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Gender Differences in Physical Activity, Sedentary Behaviour and Obesity among Adults in Benghazi, Derna and Al Bayda, Libya: The Moderating Role of Socioeconomic and Demographic Characteristics

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الاختلافات بين الجنسين في النشاط البدني والسلوك المستقر والسمنة بين البالغين في بنغازي ودرنة والبيضاء، ليبيا: الدور المعتدل للخصائص الاجتماعية والاقتصادية والديموغرافية

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Abstract:

Background/Objectives: Overweight, obesity, physical inactivity and sedentary behaviour are important public-health concerns in Libya, with substantial differences between women and men. However, multi-city evidence examining whether gender and socioeconomic characteristics modify the relationships between movement-related behaviours and adiposity remains limited. This study estimated BMI-defined overweight/obesity and insufficient physical activity and examined the associations of physical activity (PA) and sedentary behaviour (SB) with adiposity among Libyan adults in Benghazi, Derna, and Al Bayda, with particular attention to gender and socioeconomic/demographic moderation. Methods: A cross-sectional online survey included 2,000 Libyan adults aged 20–65 years recruited using a city-stratified, quota-based non-probability strategy. Participants completed a self-administered Arabic Microsoft Forms questionnaire incorporating the WHO Global Physical Activity Questionnaire. PA was expressed as MET-minutes/week, insufficient activity as <600 MET-min/week, and SB as daily sitting/reclining time. BMI was calculated from self-reported height and weight. Multivariable linear regression examined continuous BMI, while modified Poisson regression with robust variance estimates adjusted prevalence ratios (aPRs) for BMI-defined overweight/obesity. Gender and socioeconomic/demographic moderation were examined using prespecified interaction terms. Results: Overall, 72.4% had overweight/obesity and 39.2% had obesity; prevalence of overweight/obesity was higher among women than men (79.2% vs. 65.0%). Insufficient PA affected 42.0% overall and was more frequent among women. Higher PA was inversely associated with BMI ($\beta = -0.18$, $p < 0.001$), while greater SB was positively associated with BMI ($\beta = 0.21$, $p < 0.001$). Insufficient PA was associated with higher overweight/obesity prevalence (aPR = 1.19, 95% CI 1.13–1.25), while each additional sedentary hour/day was associated with aPR = 1.07 (95% CI 1.05–1.09). PA × gender ($p = 0.006$) and SB × gender ($p = 0.002$) interactions indicated stronger associations among women. Education, household income, and age significantly moderated these relationships, whereas employment and marital status did not. Conclusion: Overweight/obesity and insufficient physical activity were common in this three-city Libyan online sample. Movement-related behaviours were associated with adiposity, with stronger associations among women and evidence that education, income and age further conditioned these relationships. The findings support gender-responsive and socioeconomically sensitive obesity-prevention planning, while the cross-sectional, self-reported and non-probability design precludes causal or population-representative interpretation.

Keywords: Obesity; physical activity; sedentary behaviour; gender differences; Libya

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الملخص

الخلفية/الأهداف: تُعد زيادة الوزن والسمنة وقلة النشاط البدني والسلوك الخامل من التحديات المهمة للصحة العامة في ليبيا، مع وجود فروق واضحة بين النساء والرجال. ومع ذلك، لا تزال الأدلة متعددة المدن حول ما إذا كان الجنس والخصائص الاجتماعية والاقتصادية تعدل العلاقة بين السلوكيات المرتبطة بالحركة والسمنة محدودة. هدفت هذه الدراسة إلى تقدير انتشار زيادة الوزن/السمنة المحددة بمؤشر كتلة الجسم وعدم كفاية النشاط البدني، وفحص ارتباط النشاط البدني والسلوك الخامل بالسمنة لدى البالغين الليبيين في بنغازي ودرنة والبيضاء، مع التركيز على دور الجنس والعوامل الاجتماعية والاقتصادية والديموغرافية كعوامل معدِّلة. **الطرق:** شملت هذه الدراسة المقطعية الإلكترونية 2000 بالغ ليبي تتراوح أعمارهم بين 20 و65 سنة، جرى استقطابهم باستخدام استراتيجية إلكترونية غير احتمالية قائمة على التقسيم حسب المدينة والحصص المحددة. أكمل المشاركون استبياناً عربياً ذاتيّاً عبر Microsoft Forms تضمن الاستبيان العالمي للنشاط البدني التابع لمنظمة الصحة العالمية (GPAQ). عُبّر عن النشاط البدني بوحدة MET-دقيقة/أسبوع، وصُنّف النشاط غير الكافي بأنه أقل من 600 MET-دقيقة/أسبوع، بينما قيس السلوك الخامل بمتوسط وقت الجلوس/الاستلقاء يومياً. حُسب مؤشر كتلة الجسم من الطول والوزن المبلغ عنهما ذاتياً. استُخدم الانحدار الخطي متعدد المتغيرات لتحليل مؤشر كتلة الجسم المستمر، والانحدار المعدل لبواسون بتباين قوي لتقدير نسب الانتشار المعدلة (aPR)، مع اختبار تفاعلات الجنس والعوامل الاجتماعية والاقتصادية والديموغرافية.

النتائج: بلغت نسبة زيادة الوزن/السمنة 72.4%، والسمنة 39.2%، وكانت زيادة الوزن/السمنة أعلى لدى النساء مقارنة بالرجال (79.2% مقابل 65.0%). وبلغت نسبة عدم كفاية النشاط البدني 42.0%، وكانت أعلى لدى النساء. ارتبط ارتفاع النشاط البدني بانخفاض مؤشر كتلة الجسم (β = −0.18، $p < 0.001$)، بينما ارتبطت زيادة السلوك الخامل بارتفاعه (β = 0.21، $p < 0.001$). وارتبط عدم كفاية النشاط البدني بارتفاع انتشار زيادة الوزن/السمنة (aPR = 1.19، 95% CI: 1.13–1.25)، كما ارتبطت كل ساعة إضافية من السلوك الخامل يومياً بارتفاع الانتشار (aPR = 1.07، 95% CI: 1.05–1.09). وأظهرت تفاعلات النشاط البدني × الجنس ($p = 0.006$) والسلوك الخامل × الجنس ($p = 0.002$) أن الارتباطات كانت أقوى لدى النساء. كما عدّلت مستويات التعليم والدخل الأسري والعمر هذه العلاقات بصورة دالة إحصائياً، في حين لم يظهر العمل أو الحالة الاجتماعية تأثيراً معدِّلاً. **الاستنتاج:** كانت زيادة الوزن/السمنة وعدم كفاية النشاط البدني شائعتين في العينة الإلكترونية المأخوذة من المدن الليبية الثلاث. وارتبطت السلوكيات المرتبطة بالحركة بالسمنة، وكانت هذه الارتباطات أقوى لدى النساء، كما تأثرت بمستوى التعليم والدخل والعمر. تدعم النتائج تطوير استراتيجيات للوقاية من السمنة تراعي الفروق بين الجنسين والظروف الاجتماعية والاقتصادية، مع ضرورة الحذر في تفسيرها سببياً أو تعميمها على السكان بسبب التصميم المقطعي والاعتماد على البيانات المبلغ عنها ذاتياً والاستقطاب غير الاحتمالي.

الكلمات المفتاحية: السمنة؛ النشاط البدني؛ السلوك الخامل؛ الفروق بين الجنسين؛ ليبيا

1. Introduction

Obesity is a chronic, relapsing, and multifactorial disease arising from complex interactions between biological, behavioural, social, and environmental influences [1]. Globally, obesity has become an increasingly important public-health challenge, with 43% of adults classified as overweight and 16% as living with obesity in 2022 [1]. Adult obesity prevalence has more than doubled since 1990, indicating that excess body weight cannot adequately be understood solely in terms of individual dietary choices or biological susceptibility [1]. Patterns of physical activity, sedentary behaviour, socioeconomic circumstances, social and cultural norms, and characteristics of the physical environment may interact to influence energy balance and subsequent weight status. Within this broader context, physical inactivity and sedentary behaviour have increasingly been recognised as potentially important behavioural correlates of overweight and obesity, although they represent conceptually distinct behaviours and may influence adiposity through different pathways. The burden is particularly important in Libya. The most recent national WHO STEPS survey conducted during 2022–2023 reported that 56.8% of Libyan adults were overweight and 28.9% were living with obesity. Importantly, a marked gender difference was observed: obesity prevalence was 36.3% among women compared with 22.0% among men, while overweight affected 62.0% of women and 51.9% of men [2]. These contemporary national estimates are consistent with earlier empirical evidence from Benghazi, where 75.3% of adults were classified as overweight or obese and obesity prevalence was 42.4%. In that study, obesity affected 47.4% of women compared with 33.8% of men [3]. Although these estimates originate from different periods and populations and should therefore not be interpreted as directly comparable secular estimates, their broadly consistent gender pattern provides a strong rationale for examining women and men separately rather than treating gender simply as an adjustment variable. Physical activity (PA) encompasses movement undertaken across several domains of daily life, including occupational activity, household activities, active transportation, recreation, leisure and exercise [4]. WHO defines physical activity as any bodily movement produced by skeletal muscles that requires energy expenditure and emphasises that activity undertaken during work, transport, domestic activities and leisure contributes to total physical activity [5]. Globally, approximately 31% of adults do not currently achieve recommended levels of physical activity [5]. Adults should undertake at least 150 minutes of moderate-intensity physical activity per week, while WHO also emphasises that any amount of activity is preferable to none and that all movement contributes to health [5]. Physical inactivity is also highly prevalent in Libya and shows an even clearer gender gap. The 2022–2023 WHO STEPS survey estimated that 45.3% of Libyan adults had insufficient physical activity, comprising 57.8% of women compared with 32.9% of men [2]. This difference is consistent with earlier regional evidence suggesting that women in Arab and Eastern Mediterranean settings frequently encounter greater barriers to participation in physical activity than men [6–10]. The coexistence of substantially higher physical inactivity and obesity prevalence among Libyan women provides a particularly important empirical basis for investigating whether the association between movement behaviours and adiposity differs according to gender rather than assuming a common association for both sexes. Regular physical activity may contribute to the prevention of excessive weight gain by increasing energy expenditure, supporting the maintenance of lean body mass and improving metabolic regulation. Conversely, insufficient physical activity could contribute to positive energy balance and increased adiposity when energy intake persistently exceeds expenditure. Epidemiological research from developed and developing countries has generally demonstrated an inverse association between physical activity and overweight or obesity, although the magnitude and consistency of this relationship have varied according to population, sex, measurement method and physical-activity domain [11–16]. Current WHO evidence further identifies regular physical activity as beneficial for body-fat measures and for the prevention and management of major non-communicable diseases [5]. Greater habitual activity may therefore be associated with a lower probability of excess adiposity, although the cross-sectional design of the present study would not establish temporal or causal relationships. Men and women in the Eastern Mediterranean Region may experience different barriers to engaging in physical activity. At the individual level, such barriers have included limited time and financial resources, tiredness, existing health conditions and concerns regarding injury [17–20]. At the sociocultural level, gender roles, domestic and caregiving responsibilities, expectations regarding appropriate recreational activities and culturally acceptable exercise environments may particularly constrain women's opportunities for leisure-time activity [8,21,10]. Environmental barriers can additionally include hot weather, limited availability of local exercise facilities, inadequate recreational infrastructure and distance between residential areas and opportunities for organised exercise [22,8,10]. Evidence from contemporary Libyan populations supports the relevance of examining these behaviours through a gender-sensitive perspective. Among Tobruk University students, 50.0% were classified as overweight or obese, with prevalence reaching 56.4% among female students compared with 42.2% among male students [23]. The authors also identified sedentary lifestyles and comparatively low physical activity as important components of the university lifestyle environment and argued that cultural, behavioural and environmental influences may differ between genders. Although university students represent a younger and more specific population than the adults examined in the present study, the direction of this gender difference adds to the justification for formally investigating gender-related heterogeneity. Sedentary behaviour (SB) represents a related but distinct component of lifestyle and should not be interpreted simply as the absence of physical activity. WHO defines sedentary behaviour as waking behaviour characterised by low energy expenditure while sitting, reclining or lying, and identifies increasing reliance on motorised transport and screen-based activities for employment, education and recreation as important contributors to contemporary sedentary lifestyles [5]. Sedentary behaviour may therefore include sitting during work, travelling by motorised transport, television viewing, computer use, reading and other prolonged periods of low-energy expenditure [24,25]. An individual may meet recommended amounts of moderate- or vigorous-intensity physical activity while simultaneously accumulating substantial sedentary time throughout the remainder of the day. Physical activity and sedentary behaviour should therefore be investigated as related but separate behavioural exposures. Numerous epidemiological studies have reported associations between prolonged sedentary behaviour and obesity, including associations that remain after consideration of leisure-time physical activity and dietary behaviour [11,26–29,25]. Nevertheless, earlier findings have not been completely consistent, with some prospective research reporting weaker relationships between specific sedentary behaviours such as television viewing and BMI [30]. Recent Libyan research provides additional context for these relationships. Among pregnant women attending public antenatal services across six Eastern Libyan cities, 60.6% were classified as having BMI-defined overweight or obesity at antenatal assessment, and greater physical inactivity and sedentary lifestyle were associated with greater pregnancy-period adiposity [31]. Because pregnancy alters body weight and composition, this prevalence cannot be directly compared with estimates from non-pregnant adults; nevertheless, the study provides contemporary Libyan evidence that movement-related behaviours and socioeconomic circumstances may operate together rather than as isolated correlates.

