Physical activity, gender, and energy intake among Indonesian adolescents: cross-sectional study of diet and behavior

Actividad física, género e ingesta energética en adolescentes indonesios: estudio transversal de dieta y conducta

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Abstract

Introduction: Adolescence was a critical period for establishing healthy lifestyle behaviors. Understanding the relationship between physical activity and energy intake was important for improving adolescent health.
Objective: This study aimed to examine the associations between physical activity, gender, and total energy intake among Indonesian adolescents, and to identify dietary pattern clustering.
Methodology: A cross-sectional study was conducted among 447 adolescents aged 13–15 years. Energy intake was estimated using a screened food frequency questionnaire, physical activity was assessed with a standardised questionnaire, and dietary patterns were identified using principal component analysis. Statistical analyses included variance testing, correlation, regression, and interaction analysis, with assumptions of normality and homogeneity evaluated.
Results: Energy intake varied significantly by physical activity level and gender, but not by area. Three dietary patterns were identified: plant-based traditional, mixed, and processed food patterns. A significant interaction between activity and gender indicated a stronger association among males. Regression analysis showed a modest positive relationship between activity and energy intake.
Discussion: These findings were consistent with previous studies showing gender differences and modest associations between activity and intake. The coexistence of traditional and modern dietary patterns reflected an ongoing nutrition transition.
Conclusions: Physical activity and gender were associated with energy intake, though the effect size was modest. These findings support the need for gender-sensitive interventions to improve adolescent nutrition.

Keywords

Adolescents; dietary behavior; energy intake; gender; physical activity.

Resumen

Introducción: La adolescencia fue un período crítico para desarrollar hábitos de vida saludables. Comprender la relación entre actividad física e ingesta energética fue clave para mejorar la salud adolescente.
Objetivo: Examinar las asociaciones entre actividad física, género e ingesta energética en adolescentes indonesios, así como identificar patrones dietéticos.
Metodología: Se realizó un estudio transversal en 447 adolescentes de 13 a 15 años. La ingesta energética se estimó mediante un cuestionario de frecuencia alimentaria filtrado, la actividad física se evaluó con un cuestionario estandarizado y los patrones dietéticos se identificaron mediante análisis de componentes principales. Se aplicaron pruebas de varianza, correlación, regresión e interacciones, verificando normalidad y homogeneidad.
Resultados: La ingesta energética varió significativamente según actividad física y género, pero no por área. Se identificaron tres patrones dietéticos: tradicional basado en plantas, mixto y de alimentos procesados. La interacción actividad–género fue significativa, indicando una asociación más fuerte en varones. La regresión mostró una relación positiva modesta.
Discusión: Los resultados coincidieron con estudios previos que muestran diferencias de género y asociaciones moderadas. La coexistencia de patrones tradicionales y modernos reflejó una transición nutricional.
Conclusiones: La actividad física y el género se asociaron con la ingesta energética, con efecto modesto. Estos hallazgos apoyan intervenciones sensibles al género para mejorar la nutrición adolescente.

Palabras clave

Actividad física; adolescentes; conducta alimentaria; género; ingesta energética.

Introduction

Adolescence represents a critical period of rapid physical growth and behavioral consolidation, during which dietary habits and physical activity patterns are established and often persist into adulthood. Nutritionally, adolescents have elevated energy and nutrient requirements, while simultaneously being highly susceptible to environmental and social factors that shape both food choices and activity behaviors (Popkin, 2004). Globally, many low- and middle-income countries (LMICs), including Indonesia, are undergoing a nutrition transition characterized by a shift from traditional diets toward increased consumption of processed, energy-dense foods and sugar-sweetened beverages, alongside declining physical activity and rising sedentary behavior (Popkin, 2002; Popkin, 2004). These shifts contribute to the emergence of a double burden of malnutrition, in which undernutrition persists alongside increasing rates of overweight and diet-related non-communicable diseases.

At the regional level, studies in Southeast Asia indicate that adolescents are increasingly exposed to obesogenic food environments, including school canteens, neighborhood food outlets, and pervasive food marketing. Such exposure promotes higher consumption of ultra-processed snacks and sugary drinks, contributing to declining dietary quality and a gradual convergence of dietary patterns across urban and rural populations (Gie et al., 2023; Mai et al., 2023; Nguyen et al., 2024). This convergence suggests that geographic disparities in dietary intake may be narrowing, particularly in transitional or peri-urban areas that combine characteristics of both rural and urban settings.

Physical activity (PA) is a key determinant of energy balance during adolescence, as it is associated with total energy expenditure and may shape patterns of energy intake. Although more active adolescents often consume more calories to meet higher physiological demands, empirical evidence suggests that this relationship is modest and influenced by a range of behavioral and environmental factors (Fulton et al., 2009). This indicates that energy intake is not solely driven by physiological needs but is also shaped by social norms, food availability, and individual behavioral tendencies.

