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Sociodemographic and lifestyle determinants of insulin resistance scores in 273,154 Spanish workers: A cross-sectional analysis using TyG, METS-IR, and SPISE-IR

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Abstract

Objective: Insulin resistance (IR) is a pivotal factor in the pathophysiology of metabolic syndrome, type 2 diabetes mellitus, and cardiovascular disease. Surrogate indices such as the triglyceride-glucose (TyG) index, the metabolic score for insulin resistance (METS-IR), and the single-point insulin sensitivity estimator (SPISE-IR) offer non-invasive, cost-effective tools to assess IR in large populations. Our aim was to investigate the sociodemographic and lifestyle determinants of insulin resistance in a large occupational cohort of Spanish workers using TyG, METS-IR, and SPISE-IR indices, and to identify high-risk subgroups for targeted preventive strategies.

Materials and methods: A cross-sectional analysis was conducted on 273,154 Spanish workers (128,197 men and 144,957 women). Sociodemographic (sex, age, social class) and lifestyle variables (smoking, physical activity, Mediterranean diet adherence, alcohol consumption) were examined in relation to TyG, METS-IR, and SPISE-IR scores. Prevalence estimates, stratified mean comparisons, and multinomial logistic regression models were applied to assess independent associations.

Results: Men exhibited higher TyG and METS-IR scores and lower SPISE-IR scores than women. Insulin resistance increased with age and was more prevalent among individuals from lower social classes. Physically inactive individuals and those not adhering to a Mediterranean diet had markedly higher IR scores across all indices. Alcohol consumption and smoking were also associated with increased odds of insulin resistance, although patterns varied by sex. Multivariate models confirmed that male sex, older age, lower social class, unhealthy diet, inactivity, smoking, and alcohol use were independently associated with elevated IR scores.

Conclusion: This study highlights the utility of TyG, METS-IR, and SPISE-IR indices in detecting insulin resistance in working populations. Sociodemographic inequalities and modifiable lifestyle factors strongly influence IR profiles, supporting workplace health programs that promote physical activity, healthy eating, and behavioral change as strategies to reduce metabolic risk.

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Introduction

Insulin resistance (IR) is a central pathophysiological mechanism linking obesity, metabolic syndrome, and cardiovascular disease. It is characterized by reduced cellular responsiveness to insulin, resulting in compensatory hyperinsulinemia and downstream metabolic disturbances such as dysglycemia, dyslipidemia, and hepatic steatosis (1). IR precedes and predicts the development of type 2 diabetes mellitus (T2DM) and plays a major role in atherosclerosis and cardiometabolic risk (2).

Traditional assessment of IR through the hyperinsulinemic-euglycemic clamp is impractical in epidemiological or clinical settings due to its invasiveness and cost. Consequently, surrogate indices have been developed and validated. Among the most commonly used are the triglyceride-glucose (TyG) index, the metabolic score for insulin resistance (METS-IR), and the single-point insulin sensitivity estimator (SPISE-IR), all of which rely on readily available biochemical and anthropometric measures (3,4).

The TyG index, derived from fasting triglycerides and glucose, correlates well with clamp-derived measures and has been associated with cardiovascular events, NAFLD, and metabolic syndrome (5). METS-IR, which includes BMI, fasting glucose, HDL, and triglycerides, has demonstrated predictive validity for T2DM and mortality in large cohorts (6). SPISE-IR, initially developed for pediatric populations, combines HDL, triglycerides, and BMI, and has proven reliable in identifying insulin-sensitive versus insulin-resistant phenotypes (7).

Spain, like many Western countries, faces increasing prevalence of obesity, physical inactivity, and poor dietary habits—all of which contribute to metabolic dysfunction. Notably, studies have shown that these behavioral and social determinants play a crucial role in modulating IR beyond traditional biomedical risk factors (8). Occupational health settings provide a unique opportunity for large-scale risk screening, especially among working adults who may not regularly access primary care services.