The need for context-specific investigation may be particularly important in Libya. Lifestyle patterns have been influenced by urbanisation, increasing reliance on motorised transportation, changing occupational structures and the availability of physically undemanding forms of recreation. These changes could reduce habitual energy expenditure while simultaneously increasing sedentary time. Previous research among Libyan adults has identified a substantial burden of overweight and obesity and has suggested that environmental and lifestyle characteristics may contribute to this pattern [32,3]. WHO identifies obesity as being shaped partly by environments that restrict opportunities for affordable healthy eating and regular physical activity and emphasises that individual behaviours operate within broader social and environmental conditions [1]. This principle is particularly relevant to Libya because physical activity opportunities may depend upon accessibility of recreational spaces, transportation arrangements, socioeconomic resources, occupational circumstances and culturally patterned gender roles. The problem is therefore not merely that obesity and physical inactivity are prevalent in Libya, but that both show pronounced gender inequalities. Contemporary national evidence indicates that women have a higher prevalence of both obesity and insufficient physical activity than men [2]. Earlier Benghazi evidence similarly reported higher obesity prevalence among women [3], while recent evidence among Tobruk University students demonstrates the same direction of gender difference in overweight and obesity [23]. These findings suggest that combining men and women within a single overall association could conceal meaningful differences in how behavioural and contextual factors are related to adiposity. A further limitation of the Libyan literature is that physical activity and sedentary behaviour have seldom been investigated simultaneously as conceptually distinct correlates of adiposity. Measurement of low physical activity does not necessarily indicate the amount of sedentary time accumulated, while a highly sedentary person may nevertheless meet recommended amounts of structured physical activity. Investigating both behaviours could therefore provide a more informative representation of movement-related exposure than considering either one alone. There is also reason to expect these relationships to vary according to socioeconomic and demographic position. Contemporary research among pregnant women in Eastern Libya found that socioeconomic disadvantage, particularly lower educational attainment and lower household income, was associated with a greater prevalence of overweight or obesity [31]. Libyan qualitative evidence further indicates that health-related behaviours and dietary counselling are experienced within cultural, socioeconomic and resource constraints, including family expectations, affordability and limited healthcare resources [33]. Similarly, previous research among Libyan adults has demonstrated that unhealthy dietary behaviours associated with obesity differ between men and women, reinforcing the possibility that behavioural influences may be socially patterned rather than uniform across the population [34]. Accordingly, socioeconomic characteristics such as education, income and occupational position, together with demographic characteristics such as age and marital status, may not merely function as confounders. They could modify the strength or direction of the relationship between movement behaviours and adiposity. Gender itself may operate as an important effect modifier because men and women may experience different occupational activity, transport patterns, domestic responsibilities, recreational opportunities and sociocultural constraints. Testing these interactions would therefore extend the original analysis from asking whether physical activity and sedentary behaviour are associated with obesity to asking for whom and under which socioeconomic and demographic circumstances those associations are strongest. The main aim of this study is to examine gender differences in the associations between physical activity, sedentary behaviour and adiposity among Libyan adults residing in Benghazi, Derna and Al Bayda. More specifically, the study seeks to describe gender-specific patterns of obesity, physical activity and sedentary behaviour; examine the associations of physical activity and sedentary behaviour with BMI-defined adiposity; determine whether these associations differ between men and women; and assess whether socioeconomic and demographic characteristics modify the relationships between movement-related behaviours and adiposity. Physical activity and sedentary behaviour are treated as related but conceptually distinct exposures, while BMI is retained as the principal epidemiological indicator of overweight and obesity. Because the study is cross-sectional, all observed relationships are interpreted as associations rather than evidence of causal or temporal pathways. The study contributes to obesity research in Libya by providing context-specific evidence on movement behaviours and adiposity in an adult population for which such evidence remains limited. Its principal contribution lies in moving beyond descriptive gender differences to formally examine whether gender modifies the relationships between physical activity, sedentary behaviour and adiposity. This is particularly relevant because previous Libyan evidence has consistently shown higher obesity prevalence among women than men, while national surveillance has also documented substantially greater insufficient physical activity among women [2,3,23]. The study further extends existing research by examining socioeconomic and demographic moderation, including education, income, occupational status, age and marital status, rather than treating these characteristics solely as adjustment variables. Such analysis may identify population groups in whom behavioural associations are stronger or weaker. This approach is consistent with WHO guidance emphasising that obesity and physical activity should not be understood solely through individual responsibility because opportunities for healthy behaviour are shaped by wider social, cultural, environmental and economic circumstances [5,1].

2. Theoretical Framework

The **Social Ecological Model (SEM)** provides the theoretical framework for this study. Emerging from Bronfenbrenner's ecological systems perspective, the SEM proposes that health behaviours and outcomes are shaped through interactions between individuals and the multiple social and environmental contexts within which they live [35,36]. It has subsequently been widely applied in public-health and health-promotion research to conceptualise influences operating at individual, interpersonal, organisational, community and societal levels [37–39]. This multilevel perspective is particularly appropriate for obesity because adiposity is unlikely to reflect a single behavioural exposure. Physical activity, sedentary behaviour, gender, family and social norms, socioeconomic resources, occupational circumstances, transport systems, recreational opportunities and the wider environment may operate simultaneously. This interpretation is consistent with WHO's contemporary view of obesity as a multifactorial condition shaped by biological, behavioural, environmental and societal influences, while opportunities for physical activity are themselves conditioned by social, cultural, environmental and economic circumstances [5,1].

Within the present study, physical activity and sedentary behaviour are conceptualised as relatively proximal behavioural exposures, whereas gender and socioeconomic and demographic characteristics represent broader contextual influences that may alter their relationships with adiposity. Education and household income may shape access to health information, transport, recreational resources and opportunities for organised exercise, while occupation may influence both movement and prolonged sitting. Genders may additionally interact with these circumstances through differences in employment, domestic responsibilities, culturally acceptable recreation and access to exercise environments. Libyan evidence supports this interpretation: socioeconomic disadvantage has been associated with greater adiposity in Eastern Libya [31], while dietary and health behaviours have been described as influenced by affordability, cultural expectations, family circumstances and healthcare resources [33]. Previous Libyan research has also identified gender-patterned behavioural associations with obesity [34]. Accordingly, the first two hypotheses are: *H1: Physical activity and sedentary behaviour will be significantly associated with adiposity among Libyan adults, such that higher physical activity will be associated with lower adiposity, whereas greater sedentary behaviour will be associated with higher adiposity. H2: Gender will significantly moderate these associations, such that their magnitude will differ between Libyan men and women.* These propositions are additionally supported by evidence that physical activity and sedentary behaviour are distinct exposures associated with adiposity [11,12,25–28] and by documented Libyan gender differences in obesity and physical inactivity [2,3,23].

The SEM also provides the rationale for examining whether socioeconomic and demographic circumstances modify these behavioural associations. Education, income, occupational position, age and marital status may influence access to resources, transport, recreational opportunities and health information, meaning that the relationship between movement behaviour and adiposity may not be uniform across population groups [31,33,34]. Consequently, *H3: Socioeconomic and demographic* characteristics will significantly moderate the associations of physical activity and sedentary behaviour with adiposity, with the pattern and magnitude of these moderating relationships differing between Libyan men and women. The three hypotheses therefore correspond directly to the study's analytical structure: the overall behavioural association, gender-based effect modification and socioeconomic/demographic moderation. Importantly, the SEM is used as an organising and interpretative framework rather than a formally tested causal model. Because the study is cross-sectional, the proposed relationships are interpreted as associations and effect modification rather than causal or temporal pathways (Figre1).