To explain these complex interactions, this study draws on the Theory of Planned Behavior (TPB) and the Prototype Willingness Model (PWM) as complementary theoretical frameworks. TPB posits that behaviors such as physical activity and dietary choices are influenced by attitudes, subjective norms, and perceived behavioral control, while PWM extends this perspective by incorporating social-reactive processes, including prototype perceptions and behavioral willingness, which are particularly salient during adolescence (Gibbons et al., 2003; Wheatly et al., 2020). Within this combined framework, energy intake can be understood as the outcome of both reasoned and reactive processes, shaped not only by individual intentions but also by social expectations and situational contexts.

Importantly, gender and environmental context are likely to condition these relationships. Gender differences in physical activity and dietary behaviors are well documented, with boys typically reporting higher levels of physical activity and energy intake, whereas girls may demonstrate greater dietary restraint influenced by body image and social norms (Gorely et al., 2009). At the same time, differences across urban, transitional, and rural settings may reflect variations in food environments and opportunities for physical activity, with transitional areas representing critical contexts where shifts toward urbanized dietary and behavioral patterns are emerging.

Despite these global and regional insights, a significant gap remains in the Indonesian context. Previous studies have tended to examine physical activity, dietary intake, or geographic variation in isolation, with limited attention to their joint influence or to the moderating roles of gender and residential context. Moreover, few studies have explicitly applied behavioral theory to explain how these factors interact in shaping adolescent energy intake and dietary patterns.

Against this background, the present study examines the relationship between physical activity and total energy intake among Indonesian adolescents and explores how this relationship varies across gender and urban–transitional–rural settings, while also identifying underlying dietary patterns using principal component analysis (PCA). Guided by TPB and PWM, it is expected that higher levels of physical activity will be associated with higher energy intake, but that this association will not be uniform across populations. Specifically, the strength of this relationship is anticipated to differ by gender, reflecting distinct social norms and behavioral expectations, and to vary across residential contexts, with transitional areas exhibiting intermediate or emerging patterns. Furthermore, variations in energy intake are expected

to correspond to distinct dietary patterns that differ across gender and geographic settings, reflecting the combined influence of environmental exposure and social-behavioral processes. By integrating behavioral theory with empirical analysis, this study aims to provide a more comprehensive understanding of how physical activity, gender, and environmental context jointly shape adolescent dietary behavior in Indonesia

Method

Participants

A cross-sectional study was conducted among adolescents aged 13–15 years attending four public junior high schools located in urban, transitional, and rural areas of Bali, Indonesia, from August to November 2025. A total of 692 eligible adolescents completed the questionnaires (all students in selected classes who provided consent). After plausibility screening using the EI/BMR ratio (1.1–2.5 cut-off to exclude under- or over-reporters, following standard nutritional epidemiology methods), 245 were excluded due to implausible energy intake. A total of 447 plausible respondents (137 males, 310 females) were included in the final analysis. This resulted in a gender imbalance, with a higher proportion of female participants, which may reflect differential participation or reporting patterns and could introduce bias in gender-stratified analyses as well as limit the generalizability of findings across sexes. Accordingly, results related to gender differences should be interpreted with caution. Sample size was calculated based on a power of 0.80 to detect moderate effect sizes (f = 0.25) in ANOVA interactions, assuming alpha = 0.05 and accounting for clustering within schools. This study was approved by the Ethics Committee of the Faculty of Medicine, Universitas Udayana, Bali, Indonesia (Approval No. 2614/UN14.2.2.VII.14/LT/2025). Written informed consent was obtained from the school authorities and parents or guardians of all participating students.

Procedure

Energy Intake

Dietary intake was assessed using a semi-quantitative Food Frequency Questionnaire (FFQ) adapted for Indonesian adolescents. Energy intake was assessed using a semi-quantitative FFQ previously validated for selected nutrient intake among Indonesian adolescents; however, validation for total energy intake remains limited and should be interpreted with caution. A previous validation study reported moderate to good validity for estimating sugar intake among Indonesian adolescents (Rachmah et al., 2021). The FFQ recorded frequency and portion size of major food groups over the past month, from which daily energy intake (kcal/day) was calculated. Implausible intakes (EI/BMR < 1.1 or > 2.5) were excluded following standard approaches in adolescent nutrition research to reduce misreporting bias.

Physical Activity

Physical activity was measured using the Physical Activity Questionnaire for Adolescents (PAQ-A), a self-administered 7-day recall instrument validated across multiple cultural settings (e.g., Spanish adolescents, with established reliability and validity). Scores range from 1 (low) to 5 (high). Participants were categorized into Low (≤2.0), Moderate (>2.0–≤3.0), and High (>3.0) activity levels based on score distribution thresholds rather than exact tertile cut-offs. These thresholds are commonly applied in PAQ-A-based studies to facilitate interpretability and comparability across adolescent populations, and were intentionally used instead of constructing equal sample tertiles (Martínez et al., 2009).