Sociodemographic and lifestyle factors such as sex, age, social class, physical activity, diet, and alcohol consumption are well-documented modulators of insulin sensitivity (9,10). Men tend to have higher visceral fat and liver enzyme levels, contributing to greater IR than women (11). Increasing age is associated with a physiological decline in insulin sensitivity, which can be exacerbated by poor lifestyle choices (12). Lower social class has been repeatedly linked to increased metabolic risk, likely due to reduced access to healthcare, lower health literacy, and limited resources for healthy living (13).

Healthy behaviors, particularly adherence to the Mediterranean diet and regular physical activity, have been associated with better metabolic profiles and lower IR (14,15). Conversely, sedentary lifestyle, smoking, and excessive alcohol consumption negatively influence insulin action and lipid metabolism (16,17).

This study aimed to assess the distribution and determinants of IR using TyG, METS-IR, and SPISE-IR scores in a large, occupational cohort of over 270,000 Spanish workers. By analyzing these indices across sociodemographic strata and lifestyle categories, and stratifying by sex, we sought to identify high-risk subgroups for targeted intervention. The use of three complementary IR indices allows a more comprehensive and nuanced analysis, as each reflects different aspects of metabolic physiology. Our findings may inform occupational health policies and public health strategies aimed at early detection and prevention of insulin resistance-related conditions.

Materials and methods

Study design and population

This cross-sectional study was conducted using health surveillance data from a large cohort of Spanish workers. A total of 273,154 participants (128,197 men and 144,957 women) were included after undergoing routine occupational medical examinations between 2018 and 2022. These examinations are mandatory in Spain and follow standardized national protocols across all sectors and regions (18).

Inclusion criteria

Eligible individuals met the following criteria:

1. Age between 18 and 69 years.

2. Active employment at the time of assessment.

3. Complete occupational health examination, including biochemical, anthropometric, and clinical data.

4. Availability of validated fasting laboratory measures: glucose, triglycerides, and HDL-C.

5. Completion of a standardized lifestyle questionnaire covering physical activity, dietary habits, smoking, and alcohol use.

6. Provision of informed consent for the anonymized use of health data for research.

Participants were excluded if they had missing or biologically implausible values in any of the variables required to compute insulin resistance scores or if they failed to complete lifestyle questionnaires (**Figure 1**).

Data collection

Demographic variables included sex, age (categorized into five age bands), and occupational social class (classified as I, II, or III based on the Spanish National Classification of Occupations).

Anthropometric measures (weight, height, BMI, waist circumference) and blood pressure were obtained using calibrated equipment and standardized protocols (19). Biochemical analyses were performed on fasting blood samples in certified laboratories and included glucose, triglycerides, HDL-cholesterol, liver enzymes (AST, ALT, GGT), and creatinine.

Lifestyle habits were assessed using a structured and previously validated questionnaire (20). Physical activity was defined as engaging in regular moderate or vigorous activity. Adherence to the Mediterranean diet was evaluated using a short screener adapted from the PREDIMED study (21). Alcohol intake was quantified in units of alcohol (UA), with one UA corresponding to 10 grams of pure ethanol, as per Spanish guidelines. High alcohol consumption was defined as an intake of ≥14 UA per week for women and ≥21 UA per week for men (22).

Insulin resistance indices

Three surrogate indices were calculated:

- TyG index: ln (fasting triglycerides (mg/dL) × fasting glucose (mg/dL)/2), which has shown good agreement with the hyperinsulinemic-euglycemic clamp (23).

- METS-IR: ln ((2 × glucose) + triglycerides) × BMI / ln (HDL-C), validated in diverse populations and associated with cardiometabolic outcomes (24).

- SPISE: 600 × $HDL^{0.185}$ / ($triglycerides^{0.202}$ × $BMI^{0.368}$), originally designed for adolescents but recently validated in adults (25). SPISE-IR: 10/SPISE.

Each index was used as a continuous variable and dichotomized using sex-specific threshold values reported in previous epidemiological studies (26).