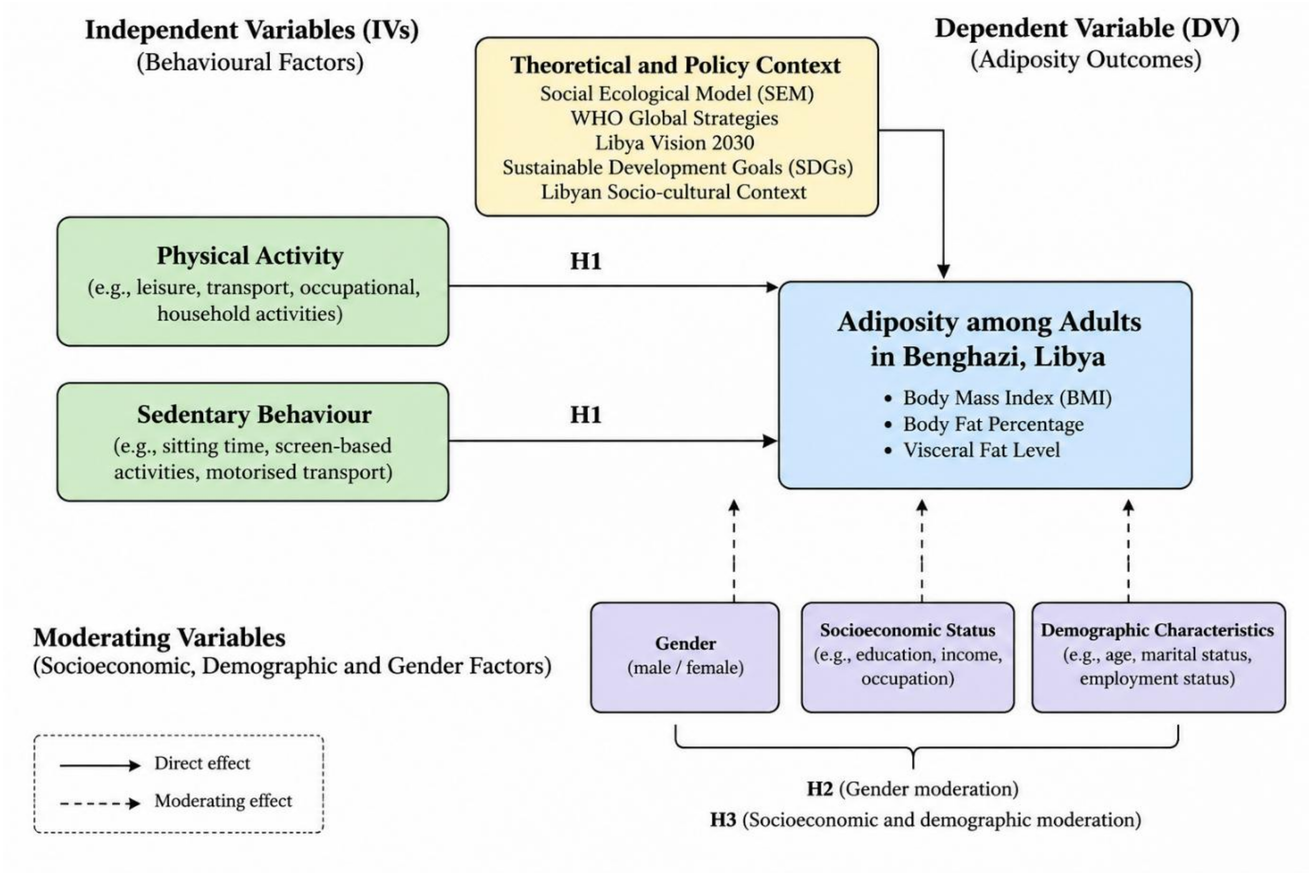

Figure 1. Conceptual Framework of the Relationships Between Physical Activity, Sedentary Behaviour and Adiposity Among Libyan Adults, Including Gender, Socioeconomic and Demographic Moderation

2. Materials and Methods

2.1. Study Design and Population

A quantitative **cross-sectional online survey** was conducted to estimate the prevalence of BMI-defined overweight/obesity and insufficient physical activity and to examine associations between physical activity, sedentary behaviour and adiposity among Libyan adults. Cross-sectional studies are appropriate for estimating prevalence and assessing concurrent relationships between outcomes and behavioural, demographic and socioeconomic exposures within defined populations [40–42]. Because exposures and outcomes were assessed at the same point in time, all findings were interpreted as associations rather than causal relationships.

The study involved adults residing in Benghazi, Derna and Al Bayda in Eastern Libya. Data was collected electronically using an Arabic-language questionnaire administered through Microsoft Forms. Online administration facilitated standardised recruitment across geographically separated populations, reduced manual data-entry requirements and enabled efficient collection of a large dataset [43,44]. Nevertheless, the potential for self-selection, internet-access inequalities and differential non-response inherent in online surveys was considered when interpreting external validity.
Eligible participants were Libyan men and women aged 20–65 years, currently resident in one of the three participating cities, able to understand Arabic and complete the electronic questionnaire, and willing to provide electronic informed consent. The age range-maintained comparability with previous Libyan adult obesity research [34]. Pregnant women were excluded because pregnancy-related physiological weight gain limits interpretation of conventional adult BMI categories. Submissions were additionally excluded when eligibility criteria were not met, consent was not provided, substantial questionnaire data were incomplete, or duplicate or biologically implausible records were identified.

22. Sampling Strategy and Sample Size

A **city-stratified, quota-based online recruitment strategy** was applied. Benghazi, Derna and Al Bayda constituted predefined geographical strata. The target sample comprised **2,000 adults**, distributed as 1,000 participants from Benghazi and 500 each from Derna and Al Bayda.

City	Target sample, n	Allocation
Benghazi	1,000	50.0%
Derna	500	25.0%
Al Bayda	500	25.0%
Total	**2,000**	**100%**

The larger Benghazi allocation reflected its larger urban population and increased the observations available for gender- and subgroup-specific analyses. Because recruitment occurred electronically without a complete individual sampling frame or known selection probabilities, the strategy was not considered probability cluster sampling. The resulting pooled estimates therefore characterise the recruited three-city sample rather than population-weighted prevalence for all adults in Eastern Libya (Figure 2).

The initial minimum sample requirement was estimated using the single-proportion formula with **95% confidence, 50% expected prevalence and a 5% margin of error**, yielding approximately 384 participants [45,46]. The target was increased to 2,000 to enhance precision, permit meaningful city and gender comparisons, and provide sufficient observations for adjusted regression and interaction analyses. Increasing recruitment was also appropriate because online surveys may experience substantial participant attrition and non-response [43,44].

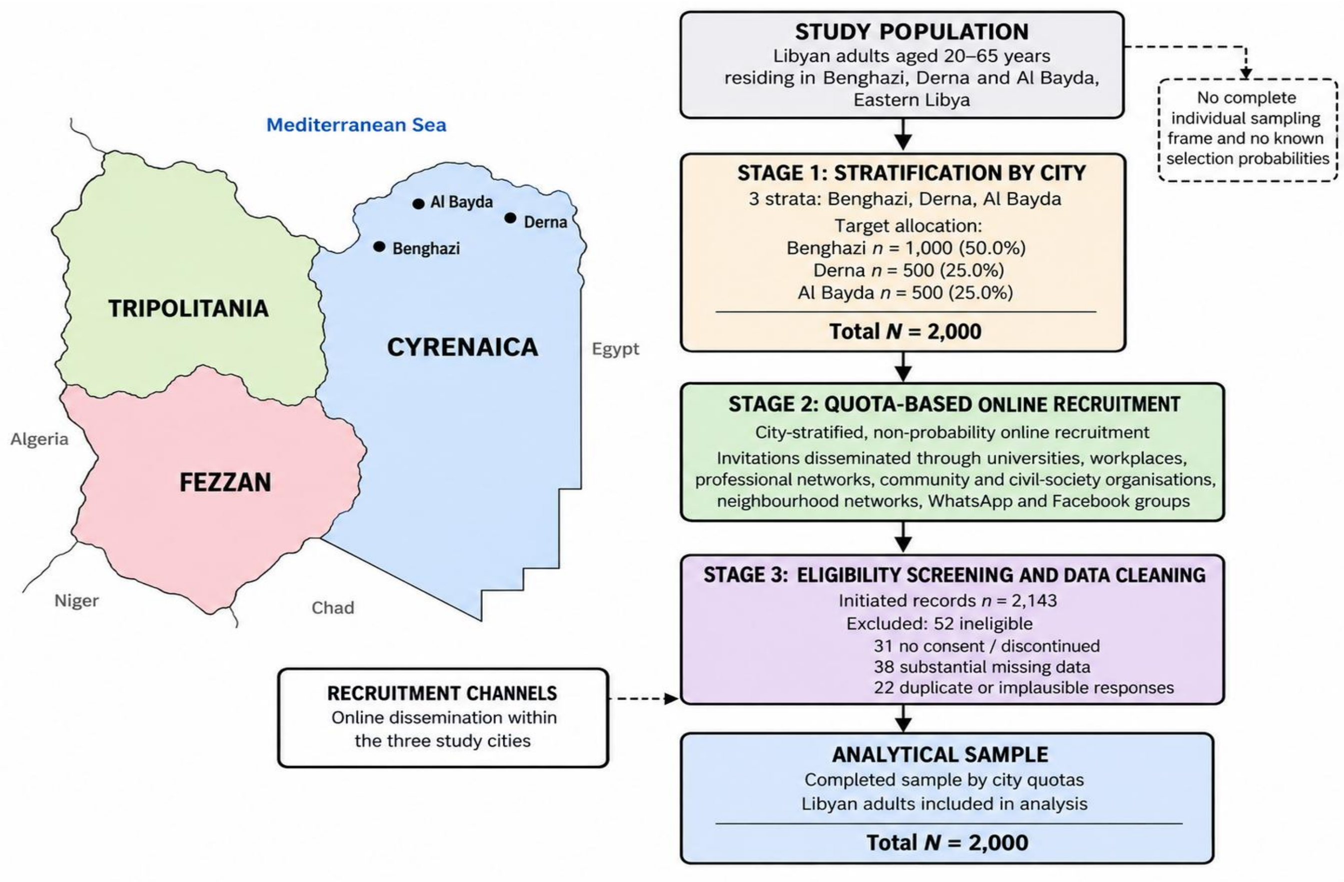

Figure 2. City-Stratified, Quota-Based Online Recruitment Strategy and Participant Flow Across Benghazi, Derna and Al Bayda, Eastern Libya

2.3. Questionnaire and Study Measures

The questionnaire consisted of three principal components: demographic and socioeconomic characteristics, physical activity and sedentary behaviour, and self-reported anthropometric information. Demographic and socioeconomic items were adapted from previous Libyan obesity research and WHO non-communicable disease surveillance approaches [34,47]. Variables included age, gender, marital status, city, educational attainment, employment/occupational status and household income. These indicators were analysed separately because they represent conceptually distinct dimensions of demographic and socioeconomic position.

Physical activity and sedentary behaviour were measured using the World Health Organization Global Physical Activity Questionnaire (GPAQ), Version 2. GPAQ was developed by WHO for population physical-activity surveillance and consists of 16 questions (P1–P16) assessing activity at work, travel to and from places, recreational activity and sedentary behaviour [48]. GPAQ has been widely incorporated into WHO STEPwise surveillance of non-communicable disease risk factors [47,48].

The GPAQ domains comprised vigorous work activity (P1–P3), moderate work activity (P4–P6), active transportation (P7–P9), vigorous recreational activity (P10–P12), moderate recreational activity (P13–P15) and sitting time (P16). Its original international validation across nine countries demonstrated moderate-to-substantial test–retest reliability and supported its use for population surveillance, although criterion validity against objective activity measures was more modest [49]. Although GPAQ was originally designed principally for interviewer administration, the present study adapted it to a self-administered Microsoft Forms format. The original sequence, item meaning, recall structure, coding and skip logic were retained as closely as possible, and explanatory wording was culturally adapted without changing the underlying behavioural constructs [48].

2.3.1. MET-Minutes and Physical-Activity Classification

Physical activity was expressed as metabolic equivalent of task minutes per week (MET-min/week) according to the WHO GPAQ Analysis Guide [50]. Vigorous-intensity activity was assigned 8 METs, while moderate-intensity activity and active transportation were assigned 4 METs. Total activity was calculated as:

$$\text{Total PA MET-min/week} = [(P2 \times P3 \times 8) + (P5 \times P6 \times 4) + (P8 \times P9 \times 4) + (P11 \times P12 \times 8) + (P14 \times P15 \times 4)].$$

Participants accumulating <600 MET-min/week were classified as insufficiently active, whereas those accumulating ≥600 MET-min/week were classified as sufficiently active [50]. Sedentary behaviour was derived separately from P16 and expressed as average sitting/reclining time in minutes per day [48,50].