Dietary Pattern

Dietary data were derived from a semi-quantitative food frequency questionnaire (FFQ) that assessed habitual intake of various food items during the past month. To minimize reporting bias, only plausible reporters—participants whose reported energy intake was within a biologically plausible range—were included in this analysis (n = 447). A total of 19 food-frequency items were selected, covering staple foods, plant-based proteins, animal proteins, fruits, vegetables, beverages, and snack foods. Categorical responses (e.g., “every day”, “1–2 times per week”, “never”) were converted into frequency per day using a standard conversion approach commonly applied in FFQ-based dietary pattern analysis (Willett, 2013; Cade et al., 2002). Specifically, ≥ 2 times/day = 2.0, once/day = 1.0, 3–4 times/week = 0.47, 1–2

times/week = 0.20, 1–3 times/month = 0.07, and never = 0.00. This method assumes a uniform distribution within categories and is widely used to approximate habitual intake, although it may introduce minor measurement error (Hu et al., 1999). All variables were standardised (z-scores) prior to analysis. The FFQ used has been validated for sugar intake in Indonesian adolescents; its validity for total energy estimation is more limited. Energy estimates were plausibility-screened (EI/BMR 1.1–2.5) to reduce misreporting bias, but results should be interpreted cautiously.

Principal Component Analysis (PCA) was employed to identify underlying dietary patterns based on inter-correlations among food items. Sampling adequacy was verified using the Kaiser–Meyer–Olkin (KMO) test (> 0.6) and Bartlett's Test of Sphericity ($p < 0.001$), confirming suitability for PCA. Components were retained based on eigenvalues > 1 and the Scree Plot inflection point. To improve interpretability, a Varimax orthogonal rotation was applied, and food items with absolute factor loadings ≥ |0.30| were used to characterize each dietary pattern. Although some studies use a higher threshold (e.g., ≥ |0.40|), the ≥ |0.30| criterion is widely accepted in exploratory dietary pattern analysis to capture broader dietary constructs, particularly in heterogeneous populations (Hu, 2002; Newby & Tucker, 2004; Hair et al., 2010). This approach allows inclusion of moderately contributing food items while maintaining interpretability. Varimax rotation further enhances clarity by maximizing variance across factors and reducing cross-loadings (Kaiser, 1958). Nonetheless, the choice of threshold involves a trade-off between interpretability and parsimony; future studies may consider sensitivity analyses using stricter cut-offs. Individual component scores were calculated for each respondent to reflect adherence to each pattern, which were later used in analyses of gender differences, physical activity levels, and total energy intake.

Data analysis

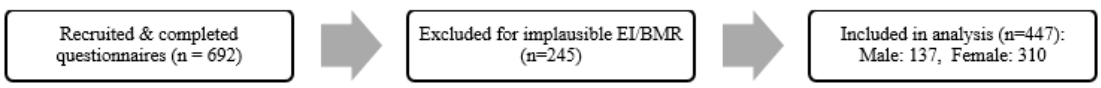
Descriptive statistics were reported for key variables by gender, activity, and area. Prior to ANOVA, normality of continuous variables was assessed using the Shapiro–Wilk test and homogeneity of variances using Levene's test. Where ANOVA assumptions were not met, appropriate transformations or nonparametric alternatives were considered and noted. Missing data were assessed for extent and pattern; no additional missing data were identified after plausibility screening and analyses were conducted using complete-case data. The number of observations included in each analysis is reported in the Results or Supplement to ensure transparency. One-way ANOVA tested differences in energy intake across activity categories and areas. Pearson correlation examined associations between PAQ-A score and energy intake. Linear regression assessed the independent effect of physical activity score (continuous) on energy intake, controlling for gender and area. A three-way factorial ANOVA (Area × Activity × Gender) evaluated interaction effects. PCA results were presented with factor loadings and interpreted patterns. Statistical significance was set at $p < 0.05$. Analyses were performed using SPSS 26.0 (IBM Corp., Armonk, NY).

Results

Participant Characteristics

A total of 447 plausible respondents (137 males and 310 females) aged 13–15 years were included in the analysis (Figure 1).

Figure 1. Participant flow diagram. From initial recruitment to final analyzed sample, showing exclusions for implausible energy intake.



The mean age of participants was 13.8 ± 0.5 years, with no significant age difference between males and females ($p > 0.05$). The mean physical activity score (PAQ-A) for the total sample was 2.46 ± 0.63, indicating predominantly *moderate* levels of habitual activity. Males demonstrated significantly higher activity levels (2.61 ± 0.62) compared to females (2.39 ± 0.60; $t(445) = 3.52$, $p < 0.001$).

