

## Promoting Glycemic Well-Being Through NEAT: A Salutogenesis-Based Analysis Using Ordinal Logistic Regression

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### ABSTRACT

**Background:** Adolescent glycemic well-being is increasingly recognized as a fundamental component of lifelong metabolic health. Within the salutogenic framework, non-exercise activity thermogenesis (NEAT) serves as a modifiable health-promoting behavior that enhances physiological resilience and supports glucose regulation. However, empirical evidence regarding NEAT as a salutogenic resource among Indonesian adolescents remains limited. **Objective:** This study aimed to analyze NEAT's role in determining glycemic status among adolescents and to identify significant predictors using Ordinal Logistic Regression. **Methods:** An analytic cross-sectional study was conducted among 101 adolescents at SMAN 1 Menganti, Gresik, selected through simple random sampling. NEAT was indirectly estimated as total energy expenditure (TEE) minus basal metabolic rate (BMR) and the thermic effect of food (TEF). Glycemic status was classified according to American Diabetes Association (ADA) criteria as normal, prediabetes, or diabetes. Data were analyzed using ordinal logistic regression with a significance level of  $p < 0.05$ . **Results:** Most adolescents exhibited normal glycemic status (73.3%), followed by prediabetes (26,7.8%). A family history of diabetes emerged as the strongest predictor of poorer glycemic category (OR = 34.88,  $p < 0.001$ ). NEAT demonstrated a significant protective effect (OR = 1.004,  $p = 0.010$ ), indicating that higher NEAT levels were associated with a reduced likelihood of progression to worse glycemic categories. **Conclusions:** NEAT is a key health-promoting resource that supports metabolic resilience and glycemic well-being in adolescents. Simple, low-cost strategies to increase daily movement may effectively improve glycemic health, supporting the need for salutogenesis-oriented school interventions in adolescent health promotion.

**Keywords:** Adolescents, Glycemic, NEAT, Salutogenic

### INTRODUCTION

Dysglycemia among adolescents has emerged as an increasingly serious public health concern, both globally and in Indonesia. According to the 2023 National Basic Health Survey, the prevalence of diabetes mellitus among individuals aged  $\geq 18$  years reached 3.3% nationwide. In East Java, the prevalence based on physician diagnosis was 2.3% across all age groups and 2.8% among individuals aged  $> 15$  years (Riskesmas, 2023). Additionally, the Indonesian Pediatric Society (IDAI) reported a dramatic 70-fold increase in diabetes cases among children and adolescents between 2010 and 2023, indicating a substantial epidemiological shift toward younger age groups (IDAI, 2020).

At the regional level, the Gresik District Health Office recorded 63,597 cases of diabetes mellitus by the third quarter of 2023, reflecting a substantial and ongoing increase in disease burden. The urgency of early identification of glycemic risk among adolescents is further supported by findings from a preliminary study conducted at SMAN 1 Menganti, Gresik, on October 24, 2024. Of 15 randomly selected students, 11 (73%) exhibited impaired blood glucose levels, with mean values ranging from 141 to 150 mg/dL, while only 4 students (27%) demonstrated normal glucose levels, with a mean of 98 mg/dL. All measurements were obtained using standardized glucometer procedures, underscoring the potential early onset of dysglycemia among adolescents in this area.

Despite this increasing trend, adolescent dysglycemia cannot be adequately addressed through a disease-oriented paradigm alone. A shift toward health-promotion frameworks is therefore essential to identify protective factors that support metabolic resilience. Salutogenesis—a concept introduced by Antonovsky—emphasizes factors that generate and sustain health rather than those that cause disease (Mittelmark *et al.*, 2017). Within this framework, Generalized Resistance Resources (GRRs), including behavioral, psychological, social, and environmental resources, strengthen an individual's Sense of Coherence (SOC). SOC is characterized by three components: comprehensibility, manageability, and meaningfulness, which together influence how individuals cope with physiological and lifestyle challenges.

One behavioral factor that may influence adolescent glycemic status is Non-Exercise Activity Thermogenesis (NEAT), which refers to energy expenditure from non-exercise physical activities such as walking, standing, and performing light daily movements. NEAT constitutes a substantial portion of total daily energy expenditure and is strongly affected by sedentary behaviors (Levine and Kotz, 2005). Previous evidence has demonstrated that reduced NEAT is associated with insulin resistance, increased adiposity, and impaired glucose regulation (Hammoudeh *et al.*, 2013).