2.3.2. BMI and Weight Status

Participants reported current height and weight electronically. BMI was calculated as weight (kg)/height^2 (m^2) and classified as underweight (<18.5 kg/m^2), healthy weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2) or obesity (≥30.0 kg/m^2) [1]. Because these measurements were self-reported, BMI was interpreted as a self-reported anthropometric indicator rather than an objectively measured clinical assessment.

2.4. Translation and Cultural Adaptation

The questionnaire was translated from English into Arabic using a structured forward–backward translation procedure to maximise semantic and conceptual equivalence [51,52]. Two independent bilingual translators whose first language was Arabic completed forward translations. One was familiar with health terminology, whereas the other focused on natural language and cultural comprehensibility. Their translations were reconciled into one Arabic version.

Two additional bilingual translators, blinded to the original questionnaire, independently back-translated the Arabic version into English. The original and back-translated versions were compared for discrepancies concerning physical-activity intensity, recall periods, terminology, response options and skip instructions. An expert panel representing public health, epidemiology, nutrition, physical activity and Arabic language reviewed the final version. Conceptual equivalence was prioritised over literal word-for-word translation. Following reconciliation, the Arabic questionnaire was programmed into Microsoft Forms and tested across smartphones, tablets and computers.

2.5. Pilot Testing, Validity and Reliability

The Arabic online questionnaire was pilot-tested among 60 Libyan adults aged 20–65 years, with representation of men and women from all three cities. Pilot participants met the principal eligibility criteria but were excluded from the main analytical sample. Testing evaluated cultural appropriateness, comprehension, electronic navigation, skip functionality, completion time, and interpretation of GPAQ intensity categories.

Face and content validity were assessed independently by 10 experts. Item-level Content Validity Index (I-CVI) values ranged from 0.80–1.00, while the overall S-CVI/Ave was 0.94. Expert agreement concerning relevance and clarity was strong (κ = 0.82). Minor modifications involved simplifying instructions and clarifying examples of moderate/vigorous activity, active transportation and reporting of days and minutes.

A subsample of 40 participants repeated the questionnaire after approximately 14 days. Test–retest reliability was good for total MET-minutes/week (ICC = 0.87, 95% CI 0.79–0.92) and sedentary time (ICC = 0.84, 95% CI 0.75–0.90). Agreement for sufficient/insufficient physical-activity classification was strong (κ = 0.81).

Table 2. Validity and reliability of the Arabic online questionnaire.

Property	Method	Result	Interpretation
Pilot testing	Participants	n = 60	Adequate preliminary testing
Expert review	Specialists	n = 10	Multidisciplinary assessment
Item content validity	I-CVI	0.80–1.00	Acceptable–excellent
Overall content validity	S-CVI/Ave	0.94	Excellent
Expert agreement	Cohen's κ	0.82	Strong
Test–retest sample	14-day reassessment	n = 40	—
Total PA	ICC (95% CI)	0.87 (0.79–0.92)	Good
Sedentary time	ICC (95% CI)	0.84 (0.75–0.90)	Good
PA classification	Cohen's κ	0.81	Strong
Completion burden	Median time	11.4 min	Acceptable

2.6. Online Recruitment and Data Collection

Data were collected from 15 February to 15 August 2026 through a self-administered Arabic-language questionnaire developed in Microsoft Forms. The first page contained concise study information, eligibility criteria, confidentiality and data-privacy information, the expected completion time, and an electronic informed-consent statement. Participants who did not meet the eligibility criteria or declined consent were unable to proceed to the main questionnaire.

Recruitment was conducted independently within Benghazi, Derna, and Al Bayda. Invitations were disseminated through universities, workplaces, professional networks, community and civil-society organisations, neighbourhood networks, and established WhatsApp and Facebook groups. Multiple recruitment channels were deliberately used to broaden participation across age, gender and socioeconomic groups and to reduce over-reliance on a single online population. Clear invitations, multiple recruitment routes and appropriately timed reminders are recommended strategies for improving participation in online surveys [43,44].

Separate city identifiers allowed recruitment to be monitored against the quotas of 1,000, 500 and 500. Gender and broad age distributions were also monitored during recruitment; where marked under-representation emerged, subsequent dissemination was directed towards networks more likely to reach those groups. This quota monitoring improved sample balance but did not convert the design into probability sampling.

A total of 2,143 Microsoft Forms records were initiated. Fifty-two failed eligibility criteria, 31 did not provide consent or discontinued before substantive completion, 38 had substantial missing data, and 22 were removed following duplicate or implausible-response screening, leaving 2,000 participants for analysis. Because invitations circulated through open electronic networks, the number of adults actually exposed to the survey could not be determined; therefore, a conventional response rate was not calculated. Participant-flow statistics were reported instead of [43,44].

2.8. Data Analysis Technique

Data were analysed using IBM SPSS Statistics version 29.0 (IBM Corp., Armonk, NY, USA). Before analysis, Microsoft Forms data were screened for eligibility, completeness, duplicate submissions, implausible height or weight values, and inconsistent GPAQ responses. GPAQ frequency and duration data were checked according to WHO guidance before calculation of MET-minutes/week, including review of values exceeding seven days/week and implausible activity durations. BMI was calculated only after checking self-reported height and weight. Original and cleaned datasets were retained separately to maintain an audit trail. No missing data were present for variables required for H1–H3; therefore, complete-case analysis included the full n = 2,000 sample.

Descriptive statistics summarised demographic and socioeconomic characteristics, BMI-defined weight status, physical activity and sedentary behaviour. Categorical variables were reported as frequencies and percentages, while continuous variables were presented as means ± standard deviations or, for substantially skewed variables such as MET minutes/week and sedentary time, medians and interquartile ranges. Normality was assessed using Q–Q plots, skewness, kurtosis, and the Shapiro–Wilk test. Gender and city differences were examined using chi-square tests for categorical variables and independent-samples *t*-tests or one-way ANOVA for continuous variables when parametric assumptions were satisfied; Mann–Whitney U and Kruskal–Wallis tests were used otherwise. Spearman's rank correlation assessed preliminary relationships between physical activity, sedentary behaviour and BMI.

Physical activity was analysed both continuously as total MET-minutes/week and categorically as insufficient (<600 MET-min/week) or sufficient (≥600 MET-min/week). Sedentary behaviour was analysed separately as average sitting/reclining time in minutes per day. Continuous BMI was examined using multivariable linear regression, with β coefficients, 95% confidence intervals and *p*-values reported. Model assumptions were assessed through residual plots, homoscedasticity, residual normality, variance inflation factors, and tolerance statistics.

For the binary outcome of BMI-defined overweight/obesity (BMI ≥25 kg/m² versus <25 kg/m²), modified Poisson regression with robust variance was used to estimate adjusted prevalence ratios (aPRs) and 95% confidence intervals. This approach was selected because overweight/obesity was common and prevalence ratios are more directly interpretable than odds ratios in cross-sectional studies. Covariates were specified as a priori according to the conceptual framework rather than selected solely on statistical significance.

For H1, physical activity and sedentary behaviour were entered simultaneously and adjusted for age, gender, city, marital status, education, employment/occupation and household income. For H2, gender moderation was tested using physical activity × gender and sedentary behaviour × gender interaction terms; significant interactions were followed by gender-stratified estimates. For H3, moderation by education, income, employment/occupation, age and marital status was assessed using prespecified two-way interaction terms. Where theoretically appropriate, three-way interactions with gender were examined to determine whether socioeconomic or demographic moderation differed between men and women. Significant interactions were explored using stratified estimates and adjusted predicted prevalence.

Study city remained in all adjusted models because of the unequal 1,000:500:500 allocation across Benghazi, Derna and Al Bayda. No population sampling weights were applied because individual selection probabilities were unavailable; therefore, estimates refer to the recruited three-city online sample rather than the overall Eastern Libyan population. All tests were two-sided, with $p < 0.05$ considered statistically significant. Interpretation emphasised effect size, direction and 95% confidence intervals, and all findings were treated as associations rather than causal effects because of the cross-sectional design.

1.1.1. Ethical considerations

The study involving human participants was approved by the Ethics Committee of the Faculty of Medical Sciences, University of Tobruk, Libya **(**Reference No. 12-28 Med.Sci.TU; approved on 1 February 2026**)**. The study was conducted in accordance with the principles of the Declaration of Helsinki and relevant institutional and national ethical requirements. Eligible Libyan adults aged 20–65 years residing in Benghazi, Derna and Al Bayda received electronic study information and provided electronic informed consent before accessing the Arabic Microsoft Forms questionnaire. Participation was voluntary, and respondents could discontinue before submission. No names, national identification numbers or unnecessary directly identifying information were collected. Confidentiality, anonymity and data privacy were maintained throughout data collection, storage and analysis. This procedure was consistent with the study's self-administered online survey design.

3. Findings

3.1. Participant Demographic and Socioeconomic Characteristics

Table 4 presents the demographic and socioeconomic characteristics of the 2,000 Libyan adults included across Benghazi, Derna, and Al Bayda. Benghazi contributed 1,000 participants (50.0%), while Derna and Al Bayda each contributed 500 (25.0%). Women represented 52.0% of the sample and men 48.0%. Participants aged 30–39 years constituted the largest age category (26.0%), followed by those aged 40–49 years (25.0%). Most participants were married (63.0%).

University education was the most frequently reported educational level (39.0%), followed by secondary education (26.0%). Government employment was the largest occupational category (28.0%), while 18.0% were homemakers and 15.0% were unemployed. Monthly household income was most commonly 1,500–2,999 LYD (31.0%), followed by 3,000–4,499 LYD (28.0%). The distribution indicates representation across different age, marital, educational, occupational, and income groups.

Table 4. Demographic and socioeconomic characteristics of participants (n = 2,000).

Variable	Category	n (%)
Gender	Male	960 (48.0%)
	Female	1,040 (52.0%)
Age group	20–29 years	420 (21.0%)
	30–39 years	520 (26.0%)
	40–49 years	500 (25.0%)
	50–59 years	380 (19.0%)
	60–65 years	180 (9.0%)
Marital status	Single	500 (25.0%)
	Married	1,260 (63.0%)
	Divorced	160 (8.0%)
	Widowed	80 (4.0%)
City	Benghazi	1,000 (50.0%)
	Derna	500 (25.0%)
	Al Bayda	500 (25.0%)
Education	Preparatory/basic	260 (13.0%)
	Secondary	520 (26.0%)
	Diploma	300 (15.0%)
	University degree	780 (39.0%)
	Postgraduate	140 (7.0%)
Employment/occupation	Government employee	560 (28.0%)
	Private-sector employee	280 (14.0%)
	Self-employed	320 (16.0%)
	Homemaker	360 (18.0%)
	Unemployed	300 (15.0%)
	Retired	180 (9.0%)
Monthly household income (LYD)	<1,500	300 (15.0%)
	1,500–2,999	620 (31.0%)
	3,000–4,499	560 (28.0%)
	4,500–5,999	300 (15.0%)
	≥6,000	220 (11.0%)

3.2. Anthropometric Profile and BMI-Defined Weight Status

Table 5 combines the anthropometric profile and BMI classification by gender. Mean BMI was **29.3 ± 5.9 kg/m²** overall, with women showing a higher mean BMI than men (29.9 ± 6.2 versus 28.6 ± 5.4 kg/m²).