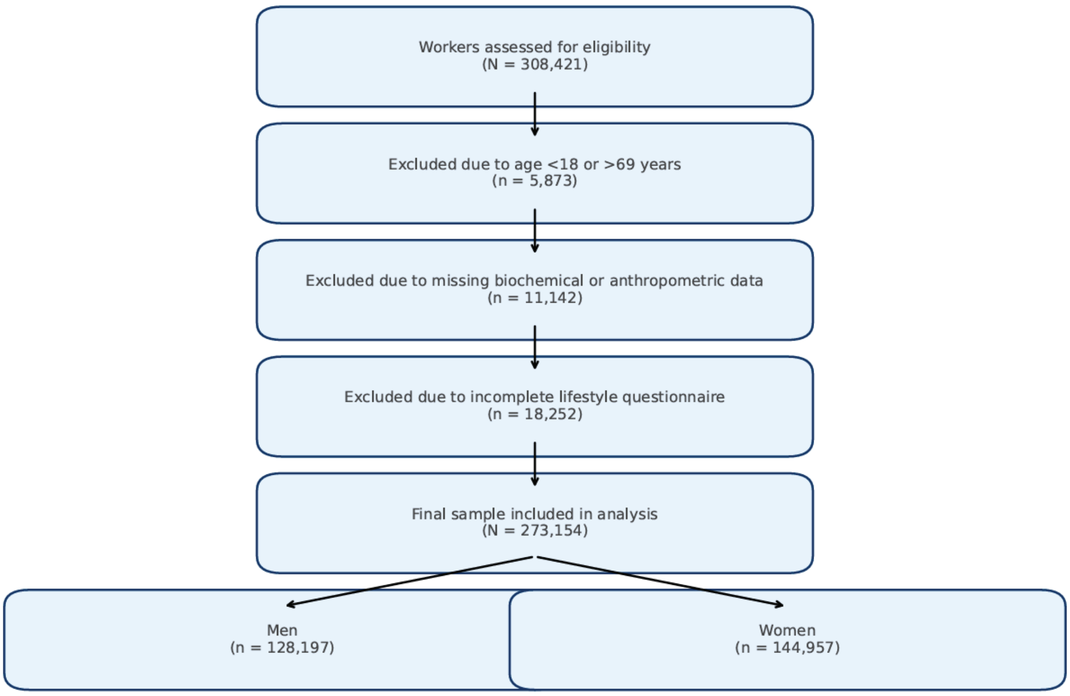

Figure 1: Flowchart of the participants

Statistical analysis

Descriptive statistics were computed to summarize participant characteristics. Mean values of TyG, METS-IR, and SPISE-IR were compared using Student's t-tests or one-way ANOVA. The prevalence of high insulin resistance, as defined by each index, was calculated across sociodemographic and lifestyle categories. Multinomial logistic regression models were used to examine the independent associations of sex, age, social class, smoking, physical activity, dietary habits, and alcohol use with the likelihood of presenting high insulin resistance. Odds ratios (ORs) and 95% confidence intervals (CIs) were reported. Analyses were conducted using SPSS (version 29). A two-sided p-value <0.05 was considered statistically significant.

Table 1: Sociodemographic, anthropometric, clinical, and biochemical characteristics of the study population by sex