From a salutogenic perspective, NEAT may serve as a behavioral GRR because it is a modifiable routine activity that enhances physiological manageability of metabolic load, contributes to meaningful engagement in daily movement, and supports comprehensibility by allowing adolescents to understand how small daily behaviors influence their glycemic well-being. Recent studies emphasize that light-intensity daily movement improves metabolic resilience, even among youth populations (García-Hermoso *et al.*, 2023).

Despite this, research exploring NEAT and its association with glycemic status among Indonesian adolescents remains scarce. Most national studies have primarily focused on structured physical activity (MVPA) rather than non-exercise activity, even though NEAT represents the largest portion of daily energy expenditure. Furthermore, there is a lack

of studies utilizing Ordinal Logistic Regression to predict the risk of glycemic category progression based on NEAT levels while controlling for confounding variables such as age, body weight, and family history of diabetes.

Based on these gaps, this study aims to analyze the role of NEAT in determining the glycemic status of adolescents and to identify significant predictors using Ordinal Logistic Regression.

## METHODS

This study employed an analytic correlational design with a cross-sectional approach. The study population comprised students at SMAN 1 Menganti, Gresik, from whom 101 adolescents were selected using simple random sampling. Data collection was conducted in March 2025 following ethical approval from the Ethics Committee of Sekolah Tinggi Ilmu Kesehatan Hang Tuah Surabaya (No. PE/60/II/2025/KEP/SHT). Written informed consent was obtained from all participants and their parents or guardians.

**Inclusion Criteria:** Adolescents aged 14-17 years, Active as students at SMAN 1 Menganti Gresik, Willing to participate and provide informed consent.

**Exclusion Criteria:** Adolescents with a history of diabetes mellitus diagnosed by a physician, Those taking medications that affect glucose metabolism, Individuals with acute illness at the time of data collection.

Measurement of NEAT was assessed using an indirect calculation referring to Levine's conceptual model, in which NEAT represents all energy expenditure derived from non-exercise daily activities (Levine, 2004). NEAT was computed as Total Daily Energy Expenditure (TEE) minus the sum of Basal Metabolic Rate (BMR) and the Thermic Effect of Food (TEF).

$$\text{NEAT} = \text{TEE} - (\text{BMR} + \text{TEF})$$

BMR was calculated using the Mifflin-St. Jeor Equation, which is one of the most accurate and widely validated predictive formulas for resting metabolic rate (Mifflin *et al.*, 1990) recommended for adolescents because of its accuracy in estimating resting metabolic rate:

$$\text{Male: } 10 \times \text{weight (kg)} + 6.25 \times \text{height (cm)} - 5 \times \text{age (years)} + 5$$

Female:  $10 \times \text{weight (kg)} + 6.25 \times \text{height (cm)} - 5 \times \text{age (years)} - 161$

TEE was calculated by multiplying BMR with a light activity factor (1.4), which is recommended for populations with predominantly sedentary behavior, particularly adolescents with low habitual movement.

TEF was assumed as 10% of TEE, consistent with literature indicating the thermic effect of food contributes approximately 10% of daily energy expenditure (Westerterp, 2004). It should be noted that NEAT in this study was estimated indirectly using calculated energy expenditure rather than measured objectively using wearable devices such as accelerometers. Therefore, the obtained NEAT values represent a subjective estimation based on anthropometric parameters and activity-related assumptions, which may be subject to measurement bias.

NEAT was selected as a key variable because it represents a spontaneous, naturally occurring health-promoting behavior that can be strengthened within the school environment. Adolescents spend most of their time in school, and everyday light intensity movements such as walking between classrooms, climbing stairs, standing during class transitions, or engaging in informal activities during break times contribute meaningfully to NEAT. Conversely, prolonged sitting during learning hours may significantly reduce NEAT and increase metabolic risk (Chaput *et al.*, 2020). Therefore, NEAT provides a relevant behavioral context for understanding how routine school-day movement patterns influence glycemic health.

NEAT values were subsequently categorized into Low / Moderate / High using tertile distribution.

Measurement of Glycemic Status Fasting Plasma Glucose (FPG) was measured using a calibrated glucometer following standardized procedures. Glycemic status was categorized based on American Diabetes Association recommendations, Normal: FPG < 100 mg/dl, Prediabetes: FPG 100-125 mg/dl, Diabetes: FPG  $\geq$  126 mg/dl (American Diabetes Association Professional Practice Committee, 2023)

These categories constitute an ordinal outcome, justifying the use of Ordinal Logistic Regression.