Overall, 33.2% of participants were overweight, and 39.2% were living with obesity. The combined prevalence of overweight/obesity was therefore **72.4%**. A clear gender difference was observed descriptively: 79.2% of women had overweight/obesity compared with 65.0% of men. The difference was driven mainly by obesity, which affected 46.5% of women compared with 31.2% of men.

Table 5. Anthropometric profile and BMI-defined weight status by gender.

Indicator	Male (n = 960)	Female (n = 1,040)	Overall (n = 2,000)
Height, cm, Mean ± SD	174.1 ± 7.2	162.4 ± 6.6	168.0 ± 8.7
Weight, kg, Mean ± SD	86.8 ± 17.1	78.9 ± 16.7	82.7 ± 17.3
BMI, kg/m², Mean ± SD	28.6 ± 5.4	29.9 ± 6.2	29.3 ± 5.9
Underweight	18 (1.9%)	30 (2.9%)	48 (2.4%)
Normal weight	318 (33.1%)	186 (17.9%)	504 (25.2%)
Overweight	324 (33.8%)	340 (32.7%)	664 (33.2%)
Class I obesity	190 (19.8%)	270 (26.0%)	460 (23.0%)
Class II obesity	80 (8.3%)	140 (13.5%)	220 (11.0%)
Class III obesity	30 (3.1%)	74 (7.1%)	104 (5.2%)
All obesity	**300 (31.2%)**	**484 (46.5%)**	**784 (39.2%)**
Combined overweight/obesity	**624 (65.0%)**	**824 (79.2%)**	**1,448 (72.4%)**

BMI was calculated from self-reported height and weight collected through the online survey.

3.2.1. BMI-Defined Weight Status by Age and City

Table 6 combines the age- and city-specific distributions. The prevalence of overweight/obesity increased from 60.7% among participants aged 20–29 years to more than 77% among adults aged 40 years and above. The highest prevalence was observed among those aged 50–59 years (77.9%).

Geographical variation was also evident. Benghazi showed the highest prevalence of overweight/obesity (76.0%), followed by Derna (70.0%) and Al Bayda (67.6%). These estimates describe differences within the recruited sample and should not be interpreted as population-weighted city prevalence.

Table 6. BMI-defined overweight and obesity according to age group and study city.

Characteristic	n	Overweight n (%)	Obesity n (%)	Combined overweight/obesity n (%)
Age group				
20–29 years	420	140 (33.3%)	115 (27.4%)	255 (60.7%)
30–39 years	520	185 (35.6%)	186 (35.8%)	371 (71.3%)
40–49 years	500	175 (35.0%)	212 (42.4%)	387 (77.4%)
50–59 years	380	115 (30.3%)	181 (47.6%)	296 (77.9%)
60–65 years	180	49 (27.2%)	90 (50.0%)	139 (77.2%)
Study city				
Benghazi	1,000	340 (34.0%)	420 (42.0%)	760 (76.0%)
Derna	500	160 (32.0%)	190 (38.0%)	350 (70.0%)
Al Bayda	500	164 (32.8%)	174 (34.8%)	338 (67.6%)
Overall	**2,000**	**664 (33.2%)**	**784 (39.2%)**	**1,448 (72.4%)**

3.3. Physical Activity and Sedentary Behaviour

Table 7 combines participation in GPAQ activity domains with mean duration and MET-minutes/week. Moderate work activity was reported by 70.5% of the sample, active travel by 66.0%, and moderate recreational activity by 62.0%. Vigorous activity was less common, particularly among women.

Men accumulated greater physical activity than women across all three GPAQ domains. Mean total physical activity was 181.0 ± 93.0 minutes/week among men and 128.0 ± 81.0 minutes/week among women. Total energy expenditure showed the same pattern, with mean total activity of 940.0 ± 430.0 MET-min/week in men compared with 640.0 ± 350.0 MET-min/week in women.

Conversely, women accumulated greater sedentary time, averaging 300.0 ± 128.0 minutes/day compared with 260.0 ± 118.0 minutes/day among men.

Table 7. Physical activity participation, duration, MET-minutes and sedentary behaviour by gender.

PA/SB indicator	Male (n = 960)	Female (n = 1,040)	Overall (n = 2,000)
Participants reporting activity, n (%)			
Vigorous work	620 (64.6%)	450 (43.3%)	1,070 (53.5%)
Moderate work	730 (76.0%)	680 (65.4%)	1,410 (70.5%)
Active travel	700 (72.9%)	620 (59.6%)	1,320 (66.0%)
Vigorous recreation	540 (56.3%)	310 (29.8%)	850 (42.5%)
Moderate recreation	670 (69.8%)	570 (54.8%)	1,240 (62.0%)
Mean duration, min/week			
Total work activity	60.0 ± 39.0	42.0 ± 35.0	50.6 ± 37.8
Active travel	39.0 ± 31.0	30.0 ± 28.0	34.3 ± 29.8
Total recreation	82.0 ± 50.0	56.0 ± 45.0	68.5 ± 49.0
Total physical activity	**181.0 ± 93.0**	**128.0 ± 81.0**	**153.4 ± 89.0**
Mean MET-min/week			
Total work activity	340.0 ± 205.0	228.0 ± 185.0	281.8 ± 200.0
Active travel	156.0 ± 118.0	120.0 ± 110.0	137.3 ± 115.0
Total recreation	444.0 ± 270.0	292.0 ± 235.0	365.0 ± 255.0
Total PA MET-min/week	**940.0 ± 430.0**	**640.0 ± 350.0**	**784.0 ± 405.0**
Sedentary behaviour			
Minutes/day	260.0 ± 118.0	300.0 ± 128.0	280.8 ± 124.0
Minutes/week	1,820 ± 826	2,100 ± 896	1,965.6 ± 868

This table is much stronger than having **three separate tables** for PA participation, minutes and METs.

3.4. Distribution of Insufficient Physical Activity and Overweight/Obesity

Table 8 combines the principal descriptive outcomes across gender, age, education, income and city. Overall, **42.0%** of participants accumulated <600 MET-min/week, while **72.4%** had BMI-defined overweight or obesity.

Women had both a higher prevalence of insufficient physical activity (48.1%) and a higher prevalence of overweight/obesity (79.2%) than men. Insufficient activity increased progressively with age, from 32.1% among participants aged 20–29 years to 58.3% among those aged 60–65 years.

A socioeconomic pattern was also apparent descriptively. Overweight/obesity was more frequent among participants with lower educational attainment and lower household income. In contrast, the relationship between education and insufficient physical activity was not identical to that observed for obesity, reinforcing the need to test these relationships formally in the subsequent multivariable analyses.

Table 8. Descriptive prevalence of insufficient physical activity and overweight/obesity across participant characteristics.

Characteristic	n	<600 MET-min/week n (%)	BMI ≥25 kg/m² n (%)
Gender			
Male	960	340 (35.4%)	624 (65.0%)
Female	1,040	500 (48.1%)	824 (79.2%)
Age group			
20–29 years	420	135 (32.1%)	255 (60.7%)
30–39 years	520	190 (36.5%)	371 (71.3%)
40–49 years	500	215 (43.0%)	387 (77.4%)
50–59 years	380	195 (51.3%)	296 (77.9%)
60–65 years	180	105 (58.3%)	139 (77.2%)
Education			
Preparatory/basic	260	95 (36.5%)	200 (76.9%)
Secondary	520	205 (39.4%)	390 (75.0%)
Diploma	300	120 (40.0%)	220 (73.3%)
University	780	345 (44.2%)	545 (69.9%)
Postgraduate	140	75 (53.6%)	93 (66.4%)
Monthly household income			
<1,500 LYD	300	145 (48.3%)	235 (78.3%)
1,500–2,999 LYD	620	280 (45.2%)	470 (75.8%)
3,000–4,499 LYD	560	235 (42.0%)	410 (73.2%)
4,500–5,999 LYD	300	110 (36.7%)	205 (68.3%)
≥6,000 LYD	220	70 (31.8%)	128 (58.2%)
Study city			
Benghazi	1,000	460 (46.0%)	760 (76.0%)
Derna	500	195 (39.0%)	350 (70.0%)
Al Bayda	500	185 (37.0%)	338 (67.6%)
Overall	**2,000**	**840 (42.0%)**	**1,448 (72.4%)**

3.5. Hypothesis Testing Results

The three hypotheses were tested using multivariable linear regression for continuous BMI and **modified Poisson regression with robust variance** for BMI-defined overweight/obesity (BMI ≥25 kg/m²). Physical activity was examined using total GPAQ MET-minutes/week and the categorical indicator of insufficient physical activity (<600 MET-min/week), while sedentary behaviour was analysed as mean daily sedentary time. Models were adjusted for age, gender, marital status, educational attainment, employment/occupational status, household income and study city. Gender and socioeconomic/demographic moderation were examined using prespecified interaction terms. Because of the cross-sectional design, all estimates represent associations rather than causal effects.

Across the three sets of models, adjusted R^2 values for continuous BMI ranged from **0.156 to 0.182**, indicating modest explanatory power. The interaction models explained slightly more variation in BMI than the main-effects model.

3.5.1. Hypothesis 1: Physical Activity, Sedentary Behaviour and Adiposity

H1: Physical activity and sedentary behaviour will be statistically significantly associated with adiposity among Libyan adults, such that higher physical activity will be associated with lower adiposity, whereas greater sedentary behaviour will be associated with higher adiposity.

Initial bivariate analysis demonstrated an inverse correlation between total physical activity and BMI (**Spearman's $\rho = -0.22$, $p < 0.001$**) and a positive correlation between sedentary time and BMI (**$\rho = 0.26$, $p < 0.001$**). The correlation between physical activity and sedentary behaviour was comparatively weak ($\rho = -0.09$, $p = 0.018$), supporting their treatment as related but distinct behavioural exposures.

These relationships remained evident after adjustment for demographic and socioeconomic characteristics. Higher total physical activity was inversely associated with BMI (**$\beta = -0.18$, $p < 0.001$**), whereas greater sedentary time was positively associated with BMI (**$\beta = 0.21$, $p < 0.001$**). The complete adjusted linear model explained **15.6% of the variation in BMI (adjusted $R^2 = 0.156$)**.

For BMI-defined overweight/obesity, participants accumulating **<600 MET-min/week** had a **19% higher adjusted prevalence of overweight/obesity** than those achieving ≥600 MET-min/week (**aPR = 1.19, 95% CI 1.13–1.25, $p < 0.001$**). When physical activity was analysed continuously, each additional 100 MET-min/week was associated with a lower prevalence of overweight/obesity (**aPR = 0.98, 95% CI 0.97–0.99, $p < 0.001$**).

Sedentary behaviour demonstrated an association in the opposite direction. Each additional hour of sedentary time per day was associated with a **7% higher prevalence of overweight/obesity** after adjustment (**aPR = 1.07, 95% CI 1.05–1.09, $p < 0.001$**). The simultaneous inclusion of physical activity and sedentary behaviour in the same model indicated that each retained an independent association with adiposity.