Table 1. Descriptive Characteristics of Participants

Variable	Male	Female	Total
n	137	310	447
Age (years)	13.8 ± 0.6	13.9 ± 0.5	13.8 ± 0.5
PAQ-A Score	2.61 ± 0.62	2.39 ± 0.60	2.46 ± 0.63
Energy Intake (kcal/day)	2056 ± 463	1799 ± 402	1897 ± 443

The mean daily energy intake of all participants was 1897 ± 443 kcal/day, with males reporting higher intakes (2056 ± 463 kcal/day) than females (1799 ± 402 kcal/day; $p < 0.001$). No significant differences were found across areas (urban, transitional, rural; $p = 0.73$), suggesting relative homogeneity in overall caloric intake across geographic locations (Table 1).

Energy Intake by Gender and Area

Across all areas, males consistently reported higher energy consumption than females, with mean differences ranging from 200 to 300 kcal/day. Among male students, energy intake was slightly higher in transitional areas (2086 ± 511 kcal/day) compared to urban (2069 ± 387 kcal/day) and rural (1988 ± 486 kcal/day) areas; however, these differences were not statistically significant and should therefore be interpreted cautiously as exploratory trends rather than definitive associations ($F(2,134) = 0.51$, $p = 0.60$) (Table2).

Table 2. Energy Intake by Area and Gender

Gender	Area	n	Mean ± SD (kcal/day)
Male	Urban	43	2069 ± 387
	Transitional	60	2086 ± 511
	Rural	34	1988 ± 486
Female	Urban	88	1818 ± 432
	Transitional	142	1778 ± 373
	Rural	80	1820 ± 423

Similarly, for female students, mean energy intake did not differ significantly across areas ($F(2,302) = 0.40$, $p = 0.67$), with the highest average intake observed in urban schools (1818 ± 432 kcal/day). These findings indicate that gender is a stronger determinant of energy intake than area of residence, and no statistically significant differences in mean energy intake were detected across areas; however, proportional differences in adequacy categories warrant cautious interpretation.

Energy Adequacy

As shown in Table 3, the majority of respondents (59.1%) fell into the low adequacy category, 24.2% reported adequate intake, and 16.7% exceeded recommendations. A clear gradient was observed across areas: urban students had the highest proportion of adequate intake (32.1%), while rural students showed the greatest proportion of insufficient intake (66.1%). Although gender differences were not pronounced in adequacy distribution, male participants tended to have slightly higher proportions of both adequate and excess energy intake compared to females, aligning with their higher mean caloric consumption. These results suggest that while mean energy intake does not differ significantly by area, a larger proportion of rural adolescents experience suboptimal caloric adequacy, potentially reflecting lower dietary diversity or meal frequency. A chi-square test examining differences in energy adequacy distribution across areas yielded $\chi^2(4) = 8.90$, $p = 0.064$, with a small effect size (Cramér's $V = 0.10$), indicating that proportional differences were modest and did not reach statistical significance (Table 3).

Table 3. Energy Adequacy by Area

Area	Low (<90% RDA)	Adequate (90 - 110%)	High (>110%)
Rural	66.1%	15.6%	18.3%
Transitional	58.9%	23.8%	17.3%
Urban	53.4%	32.1%	14.5%

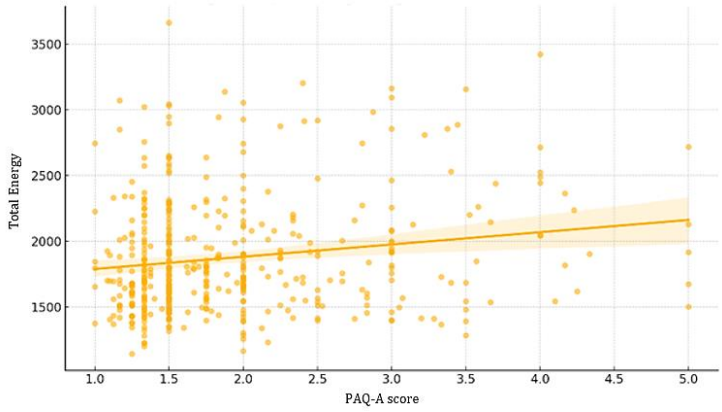
Relationship Between Physical Activity and Energy Intake

Figure 2 and Table 4 describe the relationship between energy intake and physical activity level. A clear upward trend was observed: adolescents classified in the high activity category reported the highest mean energy intake (2051.8 ± 523.8 kcal/day), followed by moderate (1868.3 ± 438.6 kcal/day) and low activity groups (1839.9 ± 404.1 kcal/day). Prior to conducting ANOVA, normality of residuals was assessed using the Shapiro–Wilk test and homogeneity of variances was evaluated using Levene's test. Assumptions were met ($p > 0.05$ for all tests). ANOVA results confirmed significant differences across activity levels ($F(2,444) = 6.23$, $p = 0.002$). Post-hoc Tukey HSD tests indicated that the high activity group differed significantly from the low activity group ($p < 0.01$), while differences between moderate and low, and moderate and high groups were not statistically significant ($p > 0.05$). This suggests that students with higher physical activity levels tend to report higher energy intake, consistent with expected energy balance patterns. The effect size was small ($\eta^2 = 0.027$), indicating that physical activity level accounted for approximately 2.7% of the variance in total energy intake.