Other Variables: Age measured in years (14-17), Body weight measured using a digital scale (kg), Family history of diabetes: determined by self-report of first-degree relatives diagnosed with diabetes.

Statistical Analysis Data were analyzed using SPSS version 25. Descriptive statistics were presented as frequencies and percentages. Model fit was assessed using Pearson Chi-square and Deviance statistics. Multivariable analysis was performed using Ordinal Logistic Regression to determine predictors of glycemic category while controlling for potential confounders. Significance was set at  $p < 0.05$ .

## RESULTS AND DISCUSSION

### Distribution of NEAT Categories Across Glycemic Status

**Table 1.** Characteristics Subjects Based Age, Weight, Family History, FPG, and NEAT

Characteristics	Frequency	%
<b>Age</b>		
14	1	1.0
15	15	14.9
16	49	48.5
17	36	35.6
<b>Total</b>	<b>101</b>	<b>100</b>
<b>Weight</b>		
36-48	34	33.6
49-61	51	50.4
62-74	10	10
75-88	6	6
<b>Total</b>	<b>101</b>	<b>100</b>
<b>Family History</b>		
Yes	74	73.3
No	27	26.7
<b>Total</b>	<b>101</b>	<b>100</b>
<b>NEAT</b>		
Low	13	12.9
Moderate	28	27.7
High	60	59.4
<b>Total</b>	<b>101</b>	<b>100</b>
<b>FPG</b>		
Normal	74	73.3
Prediabetes	27	26.7
Diabetes Mellitus	0	0
<b>Total</b>	<b>101</b>	<b>100</b>

The table demonstrates a complete distribution with no missing data. The age distribution is predominantly concentrated at 16 years (48.5%), body weight is largely within the 49-61 kg range, and a substantial proportion of participants

(74.3%) reported a family history of diabetes mellitus.

**Table 2.** Goodness of Fit Ordinal Regression Logistics Model

	Chi-Square	df	Sig.
Pearson	174.243	195	0.855
Deviance	95.016	195	1.000

The table shows that the model exhibits an adequate goodness of fit, as indicated by the significance value of 0.855 (>0.05). This result suggests that the model aligns well with the observed empirical data and is suitable for further analysis.

**Table 3.** Pseudo R Square Ordinal Regression Logistic Model

Pseudo R-Square	
Cox and Snell	0.393
Nagelkerke	0.515
McFadden	0.347

Based on the results, Nagelkerke R<sup>2</sup> value obtained was 0.515, indicating that the independent variables in the model explain approximately 51.5% of the variance in glycemic status. This demonstrates a moderate explanatory power of the model in predicting the outcome.

**Table 4.** Parameter Estimates Ordinal Regression Logistic Model

Variable	Estimate	OR	95% CI	P-Value
Age	0.082	1.085	0.93-1.26	0.334
Weight	0.027	1.027	0.91-1.15	0.412
Family History	3.553	34.88	12.61-96.48	0.000
NEAT	0.004	1.004	1.001-1.009	0.010

The results show that adolescents with a family history of diabetes have 34.9 times higher odds of being in a worse glycemic category compared with those without such a history. Meanwhile, the NEAT variable demonstrates an odds ratio of 0.996, indicating that each one-unit increase in NEAT reduces the likelihood of being in a poorer glycemic category by approximately 0.4%. Although the protective effect of NEAT is modest per unit, it is consistent, suggesting that higher levels of non-exercise physical activity are

associated with a lower risk of glycemic impairment among adolescents. These findings align with the salutogenic perspective, which emphasizes strengthening health-promoting resources rather than solely reducing risk. Higher NEAT may function as a behavioral GRR, supporting adolescents' capacity to regulate glucose more effectively by enhancing metabolic resilience.

This study indicate that NEAT plays an important protective role in determining adolescents' glycemic status, even after controlling for age, BMI, and family history of diabetes. This aligns with previous research by (Levine and Kotz, 2005), who emphasized that increases in non-exercise physical activity can reduce insulin resistance through repeated small-muscle contractions and increased glucose uptake independent of insulin.

Previous research has shown that increased daily movement and reduced sedentary time contribute to better metabolic profiles in adolescents, including lower fasting insulin and improved insulin resistance (García-Hermoso *et al.*, 2023). Cohort evidence also indicates that more active youth demonstrate lower adiposity and better insulin sensitivity during early adolescence (Kehoe *et al.*, 2019). These findings align with the strong protective effect of NEAT identified in the present study.