Table 9. Adjusted associations of physical activity and sedentary behaviour with BMI and BMI-defined overweight/obesity (n = 2,000).

Exposure	Spearman's ρ with BMI	Adjusted β for BMI	Adjusted aPR (95% CI) for BMI ≥25 kg/m²	p-value
Total PA, per 100 MET-min/week	−0.22	−0.18	0.98 (0.97–0.99)	<0.001
Insufficient PA, <600 MET-min/week	—	0.15	1.19 (1.13–1.25)	<0.001
Sedentary behaviour, per additional hour/day	0.26	0.21	1.07 (1.05–1.09)	<0.001

Notes: Adjusted for age, gender, marital status, education, employment/occupation, household income and city. PA = physical activity; MET = metabolic equivalent of task; aPR = adjusted prevalence ratio. Adjusted R^2 for the continuous BMI model = 0.156.

The direction and statistical significance of both behavioural exposures therefore supported **H1**. Higher physical activity was associated with lower adiposity, whereas greater sedentary behaviour was associated with higher adiposity.

3.5.2. Hypothesis 2: Gender as a Moderator

H2: *Gender will significantly moderate the associations of physical activity and sedentary behaviour with adiposity, such that the magnitude of these associations will differ between Libyan men and women.*

Gender moderation was tested formally rather than inferred from separate significance tests in men and women. The **physical activity × gender interaction was statistically significant ($p = 0.006$)**, as was the **sedentary behaviour × gender interaction ($p = 0.002$)**. Addition of these interaction terms increased the adjusted R^2 of the continuous BMI model from 0.156 to **0.169**.

Gender-stratified estimates demonstrated that the inverse physical activity–adiposity relationship was stronger among women. Among women, each additional 100 MET-min/week was associated with a lower prevalence of overweight/obesity (**aPR = 0.96, 95% CI 0.95–0.98, $p < 0.001$**), whereas the corresponding association among men was smaller and did not reach conventional statistical significance (**aPR = 0.99, 95% CI 0.97–1.00, $p = 0.084$**).

The categorical analysis showed the same pattern. Women with insufficient physical activity had a **27% higher prevalence of overweight/obesity** than sufficiently active women (**aPR = 1.27, 95% CI 1.18–1.36, p < 0.001**). Among men, the corresponding estimate was smaller (**aPR = 1.09, 95% CI 1.00–1.19, p = 0.058**).

Sedentary behaviour also showed a stronger association among women. Each additional sedentary hour per day was associated with an **11% higher prevalence of overweight/obesity among women** (**aPR = 1.11, 95% CI 1.08–1.14, p < 0.001**), compared with a smaller association among men (**aPR = 1.04, 95% CI 1.00–1.08, p = 0.071**).

Table 10. Gender-specific associations and formal gender interactions for physical activity, sedentary behaviour and adiposity.

Exposure	Men aPR (95% CI)	p-value	Women aPR (95% CI)	p-value	p for gender interaction
Total PA, per 100 MET-min/week	0.99 (0.97–1.00)	0.084	0.96 (0.95–0.98)	<0.001	**0.006**
Insufficient PA, <600 MET-min/week	1.09 (1.00–1.19)	0.058	1.27 (1.18–1.36)	<0.001	**0.004**
Sedentary behaviour, per hour/day	1.04 (1.00–1.08)	0.071	1.11 (1.08–1.14)	<0.001	**0.002**

Notes: Gender-specific models were adjusted for age, marital status, education, employment/occupation, household income and city. Interaction *p*-values were obtained from pooled models containing exposure × gender terms. aPR = adjusted prevalence ratio.

The results therefore provide support for **H2**. The associations of both physical activity and sedentary behaviour with adiposity differed significantly by gender, with stronger behavioural associations observed among women.

Importantly, this conclusion is based on the **statistically significant interaction terms**, not merely on the observation that individual associations reached significance among women but not among men. This distinction is methodologically important when establishing effect modification.

3.5.3. Hypothesis 3: Socioeconomic and Demographic Moderation

H3: *Socioeconomic and demographic characteristics will significantly moderate the associations of physical activity and sedentary behaviour with adiposity, with the pattern and magnitude of these moderating relationships differing between Libyan men and women.*

The H3 models examined whether education, household income, employment/occupational status, age and marital status modified the relationships of physical activity and sedentary behaviour with adiposity. The complete interaction model had an adjusted R^2 of 0.182 for continuous BMI, representing a modest increase over the H1 and H2 models.

Significant moderation was identified for education and household income. The interaction between physical activity and educational attainment was significant ($p = 0.008$), as was the interaction between sedentary behaviour and education ($p = 0.006$). Similarly, household income moderated both the physical activity association ($p = 0.016$) and the sedentary behaviour association ($p = 0.011$).

Age also showed evidence of effect modification, although the interactions were weaker than those observed for socioeconomic position. The physical activity × age interaction was significant at $p = 0.032$, while the sedentary behaviour × age interaction was significant at $p = 0.024$. In contrast, employment/occupational status and marital status did not significantly modify either behavioural association.

The socioeconomic interactions were particularly evident among women. Among women in the lower educational category, insufficient physical activity was associated with a 35% higher prevalence of overweight/obesity (aPR = 1.35, 95% CI 1.23–1.48, $p < 0.001$), compared with aPR = 1.13 (95% CI 1.02–1.25, $p = 0.019$) among women with higher educational attainment. The corresponding association among lower-educated men was smaller (aPR = 1.12, 95% CI 1.00–1.26, $p = 0.052$).

A similar pattern occurred for sedentary behaviour. Among lower-educated women, each additional sedentary hour was associated with a 15% higher prevalence of overweight/obesity (aPR = 1.15, 95% CI 1.11–1.19, $p < 0.001$), compared with 6% among higher-educated women (aPR = 1.06, 95% CI 1.02–1.10, $p = 0.004$).

Household income demonstrated a comparable pattern. Insufficient physical activity among women in the lower-income groups was associated with overweight/obesity at aPR = 1.32 (95% CI 1.21–1.44, $p < 0.001$), whereas the association among women in the higher-income groups was weaker (aPR = 1.14, 95% CI 1.03–1.26, $p = 0.012$).

Formal three-way interaction analyses supported the gender-specific nature of these socioeconomic relationships. The physical activity × education × gender interaction was significant ($p = 0.012$) and the sedentary behaviour × education × gender interaction was significant ($p = 0.007$). Likewise, significant three-way interactions were observed for household income with physical activity ($p = 0.021$) and sedentary behaviour ($p = 0.010$).

Age-related three-way interactions were weaker but remained significant for physical activity ($p = 0.039$) and sedentary behaviour ($p = 0.031$), indicating some gender variation in age-related modification. No significant three-way interactions were identified for occupational status or marital status.

Table 11. Socioeconomic and demographic moderation of the associations between physical activity, sedentary behaviour and adiposity.

Moderator	PA × moderator p-value	SB × moderator p-value	PA × moderator × gender p-value	SB × moderator × gender p-value	Interpretation
Educational attainment	**0.008**	**0.006**	**0.012**	**0.007**	Significant moderation; stronger among women
Household income	**0.016**	**0.011**	**0.021**	**0.010**	Significant moderation; stronger among lower-income women
Age	**0.032**	**0.024**	**0.039**	**0.031**	Modest gender-specific moderation
Employment/occupation	0.281	0.192	0.346	0.274	No significant moderation
Marital status	0.418	0.364	0.491	0.438	No significant moderation

Notes: Models adjusted for the remaining demographic and socioeconomic covariates and study city. PA = physical activity; SB = sedentary behaviour. Two-way interactions tested whether socioeconomic/demographic characteristics modified the behavioural associations. Three-way interaction terms tested whether these moderation effects differed between men and women.

The results therefore partially supported H3. Socioeconomic position, particularly educational attainment and household income, significantly modified the associations of physical activity and sedentary behaviour with adiposity, and these relationships were stronger among women. Age provided additional, although weaker, evidence of demographic moderation. In contrast, occupational status and marital status did not significantly modify the behavioural associations.

3.5.4. Summary of Hypothesis Testing

Taken together, the hypothesis analyses revealed a progressive pattern. First, physical activity and sedentary behaviour were independently associated with adiposity in the overall sample. Second, these relationships were not uniform across genders and were appreciably stronger among women. Third, socioeconomic circumstances further modified these behavioural relationships, particularly among women with lower educational attainment and lower household income.

Table 12. Summary of hypothesis-testing outcomes.

Hypothesis	Principal statistical evidence	Outcome
H1 Physical activity and sedentary behaviour are associated with adiposity	PA: $\beta = -0.18$, $p < 0.001$; insufficient PA: aPR = 1.19; SB: $\beta = 0.21$, aPR = 1.07, $p < 0.001$	**Supported**
H2 Gender moderates PA/SB–adiposity associations	PA × gender $p = 0.006$; SB × gender $p = 0.002$; stronger associations among women	**Supported**
H3 SES/demographic factors moderate the associations and differ by gender	Significant education, income and age interactions; significant gender-specific three-way effects for education and income	**Partially supported**

Discussion

The present study examined the prevalence and distribution of overweight and obesity among 2,000 Libyan adults in Benghazi, Derna and Al Bayda and investigated whether physical activity and sedentary behaviour were associated with adiposity, whether these associations differed between men and women, and whether socioeconomic and demographic characteristics modified these relationships. The findings reveal a substantial burden of excess body weight: 72.4% of participants had BMI-defined overweight or obesity and 39.2% were classified as living with obesity. Women consistently demonstrated a less favourable profile than men, with overweight/obesity affecting 79.2% of women compared with 65.0% of men. Insufficient physical activity was also more frequent among women, while men accumulated greater physical activity across occupational, transport and recreational domains. These patterns were reinforced by the multivariable findings: greater physical activity was associated with lower adiposity, greater sedentary behaviour with higher adiposity, and both associations were significantly stronger among women. Socioeconomic and demographic moderation further indicated that education, household income and age altered these behavioural relationships, whereas employment and marital status did not.

The prevalence estimates are highly consistent with earlier Libyan adult evidence. Lemamsha et al. [3] reported that 75.3% of adults in Benghazi had overweight or obesity, including 42.4% with obesity, compared with 72.4% and 39.2%, respectively, in the present multicity sample. The earlier study also identified a pronounced gender difference, with obesity affecting 47.4% of women compared with 33.8% of men; the corresponding prevalences in the present study were 46.5% and 31.2%. The close correspondence is notable because the present investigation extends geographical coverage beyond Benghazi to Derna and Al Bayda while retaining the same adult age range. Rather than indicating that excess weight is restricted to one Libyan locality, the present findings suggest that a high burden persists across major Eastern Libyan urban populations. The age pattern also broadly reflects earlier Libyan evidence, where obesity was concentrated particularly among middle-aged and older adults [3]. In the present sample, combined overweight/obesity increased from 60.7% at 20–29 years to more than 77% in most groups aged 40 years and above.