	Men (n=128.197)	Women (n=144.957)	
	Mean (SD)	**Mean (SD)**	**p-value**
Age (years)	40.4 (11.2)	39.6 (10.9)	<0.001
Height (cm)	175.0 (6.9)	161.8 (6.5)	<0.001
Weight (kg)	81.7 (14.7)	66.0 (13.8)	<0.001
Body mass index (kg/m²)	26.6 (4.5)	25.2 (5.1)	<0.001
Waist (cm)	86.5 (11.1)	74.6 (10.5)	<0.001
Systolic blood pressure (mmHg)	127.8 (15.4)	117.4 (15.6)	<0.001
Diastolic blood pressure (mmHg)	77.6 (10.9)	72.5 (10.4)	<0.001
Total cholesterol (mg/dL)	192.3 (38.7)	190.6 (35.9)	<0.001
HDL-cholesterol (mg/dL)	50.4 (8.6)	56.8 (8.7)	<0.001
LDL-cholesterol (mg/dL)	117.8 (36.5)	116 (2 (34.9)	<0.001
Triglycerides (mg/dL)	123.6 (84.6)	88.6 (46.2)	<0.001
Glucose (mg/dL)	92.8 (21.1)	87.8 (15.0)	<0.001
AST (U/L)	30.7 (19.6)	20.3 (13.7)	<0.001
ALT (U/L)	24.5 (14.8)	18.2 (7.8)	<0.001
GGT (U/L)	34.6 (36.4)	20.4 (19.2)	<0.001
Creatinine (mg/L)	0.92 (0.18)	0.74 (0.14)	<0.001
	%	%	p-value
18-29 years	20.2	21.2	<0.001
30-39 years	26.5	29.1	
40-49 years	29.8	29.4	
50-59 years	19.6	17.0	
60-69 years	3.9	3.3	
Social class I	8.6	7.4	<0.001
Social class II	23.7	25.4	
Social class III	67.7	67.2	
Non-smokers	67.0	67.3	0.147
Smokers	33.0	32.8	
No, physical activity	60.4	50.4	<0.001
Yes, physical activity	39.6	49.6	
No, Mediterranean diet	65.0	53.9	<0.001
Yes, Mediterranean diet	35.0	46.1	
No, alcohol consumption	69.8	86.1	<0.001
Yes, alcohol consumption	30.2	13.9	

HDL High density lipoprotein. LDL Low density lipoprotein. AST aspartate transaminase. ALT alanine transaminase. GGT gamma-glutamyl transferase. SD Standard deviation.

Table 2: Mean values of TyG, METS-IR, and SPISE-IR indices according to sociodemographic and lifestyle variables by sex

		TyG	METS-IR	SPISE-IR
Men	**n**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
18-29 years	25.924	8.2 (0.5)	34.7 (7.4)	1.4 (0.4)
30-39 years	34.004	8.4 (0.6)	37.9 (7.7)	1.6 (0.5)
40-49 years	38.200	8.6 (0.6)	40.6 (8.4)	1.8 (0.5)
50-59 years	25.057	8.7 (0.6)	42.6 (8.4)	1.9 (0.5)
60-69 years	5.012	8.8 (0.6)	43.9 (8.2)	2.0 (0.5)
Social class I	11.091	8.4 (0.5)	38.5 (7.4)	1.6 (0.5)
Social class II	30.363	8.5 (0.6)	39.0 (7.8)	1.7 (0.5)
Social class III	86.743	8.5 (0.6)	39.3 (8.9)	1.7 (0.5)
Non-smokers	85.900	8.4 (0.6)	39.0 (8.5)	1.6 (0.5)
Smokers	42.297	8.5 (0.6)	39.3 (8.5)	1.7 (0.5)
No, physical activity	77.431	8.9 (0.5)	42.9 (8.3)	2.0 (0.5)
Yes, physical activity	50.766	8.0 (0.5)	35.5 (7.4)	1.4 (0.5)
No, Mediterranean diet	83.328	8.8 (0.5)	40.9 (8.1)	1.9 (0.5)
Yes, Mediterranean diet	44.869	8.1 (0.5)	37.1 (8.0)	1.5 (0.5)
No, alcohol consumption	89.482	8.1 (0.5)	38.0 (8.1)	1.5 (0.5)
Yes, alcohol consumption	38.715	8.7 (0.5)	40.7 (8.2)	1.8 (0.5)
Women	**n**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**
18-29 years	30.689	8.0 (0.4)	32.3 (7.6)	1.3 (0.4)
30-39 years	42.199	8.1 (0.4)	34.1 (8.2)	1.4 (0.5)
40-49 years	42.643	8.2 (0.5)	35.9 (8.3)	1.5 (0.5)
50-59 years	24.604	8.4 (0.5)	37.9 (8.3)	1.6 (0.5)
60-69 years	4.822	8.5 (0.5)	39.0 (8.1)	1.7 (0.5)
Social class I	10.706	8.0 (0.4)	32.7 (7.2)	1.3 (0.4)
Social class II	36.798	8.1 (0.5)	33.8 (7.7)	1.4 (0.5)
Social class III	97.453	8.2 (0.5)	35.8 (8.6)	1.5 (0.5)
Non-smokers	97.467	8.1 (0.5)	34.9 (8.3)	1.4 (0.5)
Smokers	47.490	8.2 (0.5)	35.2 (8.4)	1.5 (0.5)
No, physical activity	73.059	8.4 (0.5)	38.9 (8.0)	1.7 (0.5)
Yes, physical activity	71.898	7.7 (0.5)	31.2 (7.4)	1.0 (0.5)
No, Mediterranean diet	78.132	8.3 (0.5)	37.8 (8.0)	1.6 (0.5)
Yes, Mediterranean diet	66.825	7.8 (0.5)	32.2 (7.7)	1.1 (0.5)
No, alcohol consumption	124.808	8.3 (0.5)	33.6 (7.9)	1.2 (0.5)
Yes, alcohol consumption	20.149	7.9 (0.5)	37.0 (8.0)	1.6 (0.5)

