no discriminant validity problem. By fulfilling these two criteria, it can be concluded that Global Healthy Insights, Physical Activity, and Social Media Literacy are completely different constructs conceptually and empirically. Therefore, this model is deemed to meet the requirements to proceed to the hypothesis-testing stage (structural model analysis).

Results of Out-of-Sample Predictive Power Analysis (PLSpredict)

To ensure that the structural model built not only has explanatory power in the sample but also strong generalization capabilities, out-of-sample predictive relevance testing is conducted using the PLSpredict algorithm. Based on the statistical protocol developed by Shmueli et al. (2019), Table 4 presents a summary of the prediction error comparison using the Root Mean Square Error (RMSE) metric between the PLS-SEM model and the naive Linear Model (LM) benchmark for each manifest indicator of the target construct.

Table 4. Results of Smart PLS Predictive Power Analysis

Item	PLS-SEM RMSE	Q^2predict	LM RMSE	$RMSE_{PLS}$- $RMSE_{LM}$
PA1	0,707	0,070	0,712	-0,005
PA2	0,674	0,088	0,676	-0,002
PA3	0,708	0,031	0,713	-0,005
PA4	0,686	0,084	0,689	-0,003
PA5	0,758	0,062	0,765	-0,007

Based on the results in Table 4, all Q2 predicted values for the Physical Activity variable indicators (PA1 to PA5) are positive (>0), providing initial confirmation that the model has greater predictive relevance than the naive model (mean value). The analysis results show a highly consistent pattern: all indicators (100%) have lower RMSE values in the PLS-SEM model than in the LM model (RMSE PLS-SEM < RMSE LM), with a stable negative difference ranging from -0.002 to -0.007. Based on the prediction error distribution criteria, this model is classified as having High Predictive Power. These findings provide methodological assurance that the proposed model is not only theoretically valid but also has strong predictive capabilities for physical activity behavior across samples outside the data of this study (out-of-sample generalizability).

Path Hypothesis Testing Results and Mediation Effects

After ensuring that the measurement model (outer model) meets all validity and reliability criteria, the analysis continues to the evaluation stage of the structural model (inner model). Testing the significance of path coefficients and mediation effects was carried out using a nonparametric bootstrap procedure

with 10,000 subsamples to produce very stable, precise parameter estimates (Hair et al., 2021). A comprehensive summary of parameter estimates, t-values, p-values , and bootstrapped confidence intervals for testing linear adequacy relationships is presented in depth in Table 5.

Table 5. Results of Path Coefficients and Mediation Effect Testing

Item	β	T-stats	P values	CI 95%	Sig Supported	f^2	R^2
Direct influence							
Global Healthy _Insights -> Physical Activity	0,103	2,548	0,011	[0,023; 0,180]	Yes	0,012	0,126
Social Media Literacy -> Global Healthy Insights)	-0,015	0,321	0,748	[-0,109; 0,076]	No	0,000	0,000
Social Media Literacy -> Physical Activity)	0,348	7,616	0,000	[0,255; 0,435]	Yes	0,139	0,126
Indirect influence							
Social Media Literacy -> Global Healthy Insights -> Physical Activity	-0,002	0,294	0,769	[-0,014; 0,007]	No	0,000	0,001

Based on the results of structural model calculations summarized in Table 5, evaluation of direct paths and indirect paths through the percentile bootstrapping method with 10,000 subsamples revealed unique causal dynamics (Hair et al., 2021; Nitzl et al., 2016).

First, direct effect testing shows that Social Media Literacy (SML) has a very strong, statistically significant positive influence on Physical Activity (PA) (β = 0.348, t = 7.616, p = 0.001). The contribution of this path variance is categorized as a medium effect (f2 = 0.139), confirming that the digital media literacy capacity of junior high school students is a strong linear predictor of their daily physical activity.

Second, Global Healthy Insights (GHI) was also proven to have a significant positive direct effect on Physical Activity (PA) (β = 0.103, t = 2.548, p = 0.011. Even though the contribution is relatively small (f2 = 0.012), this finding indicates that possession of conventional global health insight and information can still stimulate students' independent physical actions. Third, a direct relationship between Social Media Literacy (SML) and Global Healthy Insights (GHI) was found. not statistically significant (β = -0.015, t = 0.321, p = 0.748, f2 = 0.000).