The age gradient also has parallels outside Libya. Bhattarai et al. [53], in a community-based study of women in Eastern Nepal, reported 41.9% overweight/obesity and found that older women, particularly those aged 40–49 years, had a less favourable weight profile. Although the absolute prevalence was substantially lower than in the present Libyan sample and the Nepalese study included only reproductive-age women, the common age pattern suggests that the accumulation of adiposity across adulthood may be observable across markedly different socioeconomic and cultural settings. However, this comparison should remain cautious because Bhattarai et al. [53] used measured anthropometry and probability-based community recruitment, whereas the present study relied on self-reported height and weight from an online sample.

The findings also extend more recent evidence from specific Libyan populations. Among Tobruk University students, Lemamsha et al. [23] reported a substantially lower combined prevalence of overweight and obesity of 50.0%, but the same gender pattern was evident: prevalence was 56.4% among female students compared with 42.2% among males. That study additionally identified positive associations between sedentary behaviour and BMI and inverse associations between physical activity and BMI [23]. The greater prevalence in the present adult sample may reflect its broader age distribution, including middle-aged and older adults, rather than contradicting the university findings. Taken together, the studies show that gender differences are apparent from early adulthood and remain evident across the wider adult population.

H1 was supported by the inverse association between physical activity and adiposity and the positive association between sedentary behaviour and adiposity. Participants accumulating less than 600 MET-min/week had a higher prevalence of overweight/obesity, while each additional hour of sedentary behaviour was associated with greater prevalence after adjustment for demographic and socioeconomic characteristics. Importantly, the weak correlation between physical activity and sedentary time indicates that they should not be treated as opposite ends of a single behavioural continuum. Adults may accumulate meaningful physical activity during part of the day while also spending substantial periods sitting. This distinction is consistent with contemporary behavioural evidence [25–28] and with the Tobruk student study, where prolonged sitting and lower activity showed independent adverse relationships with body weight [23].

The broader evidence nevertheless cautions against assuming that the PA–BMI association is uniformly linear or that all activity intensities are equivalent. Liu et al. [54], using GPAQ data from adults in Northwest China, found different relationships for sufficient and vigorous physical activity: vigorous activity was inversely associated with BMI across the higher BMI distribution, whereas the association for merely sufficient activity was more complex. This qualifies a simple interpretation of total MET-min/week in the present study. The inverse overall association may partly conceal differences according to intensity and activity domain, particularly because occupational, transport and recreational activity contribute to the same total GPAQ score. Similarly, Pedisic et al. [55] reported exceptionally high self-reported total activity in Nepal because occupational activity constituted a large proportion of overall PA, despite very limited leisure-time activity. This indicates that equal MET totals may reflect behaviourally different activity profiles and should not necessarily be interpreted as equivalent social or environmental exposures.

These findings also reinforce earlier Libyan work. Lemamsha [56] identified an inverse relationship between total physical activity and BMI and a positive relationship between sedentary behaviour and BMI, with adjusted associations particularly evident among women. The present study therefore reproduces the same general behavioural pattern in a substantially larger three-city sample. From an energy-balance perspective, greater activity increases energy expenditure, whereas extended sitting involves very low energy expenditure and may coexist with other behaviours that favour positive energy balance. The 2022 Libyan adult study similarly located obesity within a broader nutrition transition characterised by changes in diet alongside increasingly sedentary lifestyles and explicitly emphasised that both energy intake and energy expenditure need to be considered when examining obesity [34].

The strength of the present H1 finding is also supported by higher-level evidence. Silveira et al. [57], synthesising 23 studies involving approximately 638,000 adults, found that both sedentary behaviour and physical inactivity were associated with obesity. However, the review also identified substantial variation in prevalence estimates according to measurement methods and cut-off definitions. This heterogeneity is important because it suggests that agreement in direction across studies does not imply that the magnitude of the association can be compared directly. Indeed, Van Dyck et al. [58], using accelerometer-based measures in 5,712 adults across 10 countries, found an inverse curvilinear association between moderate-to-vigorous activity and BMI but no association between objectively measured sedentary time and weight outcomes. Their results therefore provide an important counterpoint to the present positive sedentary-behaviour finding and indicate that the sedentary–adiposity relationship may depend on measurement method, study context and behavioural pattern rather than representing a universally consistent association.

H2 provides a particularly important extension of this earlier evidence because gender differences were tested through formal interaction terms rather than inferred from separate male and female models. Both the physical activity × gender and sedentary behaviour × gender interactions were significant, with stronger associations among women. This finding is consistent with the longstanding gender disparity in Libyan obesity prevalence reported by Lemamsha et al. [3] and with the more recent Tobruk student study [23]. It also accords with earlier Libyan physical-activity research indicating gender differences in compliance with recommended activity patterns [59]. The convergence suggests that gender may influence not only the absolute prevalence of obesity and inactivity but also the strength with which behavioural exposures correspond to adiposity.

International evidence strengthens this interpretation while also demonstrating that gender modification is context dependent. Devi et al. [60], using GPAQ among adults in Delhi, reported lower mean physical activity among women than men and stronger relationships between lower physical activity and several adiposity indices among women. Conversely, the multinational IPEN Adult Study found complex site- and gender-specific associations for BMI rather than one uniform gender effect [58]. Thus, the stronger relationships among Libyan women should not be interpreted as an inherent biological female susceptibility to inactivity. They may instead reflect gender-specific combinations of activity type, social roles, environmental opportunities and socioeconomic position particular to the Libyan setting.

Several contextual mechanisms may contribute to this pattern. Physical activity opportunities do not occur independently of social roles, daily routines, mobility and access to appropriate recreational environments. Earlier Libyan evidence has described gender-specific differences in occupational, transport and recreational activity, while family responsibilities and sociocultural expectations may shape opportunities for structured and incidental movement [56]. The present descriptive findings are consistent with this interpretation: men reported more vigorous and moderate activity across work, transport and recreation, whereas women accumulated more sedentary time. The stronger relationship between sedentary behaviour and adiposity among women may therefore reflect the broader configuration of everyday activity rather than sitting time alone. This interpretation remains appropriately behavioural and contextual; the cross-sectional associations do not establish that inactivity preceded increased adiposity.

The socioeconomic findings add another layer to this gender difference. H3 was partially supported because education, household income and age, but not employment or marital status, modified the associations of physical activity and sedentary behaviour with adiposity. Moreover, the significant three-way interactions involving education, income and gender showed that socioeconomic moderation was particularly pronounced among women. Among lower-educated women, insufficient physical activity had a stronger association with overweight/obesity than among higher-educated women, and the relationship between sedentary time and adiposity followed the same pattern. Household income produced a similar gradient.

These interaction findings are closely aligned with Pan et al. [61], who examined almost 38,000 rural Chinese adults and found that the interaction between low education and physical activity in relation to obesity measures was evident particularly among women. Their interpretation emphasised that socioeconomic position may shape opportunities for activity through resources, neighbourhood characteristics, health information and social conditions. This provides stronger comparative support for H3 than studies examining SES and obesity only as independent main effects because Pan et al. [61], like the present study, explicitly considered the combined relationship between socioeconomic position, physical activity and gender. Nevertheless, the direction of socioeconomic gradients is not necessarily universal. Bhattarai et al. [53], for example, observed greater physical inactivity among higher-socioeconomic-status Nepalese women, illustrating that the relationship between SES and activity can reverse according to occupational structure, economic transition and local context.

This is consistent with emerging Libyan evidence showing that socioeconomic circumstances are relevant to health behaviour rather than functioning merely as background demographic characteristics. Among pregnant women in Eastern Libya, lower educational attainment and lower household income were independently associated with a higher prevalence of BMI-defined overweight/obesity, while physical inactivity and sedentary lifestyle were also associated with adiposity [31]. In Tobruk, Lemamsha et al. [62] similarly found that education and household income differentiated nutritional supplementation behaviour, demonstrating that socioeconomic position can shape engagement with health-related practices within the Libyan context. Although these populations and outcomes differ, their convergence supports treating education and income as meaningful contextual characteristics rather than interchangeable measures of socioeconomic status.

The pattern for education warrants particular attention. Descriptively, overweight/obesity decreased with increasing educational attainment, yet insufficient physical activity did not follow precisely the same gradient. This indicates that education cannot be interpreted simply as a proxy for greater activity. Education may instead operate through multiple pathways, including health literacy, occupational structure, access to information, food choices, perceptions of body weight and the capacity to interpret health guidance. Qualitative Libyan evidence supports this broader interpretation. Dietitians working in Tobruk described dietary and health behaviours as embedded within socioeconomic circumstances, family routines, cultural practices, affordability and health literacy rather than determined exclusively by individual knowledge [33]. Their accounts further showed that affordability, local availability and household practices can influence whether health advice can be translated into everyday behaviour [33].

A further critique concerns residual confounding. Dakanalis et al. [63] showed that physical activity, perceived stress and sleep quality were each associated with overweight/obesity in young adults. Because stress and sleep were not incorporated into the present models, some of the observed PA-, sedentary- or socioeconomic-adiposity associations could potentially represent wider clusters of correlated lifestyle and psychosocial exposures rather than isolated behavioural effects. This does not invalidate the observed interactions, but it limits interpretation of physical activity and sedentary behaviour as independently sufficient explanations of adiposity differences.

The income findings were somewhat more internally consistent: lower-income groups exhibited both higher overweight/obesity and greater insufficient physical activity. This pattern suggests that material circumstances may condition opportunities for activity through access to recreational resources, transport arrangements, neighbourhood characteristics and time constraints. However, employment status itself did not significantly moderate the behavioural relationships, indicating that employment as a simple categorical measure may not capture the relevant dimensions of occupational activity or socioeconomic advantage. Similarly, marital status did not modify the relationships, suggesting that household socioeconomic resources may be more relevant than marital category alone.

Measurement also warrants critical consideration because GPAQ and adiposity were derived from self-report in the present online survey. Jakicic et al. [64] demonstrated only weak-to-modest agreement between self-reported activity, including GPAQ measures, and objectively measured moderate-to-vigorous physical activity; importantly, only objectively measured activity was significantly associated with both BMI and body-fat percentage in their sample. They concluded that self-reported and objective physical activity should not be used interchangeably. Bhattarai et al. [53] similarly found only a weak correlation between GPAQ-derived activity and pedometer measurement and argued that differences in recall period and interpretation of moderate and vigorous activity contribute to disagreement. Accordingly, the present behavioural coefficients may be attenuated or distorted by recall and classification error, while self-reported height and weight may introduce additional misclassification of BMI. This issue is particularly relevant when interpreting gender interactions if reporting accuracy itself differs between men and women.

These results fit closely with the Social Ecological Model, which provides the organising framework for the study [35–39]. Physical activity and sedentary behaviour represent proximal behavioural exposures, while gender, education, income, age and geographical context represent broader conditions within which those behaviours occur. Previous Libyan research has similarly conceptualised socioeconomic characteristics as contextual influences and physical inactivity and sedentary behaviour as more proximal behavioural correlates [31,34]. The present findings extend that perspective by demonstrating statistically that these levels are not simply parallel correlates: the strength of the behavioural–adiposity relationship itself varied according to gender and socioeconomic position. Thus, the study supports an ecological interpretation of adult adiposity in Eastern Libya in which physical activity and sedentary behaviour are associated with weight status, but the magnitude of those associations is contingent on the social and demographic circumstances in which behaviour occurs.