TyG Triglyceride glucosa index. METS-IR Metabolic score for insulin resistance.

SPISE-IR Single point insulin sensitivity. SD Standard deviation.

Results

The table 1 summarizes the baseline characteristics of the study population, stratified by sex (128,197 men and 144,957 women). Statistically significant sex differences ($p<0.001$) are observed across nearly all variables.

• Men exhibit higher mean values for weight, height, BMI, waist circumference, systolic and diastolic blood pressure, glucose, triglycerides, and liver enzymes (AST, ALT, GGT), indicating a more adverse cardiometabolic profile.

• Women show higher HDL-cholesterol levels, which are protective against insulin resistance and cardiovascular disease, and lower creatinine and liver enzyme levels.

• Age distribution indicates slightly younger women.

• Women report more favorable lifestyle habits, including higher levels of physical activity, greater adherence to the Mediterranean diet, and markedly lower alcohol consumption.

• Smoking prevalence is similar between sexes, but men are more likely to be physically inactive and follow a non-Mediterranean diet.

The table 2 presents the mean values of the TyG, METS-IR, and SPISE-IR indices, stratified by age group, social class, and key lifestyle factors, in both men and women.

• Age-related trends are clear: TyG and METS-IR values increase progressively with age, while SPISE-IR declines, reflecting the well-known metabolic deterioration associated with aging in both sexes.

• Social class gradients are observed: individuals from lower classes (particularly Class III) have higher TyG and METS-IR and lower SPISE-IR, especially among women. This pattern indicates a higher burden of insulin resistance in more socioeconomically disadvantaged groups.

• Physical activity and adherence to the Mediterranean diet are consistently associated with favorable metabolic profiles: lower TyG and METS-IR, and higher SPISE-IR scores in both sexes.

• Smoking and alcohol consumption show more nuanced patterns. Smokers and alcohol consumers tend to have slightly worse scores, particularly in SPISE-IR, though the differences are not as marked as those related to physical activity or diet.

The table 3 reports the prevalence (%) of individuals classified as having high insulin resistance based on threshold values for each index. It provides a practical understanding of how different variables are associated with increased metabolic risk.

• Age shows the most striking association: the proportion of individuals with high TyG, METS-IR, and SPISE-IR scores (indicating lower insulin sensitivity) increases significantly with age in both sexes. For instance, 73.3% of men aged 60–69 years present with elevated SPISE-IR.

• Lower social class (Class III) is consistently associated with higher prevalence of elevated IR scores, confirming a socioeconomic gradient in metabolic risk.