Table 4. Energy Intake by Physical Activity Category

Physical Activity Level	n	Mean ± SD (kcal/day)	F	p-value
Low	277	1839.9 ± 404.1	6.23	0.002
Moderate	107	1868.3 ± 438.6		
High	63	2051.8 ± 523.8		

Figure 2. Relationship between physical activity (PAQ-A score) and total energy intake among Indonesian adolescents (n = 447). The scatter plot shows a modest positive correlation (β = +93.3, p < 0.001), with higher energy intake observed among more active participants. The shaded band indicates the 95% confidence interval.



Regression Analysis Between PAQ-A Score and Energy Intake

To further examine the relationship between activity and energy intake, a linear regression analysis was performed using total energy intake as the dependent variable and PAQ-A score as the predictor. Results showed a significant positive association, β = 93.3 kcal per 1-point PAQ-A (95% CI: 43.2 to 143.4), SE = 25.7, t = 3.64, $p < 0.001$; model $R^2 = 0.029$. The model explained 2.9% of the variance in total energy intake ($R^2 = 0.029$), indicating a modest yet statistically significant effect. In practical terms, each one-point increase in physical activity score corresponded to an average increase of 93 kcal/day in total energy consumption. This suggests that physical activity explains only a small proportion of variability in energy intake, with other factors likely playing a more substantial role. Regression diagnostics (residual plots, Leverage, and VIF for multicollinearity) showed no serious violations; VIFs were < 2 for all predictors.

Table 5. Linear Regression of Physical Activity and Energy Intake

Predictor	β	Std. Error	t	p-value
Constant	1695.6	53.6	31.7	<0.001
PAQ-A Score	93.3	25.7	3.64	<0.001

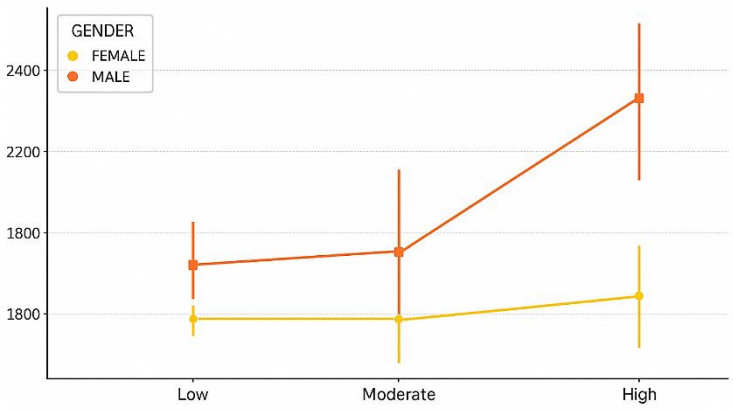
Interaction Effects of Area, Physical Activity and Gender

For the three-way ANOVA model, homogeneity of variance assumptions were also satisfied (Levene's test $p > 0.05$). The results (Table 6) revealed that physical activity ($p = 0.006$) and gender ($p < 0.001$) significantly influenced energy intake, while area ($p = 0.73$) had no effect. A significant interaction between activity and gender ($p = 0.034$) indicated that the effect of activity on energy intake was stronger among males. No significant interactions involving area were detected, suggesting that the observed relationships between activity and intake were consistent across urban, transitional, and rural environments. Graphical inspection (Figure 3) confirmed that males exhibited steeper increases in energy intake with rising activity levels, while females showed a flatter trend. The Activity × Gender interaction showed a small effect size (partial $\eta^2 = 0.016$), indicating that although statistically significant, the magnitude of the interaction effect was modest.

Table 6. Three-Way ANOVA Summary

Factor	F	p-value	Significance
Area	0.31	0.734	ns
Activity	5.12	0.006	✓
Gender	27.67	<0.001	✓✓
Activity × Gender	3.41	0.034	✓

Figure 3. Relationship Between Energy Intake, Area, and Gender. Interaction between area, physical activity, and gender on total energy intake among Indonesian adolescents (n = 447). Error bars represent standard deviations. Males show a steeper increase in energy intake with rising activity levels compared to females, indicating a stronger intake–activity linkage among boys.