Fourth, evaluation of the serial mediation effect (Social Media Literacy → Global Healthy Insights → Physical Activity) yielded a statistically insignificant result (β = -0.002, t = 0.294, p = 0.769). The absence of a linear mediation effect is emphasized by the 95% Bootstrapping Corrected Confidence Interval (BCCI) value,, which passes through zero at [-0.014; 0.007], as well as by a zero path variance contribution (f2 = 0.000). Overall, this linear sufficiency model produces a coefficient of determination (R2) of 0.126 for the endogenous construct of Physical Activity (PA). This means that the combination of the SML and GHI variables explains 12.6% of the variance in students' daily physical activity, with the remaining variance explained by factors outside the model. The fact that the linear mediation path in Table 5 is not significant indicates that increasing social media literacy does not automatically translate into a gradual increase in daily physical activity. This limitation of additive linear relationships is what underlies the importance of exploring absolute prerequisite relationships using Necessary Condition Analysis (NCA) in the next sub-chapter

NCA (Necessary Condition Analysis) analysis results

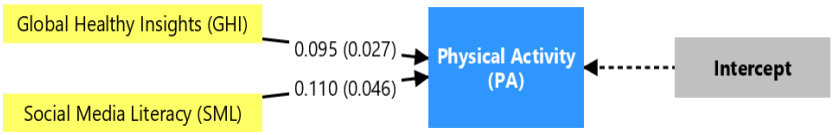
NCA was applied to reveal the absolute threshold underlying junior high school students' physical activity. By identifying cognitive bottlenecks and 'performance ceilings' (ceiling lines) that are often overlooked by conventional statistics, this hybrid approach shifts the research focus from simply looking for driving factors to mapping the absolute conditions (necessary conditions) that must be met (Sohaib et al., 2025). This concept defines the real boundary between areas of possibility and 'zones of behavioral impossibility' on data scatterplots (Bokrantz & Dul, 2023). By establishing these empirical parameters, this analysis sharply deconstructs barriers to adolescent behavior while providing precise strategic guidance for efficient health transformation in the digital era.

In evaluating this necessity logic, the analysis relies on two main NCA parameters: ceiling accuracy and the necessity effect size (d). Ceiling accuracy measures the degree of accuracy of the ceiling line in representing the minimum conditions that must be met in order to achieve an outcome, while necessity effect size (d) quantifies the strength or magnitude of the influence of these absolute conditions on stu-

dents' physical activity (Dul, 2016; Richter et al., 2020). By combining these two parameters, the methodological quality and practical significance of each adolescent's cognitive barriers can be assessed with high precision and validity.

This research presents an estimate of the effect size of CE-FDH in Figure 1, which emphasizes the significance of the relationships among SML, GHI, and Physical Activity. The statistical certainty of this necessity effect was evaluated using the percentile bootstrap method with 10,000 iterations at a 95% confidence level

Figure 2. NCA analysis results



The results of the NCA analysis confirmed significant differences in the capacity of necessity between the two predictors in limiting junior high school students' healthy behavior. Social Media Literacy (SML) was proven to act as the most dominant absolute bottleneck with an effect size of d = 0.110 ($p < 0.05$), which officially categorized it as a Medium Effect, surpassing Global Healthy Insights (GHI), which was stuck in the small effect category (d = 0.095). This critical finding provides strong statistical justification that digital literacy competency is an absolute prerequisite (necessary condition) that limits the effectiveness of other psychosocial variables, where interventions based on de-bottlenecking strategies on aspects of social media literacy will open up blockages in adolescents' physical activity capacity in a much more massive and precise manner than simply allocating resources to expand conventional health insight.

To identify bottleneck points more specifically, bottleneck analysis is used to determine the minimum threshold for each mandatory condition at various levels of student behavioral performance. The results of calculations using the Ceiling Envelopment Free Disposal Hull (CE-FDH) estimator, presented in percentage format, are summarized in Table 6. Through this numerical matrix, it can be precisely mapped when and at what level a cognitive or digital variable begins to act as a rigid limiting factor for adolescent physical activity.