• Physical activity and Mediterranean diet adherence are robustly protective. For example, only 18.2% of physically active men had high SPISE-IR, compared to 68.9% of inactive men. Similar patterns are observed in women.

• Alcohol and smoking are associated with a somewhat complex pattern. In men, alcohol consumers show higher prevalence of TyG and SPISE-IR alterations, while in women, non-abstainers have higher SPISE-IR but similar or lower TyG and METS-IR, suggesting possible sex-specific effects.

The table 4 summarizes the results of a multinomial logistic regression model assessing the independent associations of sex, age, social class, smoking status, physical activity, diet, and alcohol consumption with the probability of presenting high insulin resistance, as defined by the TyG, METS-IR, and SPISE-IR indices.

• Sex: Male sex was strongly and independently associated with higher odds of insulin resistance across all índices. These results are consistent with the more adverse cardiometabolic profile observed in men (Table 1), and reinforce the need for sex-specific strategies in prevention and screening.

• Age: There is a clear dose-response relationship between age and insulin resistance. Compared to the youngest group (18–29 years), individuals in the 60–69 group have dramatically increased odds of high IR. This confirms aging as a potent and independent determinant of insulin resistance, likely due to cumulative metabolic burden and body composition changes.

• Social Class: Both social class II and III were significantly associated with increased odds of IR, especially for METS-IR (Class III: OR = 1.87). This supports the socioeconomic gradient of metabolic risk, with lower classes showing higher vulnerability, possibly due to poorer diet, stress, and reduced access to health-promoting resources.

• Smoking: Smokers had modest but consistent increases in risk. These findings suggest that smoking independently contributes to metabolic dysregulation, possibly through inflammation, oxidative stress, and increased visceral adiposity.

• Physical Activity: The absence of regular physical activity emerged as one of the strongest modifiable risk factors, with ORs exceeding 5 for all índices. These associations highlight the profound protective role of physical activity on insulin sensitivity and underscore the critical importance of promoting exercise in workplace health programs.

• Mediterranean Diet: Not adhering to a Mediterranean dietary pattern was also robustly associated with higher odds of insulin resistance. This reinforces the well-documented anti-inflammatory and insulin-sensitizing effects of the Mediterranean diet and supports dietary counseling as a cornerstone of metabolic risk reduction.

• Alcohol Consumption: Surprisingly, alcohol consumption was associated with significantly higher odds of IR. While moderate alcohol intake has occasionally been linked to beneficial metabolic effects, these findings suggest that, in this working population, alcohol use (possibly not limited to moderate levels) is a consistent and independent risk factor for insulin resistance.

This regression model provides compelling evidence for the independent and additive effects of demographic, socioeconomic, and lifestyle factors on insulin resistance. The results support the use of TyG, METS-IR, and SPISE-IR as sensitive tools for risk stratification and the identification of vulnerable subpopulations. The findings point to several modifiable risk factors—particularly physical inactivity, poor diet, and alcohol use—that should be targeted in workplace and public health interventions to mitigate the risk of insulin resistance and related metabolic diseases.

Discussion

This large cross-sectional study among over 270,000 Spanish workers identified important associations between sociodemographic and lifestyle variables with insulin resistance, as measured by TyG, METS-IR, and SPISE-IR.

Men showed higher levels of TyG and METS-IR and lower SPISE-IR scores compared to women, consistent

Table 3: Prevalence of high insulin resistance scores (TyG, METS-IR, and SPISE-IR) by sociodemographic and lifestyle characteristics in men and women