Dietary Patterns Identified by PCA

Three principal dietary patterns were identified, together explaining approximately 65% of the total variance in food frequency data. The rotated component loadings are presented in Table 7 and the PCA loading heatmap in Figure 4. Pattern 1 (Plant-based Traditional): characterized by higher consumption of tempeh, tofu, and fish, reflecting a traditional Indonesian diet rich in local plant-based protein sources. Pattern 2 (Mixed): characterized by the absence of dominant loadings, which may reflect transitional or heterogeneous eating behaviors rather than a distinct dietary pattern. Such patterns have been reported in exploratory PCA studies and may represent overlapping consumption habits rather than clearly defined dietary structures. Pattern 3 (Processed/Junk-food): defined by frequent instant noodle consumption and lower rice intake, indicating a shift toward convenience-oriented, ultra-processed foods. The cumulative variance and scree plot confirmed adequate factor stability.

Figure 4. PCA loadings heatmap of three major dietary patterns identified among adolescents (n = 447). Red shades represent positive loadings and blue shades negative ones. Food items with absolute loadings ≥ 0.30 (★) indicate strong contributions. The three patterns were: (1) Plant-based Traditional (tofu, tempeh, fish), (2) Mixed, and (3) Processed/Junk-food (instant noodles ↓ rice), explaining ~65% of total variance.

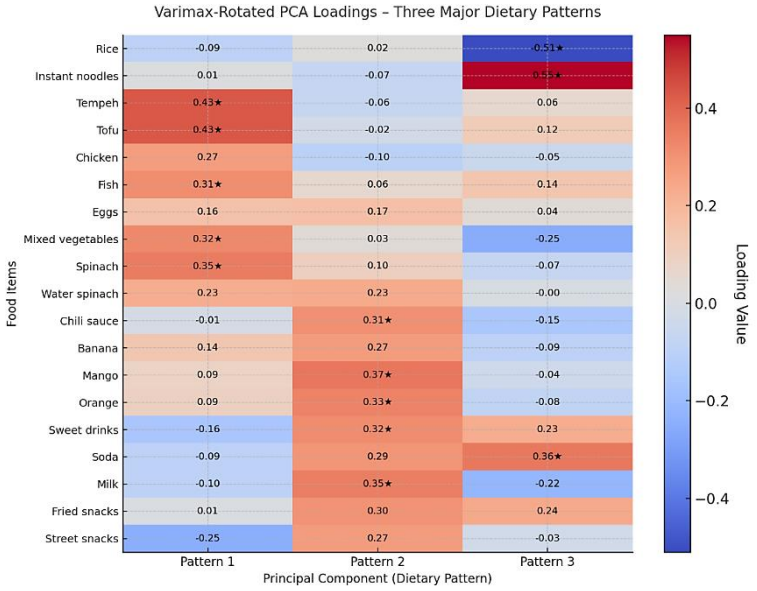


Table 7. Varimax-rotated loadings of food items on three dietary patterns

Food item	Pattern 1	Pattern 2	Pattern 3
Tempeh	0.43	–	–
Tofu	0.43	–	–
Fish	0.31	–	–
Instant noodles	–	–	0.55
Rice	–	–	−0.51

Pattern Scores and Associations

PCA scores were computed for each respondent and compared across gender and physical activity categories. Adolescents with moderate-to-high physical activity tended to have slightly higher scores for the Plant-based Traditional pattern ($p \approx 0.055$), whereas the Processed/Junk-food pattern showed no significant association with either energy intake or activity level. Correlation analyses (Spearman's ρ) between dietary pattern scores and total energy intake revealed no statistically significant relationships ($p > 0.05$ for all patterns), although a weak positive trend was observed for the Processed/Junk-food pattern (Table 8).

Table 8. Associations of dietary pattern scores with total energy intake and physical activity

Pattern	Correlation (ρ)	*p*-value	ANOVA F	*p*-value
Plant-based Traditional	Weak (+)	> 0.05	2.92	0.055
Mixed	None	> 0.05	0.89	0.411
Processed/Junk-food	Weak (+)	> 0.05	0.69	0.502

In particular, the Plant-based Traditional pattern showed a non-significant trend toward higher adherence among more active adolescents (p ≈ 0.055), and therefore should be interpreted cautiously, while the Processed/Junk-food pattern reflects modernized, low-activity consumption behavior increasingly observed in Indonesian adolescents. Dietary patterns are converging across areas, with coexistence of traditional and modern snack-based diets reflecting Indonesia's ongoing nutrition transition.

Discussion

The present study contributes to understanding adolescent energy balance by examining how physical activity, gender, and area of residence relate to energy intake and dietary patterns among Indonesian adolescents. These findings suggest that behavioral factors may play a more prominent role than geographic location in explaining variations in energy intake within this sample, and they provide empirical support for the notion of dietary convergence in a country undergoing nutrition transition.