Table 6. Bottleneck tables - CE-FDH (percentages)

Pesentase	Physical Activity (PA)	Global Healthy Insights (GHI)	Social Media Literacy (SML)
0%	-3,340	0,000	0,000
10%	-2,803	0,000	0,000
20%	-2,267	0,000	0,000
30%	-1,730	0,000	0,000
40%	-1,194	0,000	0,000
50%	-0,657	0,224	0,000
60%	-0,121	0,224	0,000
70%	0,415	1,794	1,121
80%	0,952	5,157	2,242
90%	1,488	5,157	2,242
100%	2,025	5,157	21,525

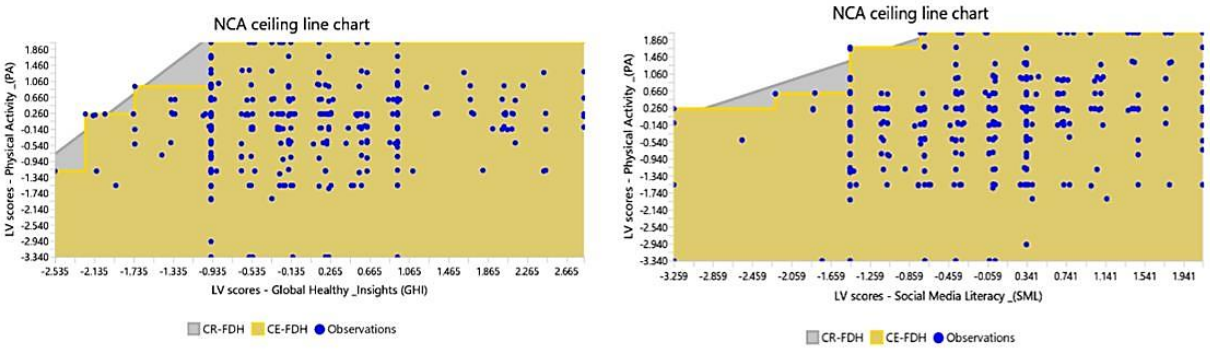
The absolute barrier characteristics of this necessity model are summarized precisely in percentage format in Table 6 (Bottleneck Table), with visual support for the data distribution in Figure 1 and NCA analysis results. This numerical matrix quantifies the minimum thresholds for the Social Media Literacy (SML) and Global Healthy Insights (GHI) predictor variables that must be met to trigger a certain level of Physical Activity (PA) among junior high school students. Using the CE-FDH estimator, empirical data show that at low PA performance levels below the lower threshold (0% to 40%), neither GHI nor SML has acted as a non-bottleneck factor, as indicated by a prerequisite value of 0.000. However, the critical bottleneck point begins to be activated when the physical activity target reaches the middle level (50%).

At this point, students must master a minimum GHI competency of 0.224 to enter the zone of behavioral impossibility.

The most massive and dramatic escalation of barriers occurred in the high-performance cluster (70% to 100%), indicating the existence of a rigid, asymmetric relationship in the structure of adolescent behavior. To achieve an optimal level of 70% for students' physical activity, the system requires strict absolute prerequisites: fulfilling the GHI limit of 1.794 and the SML of 1.121 simultaneously. The peak of the capacity anomaly occurred at the maximum PA performance target (100%), where demand to fulfil Social Media Literacy competencies skyrocketed to an absolute figure of 21,525. This finding theoretically confirms SML's status as the ultimate bottleneck; without an extreme leap in social media literacy competency at the upstream level to filter out digital information distortion, achieving higher levels of physical activity will be impossible. All conventional health intervention programs for junior high school students will reach a dead end (stagnation).

To dissect more deeply how these absolute thresholds operate at each level of behavior, the analysis continues by testing a percentage-based bottleneck analysis. The numerical representation that constructs rigid points on the ceiling line in Figure 1 is summarized comprehensively in Table 6. Through this CE-FDH estimator configuration, we can track with precision at what level of performance the Social Media Literacy (SML) and Global Healthy Insights (GHI) variables begin to lock and block the physical activity capacity of junior high school students

Figures 3. Global Healthy Insights NCA ceiling line charts Figures 4 Social Media Literacy NCA ceiling line charts



Comprehensive visual empirical evidence confirming the existence of this imperative relationship is presented in Figure 3. The graph displays a bivariate scatter plot that maps the interaction between Global Healthy Insights (GHI) and Figure 4 Social Media Literacy (SML) on Physical Activity (PA) using two estimator approaches at once, namely the CE-FDH non-parametric ceiling line (stepped yellow line) and the CR-FDH parametric estimator (linear straight line on a gray background). The existence of a significant empty area in the upper left corner of both graphs,, where no student data observations (blue dots) were found to penetrate or exceed the ceiling line,, firmly proves the existence of a zone of impossibility of behavior. This visualization emphasizes the undeniable role of GHI and SML as absolute limiting factors that constrain adolescents' capacity to achieve higher levels of physical activity.