		TyG high	METS-IR high	SPISE-IR high
Men	**n**	**%**	**%**	**%**
18-29 years	25.924	10.7	4.7	23.8
30-39 years	34.004	21.3	7.6	41.3
40-49 years	38.200	31.9	13.1	56.5
50-59 years	25.057	40.6	17.8	66.6
60-69 years	5.012	47.4	21.3	73.3
Social class I	11.091	23.9	8.1	45.4
Social class II	30.363	26.0	9.4	48.5
Social class III	86.743	27.9	12.2	48.9
Non-smokers	85.900	27.0	11.2	47.7
Smokers	42.297	27.4	11.5	48.9
No, physical activity	77.431	37.8	19.3	68.9
Yes, physical activity	50.766	8.5	7.2	18.2
No, Mediterranean diet	83.328	33.5	18.4	64.2
Yes, Mediterranean diet	44.869	10.9	8.8	22.7
No, alcohol consumption	89.482	12.5	17.3	60.2
Yes, alcohol consumption	38.715	30.6	9.5	26.4
Women	**n**	**%**	**%**	**%**
18-29 years	30.689	6.2	3.7	17.3
30-39 years	42.199	8.2	5.4	23.2
40-49 years	42.643	12.8	7.0	31.2
50-59 years	24.604	23.0	8.7	41.9
60-69 years	4.822	28.9	9.8	48.5
Social class I	10.706	7.9	3.2	18.0
Social class II	36.798	11.0	4.5	22.3
Social class III	97.453	13.3	7.2	31.7
Non-smokers	97.467	12.3	6.0	27.7
Smokers	47.490	12.6	6.3	28.6
No, physical activity	73.059	22.8	8.9	49.5
Yes, physical activity	71.898	8.1	4.2	15.3
No, Mediterranean diet	78.132	20.6	8.5	46.6
Yes, Mediterranean diet	66.825	10.3	4.9	18.9
No, alcohol consumption	124.808	11.8	8.0	43.8
Yes, alcohol consumption	20.149	19.8	5.7	22.2

TyG Triglyceride glucosa index. METS-IR Metabolic score for insulin resistance. SPISE-IR Single point insulin sensitivity.

Table 4: Multinomial logistic regression for high insulin resistance scores

	TyG high	METS-IR high	SPISE-IR high
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Female	1	1	1
Male	3.19 (3.14-3.25)	1.88 (1.83-1.93)	2.45 (2.41-2.50)
18-29 years	1	1	1
30-39 years	1.37 (1.31-1.44)	1.20 (1.13-1.28)	1.32 (1.26-1.38)
40-49 years	2.34 (2.24-2.44)	1.62 (1.53-1.72)	2.02 (1.94-2.11)
50-59 years	3.86 (3.69-4.03)	2.58 (2.42-2.74)	3.39 (3.25-3.54)
60-69 years	6.96 (6.64-7.29)	4.36 (4.07-4.67)	6.56 (6.27-6.86)
Social class I	1	1	1
Social class II	1.18 (1.16-1.21)	1.55 (1.50-1.60)	1.39 (1.36-1.42)
Social class III	1.35 (1.31-1.40)	1.87 (1.76-1.98)	1.57 (1.52-1.62)
Non-smokers	1	1	1
Smokers	1.12 (1.10-1.15)	1.20 (1.16-1.24)	1.13(1.10-1.16)
No, physical activity	1	1	1
Yes, physical activity	6.28 (6.07-6.50)	5.88 (5.47-6.30)	5.23 (5.01-5.46)
No, Mediterranean diet	1	1	1
Yes, Mediterranean diet	3.83 (3.65-4.02)	4.09 (3.80-4.39)	3.34 (3.15-3.54)
No, alcohol consumption	1	1	1
Yes, alcohol consumption	2.98 (2.87-3.09)	2.75 (2.59-2.92)	2.69 (2.58-2.80)

TyG Triglyceride glucosa index. METS-IR Metabolic score for insulin resistance. SPISE-IR

Single point insulin sensitivity. OR: Odds ratio

with previous evidence of sex-related differences in visceral adiposity, liver enzymes, and metabolic risk (27). As expected, IR worsened with increasing age, reinforcing the known age-related decline in insulin sensitivity (28).

Social class was inversely associated with insulin sensitivity. Workers from lower socioeconomic backgrounds presented with more adverse IR profiles, which aligns with studies reporting that educational and economic disadvantage limits access to healthy food, physical activity opportunities, and healthcare services (29).