Family history emerged as the most influential factor, which is in accordance with literature showing that genetic predisposition strongly impacts glucose regulation and insulin sensitivity (Denton and Fernandez, 2021). This may explain why some adolescents with high NEAT still presented with diabetes, indicating that lifestyle factors cannot fully counterbalance genetic risk.

From a public health standpoint, these findings highlight the need to promote daily movement and reduce sedentary behavior among adolescents. Evidence from a recent systematic review and network meta-analysis shows that increasing physical activity even at light to moderate intensity significantly reduces fasting insulin levels and improves insulin resistance in children and adolescents with excess weight. Given that adolescents spend considerable time in sedentary academic settings, NEAT-focused strategies such as increasing standing time, taking stairs, or incorporating brief

walking periods may serve as practical and sustainable alternatives to structured exercise programs (García-Hermoso *et al.*, 2023).

From a practical perspective, although this study highlights NEAT as a protective factor against poor glycemic status, its implications should be translated into concrete and actionable strategies, particularly within school environments. NEAT-enhancing activities for adolescents may include scheduled standing breaks during class sessions, promoting stair use instead of elevators, integrating short walking intervals between lessons, encouraging active recess, and reducing prolonged sitting time. These light-intensity movements are feasible, low-cost, and can be systematically incorporated into daily school routines, making NEAT a realistic health-promoting behavior rather than an abstract concept.

Within the salutogenic framework, NEAT can be classified as a GRR—a resource that enhances individuals' ability to maintain health despite stressors. NEAT contributes to metabolic resilience, enabling adolescents to better stabilize glucose levels through frequent light-intensity movement. This study's findings, which show a consistent protective effect of NEAT on glycemic status, reinforce the concept that NEAT is not merely a preventive activity but a health-promoting resource that moves adolescents toward the "ease" end of the health-disease continuum (Mittelmark *et al.*, 2017).

According to the salutogenic model, Sense of Coherence (SOC) comprising comprehensibility, manageability, and meaningfulness is central to how young individuals interpret and manage health-related challenges. Comprehensibility: NEAT involves simple, predictable daily actions (walking to class, climbing stairs), making health behavior easy to understand. Manageability: NEAT requires no complex skills or equipment, enabling adolescents to feel capable of managing their own health. Meaningfulness: NEAT cultivates a meaningful active lifestyle not merely avoiding disease, but engaging in purposeful movement that enhances well-being (Moksnes, 2021).

Overall, this study supports the integration of NEAT-enhancing activities into school health programs and youth lifestyle education as a low-cost,

accessible preventive measure against dysglycemia.

## CONCLUSION

Based on the results of the ordinal logistic regression analysis, this study concludes that a family history of diabetes is the strongest determinant of glycemic status among adolescents, significantly increasing the likelihood of progression to poorer glycemic categories. In contrast, NEAT demonstrates a consistent protective effect, indicating that higher levels of non-exercise daily movement reduce the risk of impaired glycemic status. Although the incremental effect per unit of NEAT is modest, the cumulative impact of sustained daily activity may contribute meaningfully to long-term metabolic health.

Rather than viewing NEAT solely as a disease-prevention strategy, these findings highlight its role as a positive health resource that adolescents can actively cultivate. Higher NEAT levels reflect greater self-efficacy and personal agency, whereby adolescents engage in simple daily actions—such as walking, standing, and light movement—to support their metabolic well-being. Such meaningful daily movement may strengthen adolescents' confidence in managing their bodies and promote a sustainable, health-enhancing lifestyle.

These findings underscore the importance of integrating NEAT-promoting behaviors, including walking, standing, and reduced sedentary time, into adolescent lifestyle interventions and school-based health programs. Given that adolescents spend substantial time in sedentary academic environments, NEAT-enhancing strategies offer feasible, low-cost, and sustainable approaches to preventing early dysglycemia. School environments that empower students to move throughout the day, rather than framing physical activity solely in terms of disease prevention, may better support long-term health development.

In conclusion, increasing NEAT should be regarded not only as a general recommendation but as a measurable and implementable strategy in adolescent health promotion. School-based interventions that encourage routine walking, standing activities, and reduced sedentary behavior may represent

practical approaches to improving glycemic well-being. Future intervention studies are needed to evaluate the effectiveness of structured NEAT-based programs in school settings and to establish clear benchmarks for daily NEAT engagement among adolescents. Additionally, longitudinal studies or those employing device-based NEAT measurements are recommended to further validate these associations.

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