The results of this analysis indicate that Global Healthy Insights (GHI) and Social Media Literacy (SML) are absolute prerequisites (necessary conditions) which act as rigid capacity plugs (bottlenecks) for Physical Activity (PA). The existence of a zone of impossibility on the graph confirms the asymmetric logic that achieving high levels of physical activity will never be possible without the cognitive thresholds of these two variables being met.

Visual empirical evidence confirming the existence of a necessary relationship is presented comprehensively in the NCA ceiling line graphs in Figures 4 and 5. The two bivariate scatter plots (scatterplots) map the interaction of Global Healthy Insights (GHI) and Social Media Literacy (SML) on Physical Activity (PA) by integrating two estimator approaches at once: the non-parametric ceiling line CE-FDH

(stepped yellow line) and the parametric estimator CR-FDH (straight line). linear). The presence of a contrasting empty area in the upper left corner of the two graphs, where no student observation data (blue dots) were found to cross or lie above the holding curve, firmly confirms the existence of a zone of behavioral impossibility. The NCA scatter plot shows that as the Physical Activity (PA) performance target increases, the minimum requirement thresholds for the predictor variables (Global Healthy Insights and Social Media Literacy) also increase gradually. This phenomenon shows that strengthening capacity or achieving a much higher level of achievement in these two predictor variables is necessary to achieve a more optimal level of adolescent physical activity.

Discussion

The central findings from structural modeling (PLS-SEM) in this research reveal a causal paradox: Global Healthy Insights (GHI fails to operate as a linear mediator that bridges Social Media Literacy (SML) to Physical Activity (PA). Referring to Swart's postulates (2021), even though modern teenagers coexist massively with algorithmic curation, this empirical experience does not necessarily foster a proactive literacy capacity to intervene in the flow of information. The majority of teenagers absorb global health insights passively without critical awareness. As a result, they have found that high exposure to social media does not automatically accelerate health knowledge into real physical action, a finding that firmly invalidates conventional linear mediation assumptions.

However, this linear deadlock was successfully rationalized in a revolutionary way through Necessary Condition Analysis (NCA), which validated that SML does not operate as a bridge, but rather as an absolute prerequisite (the ultimate bottleneck). This bottleneck mechanism is firmly rooted in the framework of cognitive psychology, grounded in three main empirical foundations. Working memory capacity limits are based on Cognitive Load Theory (Sweller, 2020). Macro health information on digital platforms is biologically secondary information that massively drains teenagers' limited working memory capacity. The threat of extraneous load in a noisy cyber ecosystem, exposure to uncurated information, will trigger extraneous cognitive load, irrelevant cognitive load, which directly damages the effectiveness of memory absorption (Skulmowski & Xu, 2022). Digital mental fatigue. Recent evidence confirms that poor navigation amid multi-platform siege will accumulate digital cognitive load, degrading psychological well-being and paralyzing the formation of healthy behavior (Ibrahim et al., 2025).

In the face of this exponential explosion of information, cognitive load management must be integrated with self-regulated learning. According to the Effort Monitoring and Regulation (EMR) framework (de Bruin et al., 2020), students face the urgency of independently monitoring and regulating their cognitive effort when surfing the web. In this context, social media literacy serves as a tool for cognitive regulation. The absence of an SML below the absolute minimum threshold will trigger regulatory failure, leading to cognitive overload. Without a precise literacy filter, exposure to macro health data can lead to digital fatigue and decision paralysis, ultimately impairing students' working memory and their ability to initiate motor actions in the real world.

Empirical confirmation of the position of SML as a cognitive safety valve (bottleneck) urges structural reform in the Physical Education, Sports and Health (PJOK) curriculum. The majority of conventional PJOK pedagogical practices today are still stuck on teaching motor techniques in the field, but paradoxically suffer from "digital blindness" towards the threat of a sedentary lifestyle that hides behind students' cyber environment. This phenomenon aligns with the danger alarm regarding "sedentarismo tecnológico" (technological sedentarism) raised by Corvetto-Castro et al. (2025). In their investigation of adolescents, they uncover a critical reality: the use of digital devices outside of school has crippled physical activity. It was recorded that 49% of students were in the sedentary category, and only 2% were truly physically active.

Evaluating this phenomenon through a cognitive load optimization framework (Castro-Alonso et al., 2021), early adolescents are considered novice learners. They are very vulnerable to executive function failure if educational institutions allow them to manage their digital cognitive load independently (learner-managed cognitive load). Therefore, the modern PJOK curriculum must shift its paradigm towards instructor-managed instructional design. Physical education teachers must imperatively inte-

grate social media literacy skills, especially algorithm navigation, as a core competency. Given that teenagers often lack the technical vocabulary and agency to control the personalization algorithms in their timelines (Swart, 2021), teachers are required to provide explicit guidance. This guide covers how to recognize algorithm bias, filter out redundant information, and break the content cycle that fuels sedentary behavior.