Lifestyle behaviors showed strong associations with IR scores. Physically active individuals had better metabolic profiles across all indices, supporting evidence that exercise improves insulin sensitivity and reduces triglyceride accumulation (30). Adherence to the Mediterranean diet was also associated with more favorable TyG, METS-IR, and SPISE-IR values, supporting its recognized role in cardiometabolic health (31).

Smoking and alcohol consumption exhibited divergent associations. Although moderate alcohol intake may confer some metabolic benefit, high consumption has been associated with elevated IR, particularly among men (32). Smoking was generally associated with worse IR indices, likely due to increased oxidative stress and central adiposity (33).

Our use of three validated surrogate indices offers a comprehensive view of metabolic dysfunction. METS-IR, in particular, was sensitive to differences across age, sex, and lifestyle strata, and has recently been linked to higher cardiovascular and all-cause mortality (34). SPISE-IR, although originally developed in younger populations, proved robust in capturing favorable metabolic profiles in adults (35).

The main strengths of our study include the very large sample size, stratified analysis by sex, and comprehensive assessment of lifestyle and clinical variables. However, limitations include its cross-sectional nature, precluding causal inference, and reliance on self-reported lifestyle data. Also, while TyG, METS-IR, and SPISE-IR are validated, they remain surrogate measures and may not fully capture all aspects of insulin signaling.

Despite these limitations, our findings underscore the value of integrating simple, cost-effective IR screening tools in occupational settings, where early identification of at-risk individuals may lead to effective prevention strategies. Longitudinal studies are warranted to confirm our findings and assess clinical outcomes.

Conclusions

This large-scale cross-sectional study demonstrates the substantial impact of sociodemographic and lifestyle factors on insulin resistance in a working population. The use of three validated surrogate indices—TyG, METS-IR, and SPISE-IR—allowed a robust and multidimensional assessment of metabolic risk.

Key findings include the significantly higher insulin resistance observed in men, older individuals, and those from lower social classes. Unhealthy lifestyle behaviors, particularly physical inactivity and non-adherence to the Mediterranean diet, were among the most influential and modifiable risk factors. Alcohol consumption and smoking were also independently associated with increased insulin resistance, although their effects varied by sex.

The consistency of these associations across different IR indices supports their integration into occupational health screening to identify high-risk subgroups. Importantly, the results advocate for comprehensive workplace-based interventions that promote physical activity, healthy dietary patterns, and behavioral changes to mitigate the burden of insulin resistance and related conditions such as type 2 diabetes and cardiovascular disease.

Future longitudinal studies are needed to evaluate the predictive validity of these indices in relation to clinical outcomes and to establish causal pathways. Nonetheless, these findings underscore the relevance of targeting social and behavioral determinants in the prevention of metabolic diseases in working populations.

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Ethical approval: The investigation complied with all applicable national and international ethical standards for research involving human participants, including those established in the Declaration of Helsinki. Special care was taken to maintain participant confidentiality and data privacy. Ethical clearance was granted by the Research Ethics Committee of the Balearic Islands (CEI-IB), under approval number IB 4383/20, on 26 November 2020. Participation was entirely voluntary. All individuals were clearly informed about the study's objectives and provided written and oral consent after reviewing an information sheet and a consent form. To ensure confidentiality, data were anonymized through coding procedures, and only the study coordinator retained access to the identification key. At no point will identifiable personal information be included in study outputs, nor will it be shared with third parties. Participants retain full rights under data protection legislation to access, correct, erase, or restrict processing of their personal data. The study was conducted in accordance with Organic Law 3/2018 of December 5, which governs the protection of personal data and digital rights in Spain.

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Contributions

Research concept and design: AALG

Data analysis and interpretation: ACRA, VOM

Collection and/or assembly of data: MTBOO, ACRA

Writing the article: ACRA, VOM, MTBOO

Critical revision of the article: AALG

Final approval of the article: ACRA, VOM, MTBOO, AALG

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