Physical Activity, Gender and Energy Intake

Our results show that higher physical activity scores were associated with higher mean energy intake, and that males reported higher energy intakes than females. These associations were statistically significant but modest in magnitude: the PAQ-A score accounted for approximately 2.9% of variance in energy intake ($R^2 \approx 0.03$). These findings suggest that physical activity is associated with energy intake; however, the magnitude of this relationship is modest, with most variability likely explained by other behavioral, environmental, and biological factors. This pattern aligns with the physiological energy-balance principle: increased expenditure via physical activity typically necessitates greater intake. For instance, in the HELENA and EYHS studies, vigorous and moderate physical activity were positively associated with higher energy intake in adolescents (Cuenca-Garcia et al., 2014). More recently, a systematic review found that acute physical activity in children and adolescents may contribute to modest increases in caloric intake, though the effect size remains small (Hahn et al., 2024). In our own data the regression model explained approximately 3% of the variance in energy intake ($R^2 \approx 0.03$), which is consistent with previous literature suggesting that physical activity is only one of many determinants of energy intake (Jodhun et al., 2016). Evidence also suggests that the interplay between physical activity and nutritional status in adolescent populations is multifaceted. For instance, Carrasco-Venturelli et al. (2024) reported variable associations between body mass index and physical activity levels among Chilean adolescents, indicating that demographic factors may modify these relationships. The stronger effect of physical activity on energy intake among males (significant Activity × Gender interaction) suggests gender-specific pathways. Possible explanations include differential energy requirements due to greater fat-free mass among males, higher habitual activity types (e.g., organized sports), and gendered behavioral norms in food consumption (e.g., girls may restrict intake for body image). Evidence from other contexts supports that adolescent boys tend to eat more and be more active than girls, which may amplify the intake-activity link (Vilhar, 2023).

Lack of Area Effect and Dietary Convergence

Perhaps the most intriguing finding is the lack of a significant difference in energy intake across areas (urban, transitional, rural). On the surface, this might appear counterintuitive given the presumed differences in food environment and access between urban and rural schools. However, this result may indicate behavioral and dietary convergence across regions. In other words, the rural and transitional school settings in our study may already mirror the urban food and snack environments — possibly via school canteens, packaged snack availability, or broader penetration of processed foods. This interpretation is supported by recent research in Indonesia. For example, Nurhasan et al. (2024) found evidence of declining diet quality and increasing consumption of processed and ultra-processed foods across urban, rural and forested areas, indicating the nutrition transition is pervasive and not confined to urban zones. Furthermore, expert qualitative work has highlighted that modernization, retail penetration and changing food norms are driving convergence of diets in Indonesia (Anyanwu et al., 2023; Briawan et al., 2023). From a policy lens, this suggests that traditional geographic targeting (i.e., "rural vs urban") may be less effective than focusing on behavioral and environmental interventions that cut across regions.

Dietary Patterns and Their Relationship with Physical Activity, Gender, and Energy Intake

The identification of three distinct dietary patterns—Plant-based Traditional, Mixed, and Processed/Junk-food—offers insight into the coexistence of traditional and modernized eating habits among Indonesian adolescents. The Plant-based Traditional pattern, characterized by higher consumption of tempeh, tofu, and fish, likely reflects adherence to culturally embedded dietary habits. In contrast, the Processed/Junk-food pattern, marked by frequent instant noodle consumption and reduced rice intake, illustrates an emerging shift toward convenience-oriented, energy-dense foods. A noteworthy finding from this study is the trend toward higher adherence to the Plant-based Traditional pattern among adolescents with moderate-to-high physical activity levels ($p \approx 0.055$). This suggests that students who

are more physically active tend to maintain healthier, locally traditional diets, a relationship supported by evidence that physical activity is often positively associated with prudent or health-conscious eating behaviors (Stea & Torstveit, 2014; Wong et al., 2021). These results align with studies indicating that active adolescents are more likely to consume fruits, vegetables, and home-prepared meals rather than processed snacks or fast foods (Fismen et al., 2020).

Gender-related tendencies may also play a role in shaping these dietary patterns, consistent with the concept of subjective norms within the Theory of Planned Behavior, where girls may face stronger social expectations regarding dietary restraint (Monteiro et al., 2019). Previous research indicates that female adolescents are more likely to adopt health-oriented dietary patterns, whereas males tend to consume more energy-dense and processed foods (Vereecken et al., 2005; Pearson et al., 2017; Askari et al., 2020). Although gender differences were not directly tested within the PCA framework, exploratory subgroup analyses did not indicate statistically significant differences in pattern scores. More broadly, gender differences in adolescent dietary behavior are shaped not only by biological factors but also by social and environmental factors, including peer norms, body image concerns, and the school food environment (Rathi et al., 2018; Neri et al., 2022).