The urgency of this school-based regulatory intervention is further strengthened locally by the findings of Megawati et al. (2026), which reveal that junior high school students have a moderate level of self-control. In general, students in Makassar have relatively high technical skills in social media literacy, but their psychological capacity to regulate themselves remains at a moderate level. Given that students with high self-regulation capacity are significantly more physically active, schools' failure to foster this cognitive capacity will perpetuate adolescents' passive lifestyle. This tactical step is also in line with the co-design roadmap from Watkins et al. (2025), who emphasized that school-based physical activity interventions must be combined with comprehensive social media literacy modules.

This transformation becomes increasingly crucial because the formation of teenagers' physical fitness is very dependent on a strict dose-response law. Referring to the findings of Lourenço et al. (2025), increasing the volume of structured physical exercise (from 2 hours to 8.75 hours per week) deterministically controls the jump in aerobic capacity, endurance and neuromuscular strength in adolescents. As a result, eliminating digital blockages through structured SML capacity building in schools is an absolute prerequisite to ensure students can tame the noise of cyberspace, free up their cognitive space, and turn global health insights into real motor actions to fulfill the optimal dose of physical activity, turning global health insights into a catalyst for an active lifestyle.

Theoretically, this study pioneers a hybrid PLS-SEM and NCA approach in digital adolescent physical activity literature, challenging the dominance of linear behavioral theories by proving that necessary conditions operate under a distinct, complementary logic to linear sufficiency. By incorporating algorithm navigation competence as a structural determinant, this framework successfully extends the conventional boundaries of the Health Belief Model and Social Cognitive Theory for high-penetration digital eras. This expansion aligns with global evidence indicating that digital health literacy fundamentally restructures health beliefs, cognitive self-efficacy, and behavioral intentions within highly persuasive, algorithmically curated systems (McAnally & Hagger, 2023; Pu & Huang, 2025). Furthermore, while traditional linear frameworks fail to capture multi-layered, nonlinear interaction feedback loops and digital-structural constraints (Su et al., 2025), our NCA application strategically addresses these limitations by uncovering indispensable nonlinear thresholds, specifically, social media literacy (SML), which serves as an absolute prerequisite. This insight complements empirical evidence showing that massive digital exposure without adequate critical literacy or self-regulation inevitably paralyzes health intentions, rendering individual motivation ineffective and driving sedentary habits among youth, regardless of the availability of physical sports infrastructure (Sluijs et al., 2021; Sönmez Sari et al., 2025; Zhao et al., 2024).

Conclusions

This study demonstrates a critical gap between theoretical health knowledge and actual physical activity among adolescents. While digital health insights offer initial stimulus, their impact is easily paralyzed by information distortion in cyberspace. Crucially, this research repositions Social Media Literacy (SML) from a linear predictor to a necessary condition and key bottleneck for adolescent behavior. Under Cognitive Load Theory, without SML filters, digital information overloads working memory, triggering mental fatigue and decision paralysis that prevent health knowledge from translating into real motor actions. In practice, these findings urge a shift in the Indonesian physical education curriculum to address digital blindness. Interventions for adolescent inactivity cannot rely solely on gross motor activities. Educational and health policymakers must integrate digital health literacy, specifically algorithmic navigation and cognitive resource management, into modern school programs to unlock the full potential of youth physical activity.

In terms of practical implications, the Ministry of Education and Culture, alongside the Ministry of Health, should pivot from conventional health campaigns toward structured, school-based SML training

modules. Resource allocation must prioritize teaching cognitive resource management and health-related fake news filtering. Strengthening students' SML capacity is an indispensable prerequisite for eliminating digital blockages, freeing up adolescent cognitive space, and ultimately fostering a physically fit, digitally savvy generation.

Despite these contributions, this investigation has distinct limitations that outline future research pathways. First, its cross-sectional design cannot fully capture the changing temporal dynamics of adolescent technology adoption, suggesting that future studies should employ longitudinal or experimental approaches. Second, relying on self-reported measures may introduce social desirability bias; further investigations should integrate objective tracking tools such as accelerometers or calibrated fitness trackers. Finally, because the sample was concentrated within urban Makassar, replicating this hybrid PLS-SEM and NCA model across suburban and rural areas is vital to validate these boundary conditions against the digital divide.

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