However, the SEM should remain an interpretative framework rather than evidence of a tested multilevel causal process [35–39]. The statistical interactions demonstrate effect modification, but they do not establish the mechanisms through which socioeconomic or gender-related contexts produce those differences. Nor can the temporal direction be determined: greater adiposity may reduce mobility and increase sedentary time just as lower activity may contribute to weight gain. Evidence from an intervention provides an additional reason for restraint. Lugones-Sanchez et al. [65] found that an app-plus-activity-tracker intervention produced short-term improvements in activity and several body-composition outcomes, but the downward weight trend was not maintained after the devices were withdrawn at 12 months. Thus, the cross-sectional association observed here should not be translated directly into an assumption that increasing measured activity alone would necessarily produce sustained reductions in adiposity.

Overall, the additional comparative evidence strengthens the central conclusion while also narrowing it: the findings are consistent with a meaningful relationship between physical activity, sedentary behaviour and adiposity, particularly among women and within different socioeconomic circumstances, but the magnitude and even form of these relationships vary across populations, activity intensities and measurement approaches. The strongest contribution of the present study therefore lies not in proposing a universal behavioural effect, but in demonstrating that, within this three-city Libyan sample, behavioural associations with adiposity were socially patterned and gender-dependent.

4. Discussion

The present study examined the prevalence and distribution of overweight and obesity among 2,000 Libyan adults in Benghazi, Derna and Al Bayda and investigated whether physical activity and sedentary behaviour were associated with adiposity, whether these associations differed between men and women, and whether socioeconomic and demographic characteristics modified these relationships. The findings reveal a substantial burden of excess body weight: 72.4% of participants had BMI-defined overweight or obesity and 39.2% were classified as living with obesity. Women consistently demonstrated a less favourable profile than men, with overweight/obesity affecting 79.2% of women compared with 65.0% of men. Insufficient physical activity was also more frequent among women, while men accumulated greater physical activity across occupational, transport and recreational domains. These patterns were reinforced by the multivariable findings: greater physical activity was associated with lower adiposity, greater sedentary behaviour with higher adiposity, and both associations were significantly stronger among women. Socioeconomic and demographic moderation further indicated that education, household income and age altered these behavioural relationships, whereas employment and marital status did not.

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These results fit closely with the Social Ecological Model, which provides the organising framework for the study [35–39]. Physical activity and sedentary behaviour represent proximal behavioural exposures, while gender, education, income, age and geographical context represent broader conditions within which those behaviours occur. Previous Libyan research has conceptualised socioeconomic characteristics as contextual influences and physical inactivity and sedentary behaviour as more proximal behavioural correlates [31,34]. The present findings extend that perspective by demonstrating statistically that these levels are not simply parallel correlates: the strength of the behavioural–adiposity relationship itself varied according to gender and socioeconomic position. Thus, the study supports an ecological interpretation of adult adiposity in Eastern Libya in which physical activity and sedentary behaviour are associated with weight status, but the magnitude of those associations is contingent on the social and demographic circumstances in which behaviour occurs.

However, the SEM should remain an interpretative framework rather than evidence of a tested multilevel causal process [35–39]. The statistical interactions demonstrate effect modification, but they do not establish the mechanisms through which socioeconomic or gender-related contexts produce those differences. Nor can the temporal direction be determined: greater adiposity may reduce mobility and increase sedentary time just as lower activity may contribute to weight gain. Evidence from an intervention provides an additional reason for restraint. Lugones-Sanchez et al. [65] found that an app-plus-activity-tracker intervention produced short-term improvements in activity and several body-composition outcomes, but the downward weight trend was not maintained after the devices were withdrawn at 12 months. Thus, the cross-sectional association observed here should not be translated directly into an assumption that increasing measured activity alone would necessarily produce sustained reductions in adiposity.

Overall, the additional comparative evidence strengthens the central conclusion while also narrowing it: the findings are consistent with a meaningful relationship between physical activity, sedentary behaviour and adiposity, particularly among women and within different socioeconomic circumstances, but the magnitude and even form of these relationships vary across populations, activity intensities and measurement approaches. The strongest contribution of the present study therefore lies not in proposing a universal behavioural effect, but in demonstrating that, within this three-city Libyan sample, behavioural associations with adiposity were socially patterned and gender-dependent.

5. Theoretical and Practical Implications

The findings extend the application of the **Social Ecological Model (SEM)** to obesity research in Libya by demonstrating that movement-related behaviours cannot be interpreted independently of the socioeconomic and gender contexts in which they occur [35–39]. Physical activity and sedentary behaviour represent proximal behavioural exposures, while gender, education, household income and age appear to condition the strength of their relationships with adiposity. The significant two- and three-way interactions are particularly relevant because they move the analysis beyond treating socioeconomic characteristics simply as confounders. This interpretation is consistent with Pan et al. [61], who similarly identified gender differences in the joint relationships between socioeconomic position, physical activity and obesity, particularly among women. However, the SEM remains an **interpretative framework rather than a tested causal pathway**, because the cross-sectional design cannot establish temporal ordering between contextual circumstances, behaviours and adiposity [40–42].

From a practical perspective, the findings indicate that obesity-prevention approaches in Eastern Libya may benefit from being **gender-responsive and socioeconomically sensitive rather than uniformly population-based**. Women had both greater insufficient physical activity and higher overweight/obesity prevalence, while the relationships of PA and sedentary behaviour with adiposity were stronger among women, particularly those with lower education and household income. Physical-activity promotion could therefore consider culturally acceptable opportunities for women, accessible community- or home-based activity, active transport where feasible, and strategies for reducing prolonged sitting. Socioeconomic circumstances should also be considered when designing health communication, because access to recreational opportunities, information and supportive environments may differ across population groups. International evidence similarly indicates that relationships between PA, obesity and socioeconomic position vary by gender and social context rather than following one universal pattern [60,61]. These implications should nevertheless be regarded as **planning considerations rather than evidence that modifying any single exposure would necessarily reduce obesity**, particularly given the cross-sectional nature of the evidence [40–42].

6. Strengths and Limitations

This study has several important strengths. The large analytical sample of **2,000 adults** recruited across Benghazi, Derna and Al Bayda provided substantial statistical power for adjusted analyses and formal interaction testing, while the relatively balanced representation of men and women enabled meaningful investigation of gender differences. The use of the internationally established **WHO Global Physical Activity Questionnaire (GPAQ)** permitted assessment of occupational, transport and recreational activity alongside sedentary behaviour using standard MET-based scoring [48–50]. The Arabic instrument underwent structured forward–backward translation [51,52], expert assessment, pilot testing and test–retest

evaluation; total PA and sedentary time demonstrated good temporal reliability, while classification agreement was strong. Methodological strengths also included examination of PA both continuously and categorically, simultaneous consideration of PA and sedentary behaviour, use of modified Poisson regression for the common overweight/obesity outcome, prespecified interaction testing for H2 and H3, adjustment for relevant covariates and complete data for the principal analytical models.
Nevertheless, several limitations require consideration. First, the **cross-sectional design** prevents establishment of temporal direction; lower physical activity or greater sedentary time may contribute to greater adiposity, but existing adiposity could conversely reduce mobility and increase sitting [40–42]. Second, recruitment was **non-probability, city-stratified and quota-based**, rather than based on known individual selection probabilities. Distribution through WhatsApp, Facebook, universities, workplaces and community networks improved reach but potentially introduced self-selection and digital-access bias. Because the number of adults exposed to the open invitation was unknown, a conventional response rate could not be calculated. Online surveys may systematically underrepresent people with limited internet access or lower digital engagement, potentially affecting external validity [43,44]. Consequently, the findings characterise the recruited three-city online sample and should not be interpreted as population-weighted prevalence estimates for Eastern Libya.
Measurement limitations provide a further qualification. Height and weight were **self-reported**, creating potential reporting error in BMI classification, while GPAQ depends on participants recalling and interpreting activity intensity and duration. Jakicic et al. [64] found only weak-to-modest correspondence between self-reported and objectively measured activity and cautioned against treating the two methods interchangeably. Similarly, Bhattarai et al. [53] reported weak agreement between GPAQ and pedometer-based activity assessment. The online self-administered adaptation of GPAQ may introduce additional interpretation differences because the instrument was originally designed primarily for interviewer administration [48,49]. Although translation, pilot testing, clear instructions, automated eligibility screening and duplicate/implausible-response checks reduced several potential errors, they cannot eliminate recall, social-desirability or self-selection bias. Residual confounding is also possible because dietary intake, sleep, psychological factors, health conditions and detailed neighbourhood characteristics were not incorporated into the principal models, and these factors may coexist with movement-related behaviours and adiposity [63].

7. Recommendations for Future Studies

Future Libyan research should prioritise **prospective and probability-based designs** to clarify the temporal relationships between physical activity, sedentary behaviour and changes in adiposity. Household- or population-frame sampling across urban, peri-urban and rural areas could improve representativeness and permit population-weighted estimates. Longitudinal assessment would be particularly valuable for determining whether lower physical activity and greater sedentary behaviour precede increases in BMI or partly arise as consequences of existing adiposity, thereby addressing the temporal limitations inherent in cross-sectional research [40–42].
Measurement should also be strengthened through **direct assessment of height, weight and additional adiposity indicators**, together with accelerometers or other objective activity monitors where feasible. This recommendation is supported by evidence demonstrating meaningful discrepancies between questionnaire-based and device-measured PA [53,64]. Future analyses could additionally incorporate dietary intake, sleep, psychological stress, transport, household responsibilities, neighbourhood walkability and access to recreational facilities to evaluate the wider ecological context and reduce residual confounding [63].
The identified interactions should also be independently replicated. In particular, future research should investigate why behavioural associations appear stronger among women with lower education and income and distinguish occupational, transport and recreational PA rather than relying solely on total MET-minutes. Mixed-methods research could clarify the cultural, environmental and economic mechanisms underlying these differences, while appropriately designed intervention studies could evaluate whether **gender- and socioeconomic-tailored approaches** produce meaningful changes in activity, sedentary behaviour and adiposity. Evidence from intervention research also indicates that short-term behavioural changes do not necessarily translate into sustained weight reduction, reinforcing the importance of longitudinal evaluation [65].

8. Conclusion

This study identified a substantial burden of overweight and obesity among adults recruited from Benghazi, Derna and Al Bayda, with particularly pronounced differences between women and men. Higher physical activity was associated with lower adiposity, whereas greater sedentary behaviour was associated with higher adiposity, supporting the first hypothesis. Gender significantly modified both relationships, with stronger associations observed among women, supporting the second hypothesis. Socioeconomic and demographic moderation was more selective: education, household income and age modified behavioural associations, while employment and marital status did not, providing partial support for the third hypothesis. The findings therefore indicate that relationships between movement behaviours and adiposity are not uniform across Libyan adults but vary according to gender and socioeconomic circumstances. Because the study was cross-sectional, online and based on self-reported anthropometry and physical activity, the results establish associations rather than causal pathways and are most appropriately interpreted within the recruited three-city sample.

Conclusion

This section should be typed in character size 10pt Times New Roman and alignment justified. All the main points of the research work are written in this section. Ensure that the abstract and conclusion are not the same. The conclusion should be concise, informative and can be started with summarizing the outcome of the study in 1-2 sentences and ended with one line stating how this study will benefit society and the way forward.

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