Despite identifying these patterns, no significant correlations were found between dietary pattern scores and total energy intake. This is consistent with previous findings among adolescents, where self-reported dietary frequency data often fail to reflect true energy intake due to underreporting or variation in portion size (Livingstone & Robson, 2000). Nevertheless, the weak positive trend observed between the Processed/Junk-food pattern and energy intake may indicate compensatory behaviors, such as higher caloric density from processed foods despite lower meal frequency. This aligns with evidence linking ultra-processed food consumption to greater energy density and poorer diet quality (Monteiro et al., 2019; Askari et al., 2020). No statistically significant differences in mean energy intake were observed across areas ($p = 0.73$), and proportional differences in adequacy categories also did not reach statistical significance ($p = 0.064$), suggesting limited geographic variation in overall energy consumption.

Public Health Implications

From a public health perspective, these findings suggest potential areas for future intervention development—particularly gender-sensitive school-based educational programs that combine activity promotion and healthy eating. However, given the cross-sectional design and the modest effect sizes observed, experimental or longitudinal studies are needed to evaluate the effectiveness and scalability of such interventions before broad policy adoption.

This duality mirrors patterns observed in other middle-income countries undergoing the nutrition transition, where traditional diets coexist with ultra-processed food consumption (Popkin, 2017; Neri et al., 2022). Interventions promoting healthy lifestyles among Indonesian youth should therefore adopt an integrated behavioral approach, reinforcing both physical activity and traditional dietary practices. Schools and communities could play a pivotal role by encouraging access to nutritious, culturally relevant foods—such as tempeh and vegetables—while restricting ultra-processed snacks and sugary drinks in the school environment (González-Carrera et al., 2025). These findings may inform the development of school-based interventions in Indonesia, emphasizing integrated nutrition and physical activity promotion with attention to gender differences. For example, physical education (PE) classes could incorporate nutrition education tailored to activity demands, while school canteens may limit high-sugar and high-fat snacks and promote healthier food options. The Indonesian Government's new labelling rules for food companies (effective by 2027) are timely and aligned with such needs (Reuters, 2025).

Strengths and Limitations

Strengths of this study include the simultaneous measurement of physical activity, plausibility-adjusted energy intake, and dietary patterning across multiple residential contexts, which remains rare in Indonesian adolescent nutrition research. The use of validated instruments (PAQ-A and FFQ) enhances comparability with international studies. Nonetheless, several limitations merit attention. The cross-sectional design precludes causal inference; thus, the directionality of associations (whether higher physical activity may contribute to higher energy intake or vice versa) cannot be established, limiting inter-

pretation of temporal behavioral pathways. In addition, reliance on self-reported FFQ and physical activity questionnaires may introduce reporting bias, including potential underreporting among females due to social desirability or overreporting of activity, which may attenuate observed associations. Although the FFQ has been validated for sugar intake among Indonesian adolescents, its validity for estimating total energy intake is limited; despite applying plausibility screening (EI/BMR 1.1–2.5), residual measurement error may remain. Notably, the exclusion of 245 out of 692 recruited participants (35%) due to implausible energy reporting, while common in adolescent FFQ-based studies, may introduce selection bias toward more accurate or health-conscious reporters; although this improves data quality by reducing misreporting bias, it also reduces effective sample size and may limit generalizability. The sample also exhibited a gender imbalance (137 males vs. 310 females), which may reduce precision in gender-stratified analyses and introduce bias. Furthermore, relevant confounders such as socioeconomic status, parental education, meal frequency, snack purchasing behavior, body image, and objective body composition were not measured and may account for additional variance. Future studies are recommended to incorporate sensitivity analyses for underreporting and objective measures, such as accelerometry for physical activity, to strengthen validity.

Conclusions

This study provides new evidence that among Indonesian adolescents, physical activity and gender were statistically significant predictors in the regression model; however, the overall variance explained was low, indicating that other unmeasured factors likely contribute substantially to energy intake variability. Male adolescents and those with higher levels of physical activity reported higher energy intake; however, given the cross-sectional design, these associations should not be interpreted as causal.

The absence of significant area effects, combined with the identification of both traditional and modern/snacking dietary patterns across all settings, suggests a behavioral and dietary convergence, consistent with Indonesia's ongoing nutrition transition. This convergence implies that adolescents, regardless of where they live, are increasingly exposed to similar food environments dominated by energy-dense, processed foods.

From a public health perspective, these findings emphasize the need for gender-sensitive, behavior-focused, and school-based interventions that integrate physical activity promotion with nutritional education. Instead of targeting specific geographic regions, future interventions could focus on improving adolescents' understanding of energy balance, moderating snack consumption, and fostering healthy, active lifestyles in both boys and girls. These findings highlight the importance of integrating behavioral and environmental perspectives when addressing adolescent nutrition in rapidly transitioning settings.

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